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The Art of Navigation in England in Elizabethan and Early Stuart Times

By

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With a Foreword by

Admiral of the Fleet

THE EARL MOUNTBATTEN OF BURMA
First Sea Lord and Chief of the Naval Staff
Elder Brother of Trinity House
Patron of the Society for Nautical Research

LONDON
HOLLIS AND CARTER
To the memory of

Eng.-Lieutenant William Waters, R.N.,
H.M.S. Formidable, 1 January 1915

and

Lieutenant-Commander William Erskine Waters, D.F.C., R.N.,
H.M.S. Illustrious, 13 January 1943

who

‘wonne that honour that no Sea can droune,
no age weare out’.

Purchas His Pilgrimes
FOREWORD

by

THE EARL MOUNTBATTEN OF BURMA

For the past four thousand years the Art of Navigation has been one of the most important contributions to the development of civilization; for perhaps the greatest achievement of man in the ancient world was his realization that he could explore new territories as a source of new materials. But the caravan routes that he established entailed large initial outlay for roads, and a vast output of energy in carrying loads; so trading along these routes was mostly confined to luxury articles (such as spices, silks, and jewels) whose value was very high in relation to their weight or bulk.

The invention of sailing, which was man’s first attempt to replace the labour of slaves or animals by the harnessing of natural forces, introduced for the first time the prospect of importing and exporting goods in bulk, and of developing a way of life that would to some extent be dependent on materials produced elsewhere.

With the introduction of sailing the need immediately arose for navigational calculations; for the stars provided the primitive seafarer with his only means of finding his way when land was no longer in sight. The beginnings of calculation are to be found in the earliest civilizations of Egypt, Sumeria, and Babylon; though the results were mainly used for the building of temples and pyramids. But these techniques spread along the great trade routes, down to and beyond the Mediterranean, where the Semitic peoples began to trade in tin and dyes.

Already by 2000 B.C. the Semites of Asia Minor had established colonies throughout the Mediterranean world; Carthage was founded in the ninth century B.C. by the Phoenicians; and three centuries later Hanno was able to coast along West Africa as far as Sierra Leone—to within 8° of the equator. The Phoenicians found out very early how to navigate by the position of the stars in the Little Bear; but scientific geography can really be said to have begun with the determination of latitude, which probably ante-dates Greek civilization.

In the sixth century B.C. Thales of Miletus, a merchant of Tyrian parentage, founded Greek geometry and astronomy; and soon in the city states of Greece calculation became a fashionable pastime. Indeed, Plato taught that geometry was the highest exercise to which human leisure could be devoted. But its practical uses were considered secondary; and it was
not until the famous school of Euclid was founded three hundred years later—in Alexandria, which at that time was becoming a centre not only of commerce but of learning and research—that geometry really came into its own.

In the second century B.C. Hipparchus, the founder of trigonometry, devised a method of fixing terrestrial positions by circles of latitude and longitude. But for some centuries after this no significant navigational advances were made; since, so long as a large part of the world (as it then seemed) could be explored by sailing close to the coast, the ancient techniques of star-lore were found adequate.

When the Dark Ages engulfed Christendom, the Alexandrians kept astronomy alive in the first instance. Later the Moslem civilization combined the techniques of the Greeks and Alexandrians with the new methods of handling numbers which the Hindus had developed; for the latter had invented number-symbols that made simple calculation possible without the use of mechanical aids. And when the conquering Moors swept across the Straits of Gibraltar they established universities in Spain in which this new arithmetic was taught. Jewish scholars from the Moorish universities in Spain brought the new arithmetic along the trade-routes of Southern Europe, and soon seafarers took to carrying Jewish astronomers who could use the star-maps which Arab scholarship had prepared from the ancient star-maps of Alexandria.

When the Renaissance of learning began to spread across Europe, coasting began to give place to ocean voyages, and the need for improved navigational methods became urgent. In A.D. 1543 Copernicus, in his De Revolutionibus, attacked the premises of Ptolemaic astronomy, still currently held—which assumed that the whole universe revolved about the earth—and boldly defended the doctrine of Aristarchus, who had taught exactly the opposite, eighteen centuries before!

It is at this point that Lieutenant-Commander Waters—a retired naval officer, an Admiralty historian, and a member of the Society for Nautical Research—takes over. His book, which I consider a true magnum opus, tackles a period in the development of navigation which has until now remained singularly neglected. It describes, in scholarly detail, the first Elizabethan era, and the problems of oceanic navigation which had suddenly assumed a vital urgency in that New Age of merchant enterprise.

Lieutenant-Commander Waters explains how seamen like Hawkins, Drake, Hudson, and Baffin were navigationally equipped to undertake their momentous voyages; and he fills in the gaps in our knowledge of the tremendous advance that took place within some 80 years (1550–1630). His book must become a standard work on this subject; it also holds a particular interest at the present time, when the advent of the Nuclear Age is providing a challenge to our navigators and scientists comparable with that which faced our ancestors four centuries ago.

For we are on the threshold of intensive deep-sea navigation; and in
addition to looking upward to take celestial observations, and horizontally for bearings of objects on shore, we shall in future be directing our attention downwards as well. The navies of the world will be sending their nuclear-powered submarines on missions that will preclude their surfacing to take sights or obtain radio-fixes—yet these submarines must be able to fix their positions with great accuracy while submerged. Since it appears, moreover, that large tankers and cargo vessels could be propelled at a high speed far more economically, if totally submerged, the same navigational problems will face the merchant navies also, if it proves feasible to operate such craft.

If this happens, much greater accuracy in the charting of the ocean-beds and sea-mounts will become necessary, and considerable hydrographic work in this field remains to be done. An entirely new ‘inertial’ system of navigation dependent solely on the rotation of the earth is now being developed by which the navigator will be able to determine his position without coming to the surface. As we enter, so to speak, a new dimension, the development of the Art of Navigation in the First Elizabethan Era—which this book so graphically describes—can provide an inspiration to our navigators and scientists in the Second.

Mountbatten of Burma
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The portrait is from the copy made in 1841 of the original portrait painted by Holbein between 1548 and 1554. The original was destroyed in the great fire at Pittsburgh in 1845. The inscription on the portrait reads: Effigies Seb. Caboti, Angli. filii Johannis Caboti Veneti Militis Aurati. Primi Inventoris Terrae Novae sub Henrico VII. Angliae Rege. Richard Hakluyt describes him as: 'So valiant a man, and so well practised in all things pertaining to navigation, and the science of cosmographic...that could make cardes for the sea with his owne hand...'.

II  PAGES 52–53 OF CAPTAIN JOHN SMITH'S An Accidence (1626). By courtesy of Henry C. Taylor page xxxiii

III  THE LEAD AND LINE: The title-page of the first part of Wagenaur's Spieghel der Zeevaerdt (1584). By courtesy of Henry C. Taylor facing page 24

The earliest illustration of a lead and line. (For details of the method of attaching the line see Pl. LXXXII.) The mariners are correctly shown holding the line palm downwards. Held thus on heaving the lead the line will fall clear when released from the leadsmen's grasp.

A mariner on the poop of the ship is shown taking a sounding.

The other instruments shown are: quadrants, sea-astrolabes, cross-staves, celestial and terrestrial globes, running glasses, compasses for pricking the chart, and sea-compasses. Each mariner wears a sheathed knife on a lanyard—an essential tool of his trade in emergency.

IV  EDWARD FIENNES, LORD CLINTON AND SAYE, LORD HIGH ADMIRAL, AND THE SEA-COMPASS, 1562. By courtesy of the Ashmolean Museum, Oxford between pages 24 and 25

As Lord High Admiral, Lord Clinton and Saye, and his successor, Charles, Lord Howard of Effingham, were both important patrons of the art of navigation in Elizabethan and early Stuart England.

The painting of the sea-compass is the earliest accurate English representation of one in perspective.


This compass incorporated a number of improvements.

VII  ESTABLISHMENT OF ENGLISH AND IRISH PORTS. One of the Tidal Charts in Brousson's Tide-Tables and Rutter of c. 1545 (see Appendix 3). By courtesy of the Master and Fellows of Magdalene College, Cambridge facing page 32
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VIII CIRCULAR TIDE-TABLES FOR PORTS WITH ESTABLISHMENTS OF SOUTH-SOUTH-EAST AND SOUTH (High Water on days of full and change at 10.30 and 12.00), Brouscon’s Tide-Tables and Almanac of c. 1545 (see Appendix 3). By courtesy of the Master and Fellows of Magdalene College, Cambridge facing page 32

IX A NOCTURNAL OF 1545. By courtesy of Henry C. Taylor between pages 32 and 33

From The Arte of Navigation (1561). Martin Cortes was the first writer on navigation to publish an illustration of a nocturnal.

The Nocturnal was used for finding the time of the night by means of the Pole Star and its Guards.

The Nocturnal was made of a disc of wood or brass, from 5 to 7 inches in diameter, with a handle on one edge (not shown by Cortes) and a pointer diametrically opposite it. The days of the month were engraved around it, the 28th October in line with the handle, the 19th April in line with the pointer, these being the dates when the guards of Ursam Minor transited respectively south and north at midnight by solar time. The hours were engraved on a ‘lesser roundel’ from twelve noon to twelve midnight, a pointer engraved ‘Time’ on the edge of this lesser roundel marking midnight. To find the time the pointer or ‘tooth’ on the lesser roundel marked ‘Time’ was set to the day of the month then ‘holding the instrument by the handle with your own hand right before your face, leave not to put that hand forward from you, or to bring it backwards towards you, until you may see with one eye, winking with the other, the North Starre through the hole of the pen, [about which the lesser roundel and hour index pivoted] which is the centre of the instrument: and so soon as you see the North Starre, lift with your other hand the index up and down [the Horn in Cortes’s diagram] until you see also at that instant the North Guard of the Loadstar on the outside of the instrument appearing even with the fiducial line or inward edge of the said index. Then staying the index there, look upon what hour it faileth, for that shall be the hour of the night.’ Blundeville’s Exercises (1594).

The nocturnal depicted shows that the time is 3.45 a.m. on 25th June.

X A TRAVERSE BOARD. By courtesy of the Trustees, The National Maritime Museum, Greenwich between pages 32 and 33

The circular portion was used by the helmsman for recording with a peg the mean course steered each half-hour of his four-hour watch.

The rectangular portion of the base was probably not provided before the first quarter of the seventeenth century when knotted log-lines and half-minute glasses began to come into use. The distance sailed was pegged each half-hour of the watch.

XI THE RULE OF THE NORTH STAR, DISTANCE TO RAISE OR LAY A’ OF LATITUDE AND THE ALMANAC FOR JANUARY AND FEBRUARY, in Brouscon’s Tide-Tables and Almanac of c. 1545 (see Appendix 3). By courtesy of the Master and Fellows of Magdalene College, Cambridge facing page 33

XII THE PTOLEMAIC WORLD SYSTEM. From William Cuningham’s The Cosmographical Glasse (1559), the first English book on cosmography. By courtesy of the Trustees of the British Museum facing page 56

This beautiful woodcut illustrates the Ptolemaic world scheme (modified to suit Christian dogmas), the popular explanation of the universe until well into the eighteenth century and the one adhered to by navigators throughout the sixteenth and early seventeenth centuries.
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XIII, XIV and XV Declination Tables, 1545–1688. Folios xxiii(a), xxv(a) and xxvi(a) of Cortes’s The Arte of Navigation (1561). By courtesy of the Trustees of the British Museum between pages 56 and 57

XVI Declination Table for ‘Abril–Mayo–Junio 2nd Year’ after a Leap Year. Folio lv(b) of Medina’s Arte de Navegar, Valladolid, 1545. By courtesy of Henry C. Taylor between pp. 56 and 57

The straightforward declination table for mariners. Contrast it with the three tables (Pls. XIII, XIV and XV) and with the calculations necessary to find the declination of the sun in Cortes’s tables, taken from Eden’s translation.

Until Bourne published his Rules of Navigation in 1567 English mariners had no printed simple declination tables like Medina’s. The French and Italians had them in 1554 when Medina’s work was translated into French and Italian.

It will be noticed in these tables and in Cortes’s that there is an apparent error of eleven days in the declination. In Medina’s table the sun’s maximum northerly declination occurs on 12th June and is given as 23° 33’. In Cortes’s table the sun is on the equinoctial on 13th September. Today the summer solstice occurs on 22nd June, the autumn equinox on 23rd September. The difference arises from the tables having been drawn up for the Old Style or Julian Calendar. The New Style or Gregorian Calendar was adopted from 1582 in various continental countries. In England it was not adopted until the eighteenth century.

Medina’s declination tables were drawn from those prepared about 1475 by the Spanish astronomer Zacuto, edited by the Portuguese astronomer Vizinho, and published in 1496 (Almanach perpetuum, Leiria).

Cortes’s declination tables were based on the astronomical tables of Regiomontanus, Johann Müller of Königsberg, whose Tabulae directionum profectionum, first published in 1475, contained tables of the position of the sun and whose Ephemerides, first published in 1474, included in the 1498 and later editions the declination of the sun. Before this edition, published in Venice, Regiomontanus’s tables were suited only to astronomers. Zacuto’s Almanach perpetuum was the source of all the earliest nautical declination tables.

XVII Taking a Pole Star Sight with a Cross-staff. From Medina’s Arte de Navegar, Valladolid, 1545. By courtesy of Henry C. Taylor between pages 56 and 57

XVIII Taking a Meridian Altitude Observation of the Sun with an Astrolabe. From Medina’s Arte de Navegar, Valladolid, 1545. By courtesy of Henry C. Taylor between pages 56 and 57

XIX(a) Spanish Sea-Astrolabe of 1545. From Cortes’s Arte of Navigation (1561). By courtesy of Henry C. Taylor between pages 56 and 57

Made from sheet brass, this type of astrolabe was developed from the medieval planispheric astrolabe introduced from the Middle East, where it had been invented in the sixth century. By the 1550s the cast ring-type of sea-astrolabe had come into use amongst mariners.

XIX(b) Sea-Astrolabe of the Cast-Ring Type, Dated 1555. By courtesy of the Curator of the Albert Institute, Dundee between pages 56 and 57

Only recently discovered in Dundee, this is the oldest known dated sea-astrolabe. The scale is remarkable in that it is engraved for zenith distances. This suggests that it is of Portuguese workmanship, though its large size suggests that it is of English design. It measures 8 inches in diameter and weighs 6 lb. 6 oz.
Plate

XX(a) The Shipman’s Quadrant or The Mariner’s Quadrant. From Blundeville’s Exercises (Seventh edition, 1636). By courtesy of the Lords Commissioners of the Admiralty between pages 56 and 57

The illustration in the first edition (1594) is identical. Designed for finding the course between places of known latitude and longitude, it was not a practical instrument.

XX(b) The Shipman’s Quadrant of Humphrey Cole’s Great Two-foot Astrolabe. By courtesy of the Department of Natural Philosophy of the University of St. Andrews between pages 56 and 57

The instrument is inscribed ‘Humphry Cole Londinensis hoc instrumentum fabricavit 21 die Maii Al Juli 1675’. Humphrey Cole made many instruments for Frobisher’s voyages of 1576–77–78 to the North-West. They included an ‘astrolabium’ (see Appendix 10).

XXI The Plane Chart’s Loxodromes. Blundeville’s Exercises, fol. 691 (Seventh edition, 1636). By courtesy of the Lords Commissioners of the Admiralty between pages 56 and 57

‘... draw... a secret circle... which circle shall signify the Horizon... the... 16 little Mariners compasses, the lines thereof signifying the windes, doe shew how one place beareth from another, and by what wind the ship hath to saile... the circle... upon the very centre of the Horizon... the Mariner... does call... the mother compass.’ The diagram in the first edition (1594) is identical.

XXII Chart of the Atlantic from Cortes’s Arte of Navigation of 1561. By courtesy of the Trustees of the British Museum between pages 56 and 57

This chart was redrawn from the Spanish original, first published in Seville in 1551. This was drawn corrected for variation and therefore with only one latitude scale. In the 1530s a great dispute raged in the Casa de Contratacion at Seville over the drawing of charts. Finally, that charts should be drawn corrected for variation—that is, on true not compass bearings—became the rule with Spanish hydrographers.

XXIII The Mediterranean, 1542. From Jean Rotz’s MS. Book of Hydrography (1542). By courtesy of the Trustees of the British Museum facing page 57

The double latitude scale was introduced in an attempt to reconcile the observed latitude of places with their positions when charted by compass bearings uncorrected for variation, and by estimated distance.

XXIV The Rhumb Line a Spiral Line. Blundeville’s Exercises, p. 693 (Seventh edition, 1636). Blundeville took the diagram from Coignet’s Instruction... touchant l’art de naviguer, Anvers, 1518. By courtesy of the Lords Commissioners of the Admiralty facing page 73

‘Whosoever saileth by any other Rhumbe than by one of the four principall, he by often changing his Meridian and Horizon must needs saile by a line Spirall...’ The diagram in the first edition (1594) is identical.

XXV The North Atlantic and Part of the Horizon Ring on Mercator’s Terrestrial Globe of 1541. By courtesy of the Trustees of the National Maritime Museum, Greenwich between pages 72 and 73

Observe the Rhumb lines, the division of the Equator into 360°; the longitude measured eastwards from a Prime Meridian passing through the For-
Plate

tuneate Islands—the Canary Islands, the various stars placed on the globe to aid position-finding. Of the latter *Humers Pegas* and *Crus Pegas* in Longitude 34° are examples.

The Horizon Circle shows the Signs and Degrees of the Zodiac—the Ecliptic can be seen on the globe crossing the Equator at the Prime Meridian; the days and months of the year; the fixed feast days; and the Rhumbs of the Winds.

This is the first globe known to have rhumb lines drawn in. It was the favourite marine globe for over half a century—until superseded by the Molynex globe of 1592 and 1603, and the Dutch globes of the early seventeenth century.

XXVI CHART OF NORTH-EAST ATLANTIC in Brouscon's Tide-Tables and Almanac of c. 1545. By courtesy of the Master and Fellows of Magdalene College, Cambridge between pages 72 and 73

This large chart folds into the book. The two top right-hand sections contain the coasts of Holland and Denmark and the name 'F. Drak' on the otherwise blank fly.

XXVII and XXVIII THE FRONT AND BACK OF THOMAS GEMINI'S UNIVERSAL PLANISPHERIC ASTROLABE OF 1552. By courtesy of Henri Michel, of Brussels facing page 73

Gemini was one of the foreign instrument-makers, engravers and printers, who started the English instrument industry and raised the standard of English book production and illustration in the middle of the sixteenth century. This magnificent astrolabe, engraved with the arms of the Duke of Northumberland, Sir John Cheke and Edward VI, and dated 1552, reflects the measures taken for the development of the art of navigation in England in the 1550s, and particularly the preparations for the voyage of 1553 to the North-East. These included the provision of astrolabes. Foreign pilots, the Portuguese Pinto and, and the Frenchman Jean Ribault, were employed on preparing charts.

Until about 1550 the planispheric astrolabe had on the front a stereographic projection of the heavens, usually from the North Pole to the Tropic of Capricorn, for a particular latitude. The circles included the equator, the two tropics, the meridian of the place, the azimuth for the latitude and the almucantars for the same latitude. Rotating above this fixed plate was the net, the projection of the celestial sphere on which was given the ecliptic and the principal fixed stars.

In 1556 Gemma Frisius published a description of a universal astrolabe or Astrolabum Catholicum. Known to Iberian astronomers in the thirteenth century, it was suitable for all latitudes, and thus of particular value to seamen, being a stereographic projection of the sphere on the colure of the solstices, the centre of the projection being the vernal point.

In 1550 de Rojas, a pupil of Gemma Frisius, published a variation of the Astrolabum Catholicum, an orthogonal projection of the sphere on the colure of the solstices. It was fitted with a diometrical rule and a cursor analogous to those also fitted on the Astrolabum Catholicum.

On the back of these types of astrolabe it was usual to include, as on the one illustrated, a zodiacal calendar, an altitude scale, a conversion scale for equal and unequal hours, a scale of *ombra recta* and *ombra versa*, and an alidade.

XXIX THE HAVEN OF DEATH, 1553. The penultimate page of Sir Hugh Willoughby's Journal of 1553. By courtesy of the Trustees of the British Museum facing page 120

The last lines of the journal end abruptly on the other side of this page. It would seem from the marginal entry on this page that Sir Hugh knew they were doomed. He and all his crew perished, frozen to death. (See Appendix 5.)
Illustrations

Plate

XXX and XXXI Tide Tables and Rules for their Use in
Leonard Digges's A Prognostication everlasting of right good
effecte . . . (1556). By courtesy of the Trustees of the British
Museum facing page 121

In the last half of the sixteenth century and first half of the seventeenth
century this was one of the most popular English almanacs covering a period
of years. First published in 1555, it was kept up to date by new editions.

By courtesy of the Trustees of the National Portrait Gallery,
London facing page 136

Founder of Gresham College, London, the 'Precursor of the Royal Society,'
and of all scientific institutions in England; and, by virtue of his munificent
endowment, father of the scientific development of navigation in England.

XXXIII(a) A Regiment for the Sea (1574). Title-page of the
earliest edition. By courtesy of the Bibliothèque nationale, Paris
facing page 137

The sea-astrolabe is of typically English design, the design is plain and
economical, the vanes fairly widely spaced. In his Rules of 1567 Bourne in-
cluded a somewhat similar illustration. However, only the upper left-hand arc
was graduated (for altitudes), the vanes were wider spaced and had only one
(sun) pin-hole.

XXXIII(b) A Regiment for the Sea (1576). By courtesy of
Boston Public Library, Massachusetts facing page 144

Title-page of the second and apparently unauthorized edition, showing the
large English warship of the early 1570s on the verso of the title page of the
1574 edition. Note the top-sails of the mizen- and bonaventure mizen-
masts and the top-gallant sails on the fore- and main-masts. The fore-sail and
main-sail are set, the fore-sail with a drabbliner laced on; reef points were not
used at this period. The bowlines for controlling the set of the sails when
close-hauled are clearly seen. Ten ships of this type were amongst the royal
warships that, a dozen years later, fought the Spanish Armada in the English
Channel.

XXXIV Title Page of Digges's A Prognostication everlastinge
(1576). By courtesy of the Trustees of the British Museum
between pages 144 and 145

This was the first English book to contain an illustration of the Copernican
theory. It also contained notes on errors in navigation, and a discourse on
variation. (See Appendix II.)

XXXV Digges's Diagram of the Copernican System from A
Prognostication everlastinge (1576). By courtesy of the Trustees of
the British Museum between pages 144 and 145

XXXVI Signed and Dated MS. Chart of 1576 of the N.W.
Atlantic by William Borough. Original size 33½ × 27 inches.
Signed: 'The first of June 1576 By W: Borough.' By courtesy of
the Marquess of Salisbury facing page 145

This chart has four endorsements on the back, '1578, Marty furbushers
Navigatio. 98', and 'North West furbushers Voyage'; these are in Lord
Burgheley's handwriting; the other two in a later hand both read: 'A Sea Carde
of Sr M'tine furbushers voyaige'. Note in particular the arrows indicating
the amount of variation observed at various points on the voyage. (See
Appendix 10A.)
Plate

By courtesy of the Trustees of the British Museum facing page 152

'Ye account of the third Voyage to Meta Incognito, made by Mr. Christopher Hall, M. of the Ship Ayde, and now Pilott in the ship Thomas Allyn.' (See Appendix 13.)

XXXVIII Typical Page of Robert Norman's The Safeguard of Sailers (1590). By courtesy of the Trustees of the British Museum facing page 153

XXXIX The Mariners Mirrour (?1588). Title-Page of The Mariners Mirrour, the (1588) translation by Anthony Ashley of Wagenaer's Spieghel der Zeevaerdt (1585). (See Pl. III.) By courtesy of the Lords Commissioners of the Admiralty facing page 168

The mariners are in English dress; the ship, despite its flags (which have been changed like the mariners' dress for this English edition), is a Flemish carrack.

Included are quadrants, astrolabes and cross-staves for shooting the sun or stars; hour-glasses and sounding leads and lines; terrestrial and celestial spheres. The leads and lines are repeated in the motif of the mariners, who are holding the lines correctly palm downwards, to ensure their running freely when cast. This repetition emphasizes the importance of the lead and line, so does the prominence given to the two sea-compasses and the beautifully wrought compasses 'for pricking the card'.

XL 'This Vpper Half Circle'. Diagram from Wagenaer's The Mariners Mirrour (?1588). By courtesy of the Lords Commissioners of the Admiralty between pages 168 and 169

Diagram to show 'Distance to Raise or Lay a Degree' and 'Distance run East or West' in raising or laying a degree on different rhumbs, incorporating a circular tide-table showing the establishment of various important ports or points on the coast of N.W. Europe, with the establishment, in the outer circle, of the tides off shore. This diagram could be used in conjunction with tables following it for finding the time of High Water on any given day of the month at the places indicated on the diagram.

XLI 'A General Carte, & Description of the Sea Coastes of Europe and Navigation in this Book contained.' The first chart in Wagenaer's The Mariners Mirrour (?1588). By courtesy of the Lords Commissioners of the Admiralty between pages 168 and 169

It shows distinct portulan characteristics which the remainder do not.

XLII 'The Coastes of England, from the Sorlings [Scilly Is.] by the Landes End to Plymouth with the Havens and Harbours.' From Wagenaer's The Mariners Mirrour (?1588). By courtesy of the Lords Commissioners of the Admiralty facing page 169

Probably published in 1588, but too late for the Armada campaign, they were the first printed charts generally available to English seamen.

XLIII Pocket Dials by Humphrey Cole, dated 1569. By courtesy of the Trustees of the National Maritime Museum, Greenwich facing page 184

They are traditionally described as having belonged to Sir Francis Drake.

(See Appendix 7A.)
Plate

XLIV and XLV  Nocturnal and Tide Computer by Humphrey Cole. (Undated. Between 1570 and 1590.) By courtesy of the Trustees of the British Museum facing page 185

XLVI  A Page of Captain John Davis's Log Book of 1587. From Richard Hakluyt's Principal Navigations (1598–1600). By courtesy of Henry C. Taylor facing page 192

The columns are: Moneth; Dayes; Hours [since last entry]; Course [made good]; Leagues [distance sailed]; Elelevation of the pole [latitude in] Deg and Min.; The winde; The Discourse. [Remarks or Journal.]

The Discourse of 31 July reads: This 31 at Noone, coming close by a foreland or great cape, we fell into a might rest, where an island of ice was carried by the force or the current as fast as our barke could sail with lum [sic] wind, all sails bearing. This cape as it was the most Southerly limit of the gulf which we passed over the 30 day of this month, so was it the North promontory or first beginning of another very great inlet, whose Southe limit at this present wee saw not. Which inlet or gulf this afternoon, and in the night, we passed over where to our great admiration we saw the sea falling down into the gulf with a mighty overfall, and roring, and with divers circular motions like whirlpools, in such sort as forcible streames passe thorow the arches of bridges.

The Discourse of 1 August reads: The true course, etc. This first of August we fell with the promontory of the sayd gulf or second passage, having coasted by divers courses for our safeguard, a great banke of ice driven out of the gulf.

The Discourse of 13 August reads: This day seeking for our ships that went to fish, we strook on a rock, being among many iles, and had a great leake.

The Discourse of 14 August reads: This day we stopped our leak in a storme. The 15 of August at noon, being in the latitude of 52 degrees 12 min. and 16 leagues from the shore, we shaped our course for England, in God's name, as followeth.*

The Discourse of 17 August reads: The true course, etc. This day upon the Banke we met a Biscaine bound either for the Grand Bay or for the passage. He chased us.

The Discourse of 24 August reads: The true course, etc. This 24 August observing the variation. I found the compass to vary towards the East, from the true Meridian, one degree.

The Discourse of 5 September reads: The true course, etc. Now we supposed our selves to be 55 leagues from Scillie.

The Discourse of 15 September reads: This 15 of September we arrived at Dartmouth.

At the foot of the page the note reads: Vnder the title of houres, where any number exceedeth 24, it is the summe or casting vp of so many other dayes and parts of dayes going next before, as containe the fore sayd summe.


The second edition (first edition, 1594) of the first English celestial globe which was also the largest manufactured up till then for sale. This globe and the companion terrestrial globe were constructed by Emers Molyneux. The gores were engraved by the Dutch engraver, Hondius. The manufacture of the globe was financed by William Sanderson.


The first English terrestrial globe (first edition, 1594), the largest globe manufactured for sale up till then. A smaller, cheaper edition of both globes was sold for students. Note the rhumbs and the tracks of Drake's and Cavendish's voyages of circumnavigation. A terrestrial globe of the first (1594) edition was recently found in the library of Petworth House, Sussex.
ILLUSTRATIONS

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XLIX THOMAS HOOD’S CHART OF THE N.E. ATLANTIC, 1592.
Engraved by Ryther, it was originally included in The Mariners guide (1592), Hood’s supplement on plane charts to his edition of Bourne’s Regiment for the Sea (1592). By courtesy of the Master and Fellows of Magdalene College, Cambridge facing page 193

The original measures 20\frac{1}{2} \times 15\frac{1}{2} inches over the extremities of the border. It is one of the earliest copper-plate charts designed for navigation as distinct from piloting. It contains the ‘pricking’ of various navigational exercises in The Mariners guide, and is the earliest known example of an English instructional chart.

The latitude scale, distance scale of English and Spanish leagues, the diagrams to raise or lay a degree, the rule of the North Star, the absence of a longitude scale, and the inclusion of the mythical islands of Brazil and Maida, should be noted.

The symbols for shoals and off-shore rocks are similar to Wagenauer’s.

L MS. CHART OF THE BAY OF BISCAY, SOUNDINGS AND CHANNEL
BY THOMAS HOOD, 1596. By courtesy of the Trustees of the National Maritime Museum, Greenwich facing page 200

The secret circle about the central point in the Bay with lesser compass flies on it at the cardinal points will be noted. To avoid obscuring the coast the flies have been omitted at the N.W., N. and N.E. points, and a half-fly only drawn at N.N.W. This is a plane chart.

The 100-fathom line is clearly shown.

Of particular interest is the fly on the West rhumb. It is lettered from A to Q on the rhumbs between North and South by East. The similar letters on the continental coast indicate the establishment of the port and the time of high water on days of full and change in terms of the compass clock. For example:

‘T’ by Guernsey indicates High Water occurs there at 3 o’clock on days of new and full moon.

The fact that the establishments of continental ports only are shown suggests that they and the idea (though suggested by Bourne in 1574) are of French origin.

LI CAPTAIN JOHN DAVIS’S LAY-OUT OF A LOG BOOK OF 1593. (The Seamans Secrets, 1657, a reprint of the 1595 edition.) By courtesy of the Lords Commissioners of the Admiralty between pages 200 and 201

LII BRASS TIDE COMPUTER OF THE LATTER HALF OF THE SIXTEENTH CENTURY. From a photograph in the possession of the author between pages 200 and 201

LIII IVORY PRESENTATION CROSS-STAFF AND RULES AND SCALES OF c. 1695. By courtesy of the Trustees of the National Maritime Museum, Greenwich facing page 201

The instruments are engraved ‘Thomas Tuttell Charing + Fecit’.

The Cross-staff is engraved for ‘Altitude’ and the ‘Complement’ and is fitted with the four transversaries common by 1630. Each side is graduated for use with one of the four transversaries. The 5° transversary is cut so that it can serve as horizon vane, the staff being used as a back-staff with either the 15°, 30° or 60° transversary being used as a combined eye- and shadow-vane.

Though dating from the last quarter of the seventeenth century and though made of ivory the instrument is typical in general design and detail of wooden cross-staves in use in the first quarter of the century.

The Rules are engraved with Gunter’s Scales.

LIV CAPTAIN JOHN DAVIS’S 45° BACKSTAFF. (The Seamans Secrets, 1657, a reprint of the 1595 edition.) By courtesy of the Lords Commissioners of the Admiralty facing page 208
ILLUSTRATIONS

Plate

This was the first backstaff in its original form. While it incorporated Hoode's principle of observing the sun's shadow it incorporated also a new one—that of observing the sun indirectly by back observation. This had the advantage of eliminating parallax arising from the eccentricity of the observer's eye, and of avoiding dazzle from the horizon beneath the sun.

LV Captain John Davis's 90° Backstaff or Quadrant. (The Seamans Secrets, 1657, a reprint of the 1595 edition.) By courtesy of the Lords Commissioners of the Admiralty between pages 208 and 209

The staff had a horizon vane and was graduated for the upper, and longer, 'cross', and for the shorter and lower one. The latter was also graduated and carried a sight-vane, omitted from Davis's illustration. The shadow cast was not sharp owing to the distance of the shadow 'cross' from the horizon vane. The upper cross was a chord of a circle, the lower an arc.

LVI(a) Horizontal Plane Sphere by Humphrey Cole, dated 1574. By courtesy of the Trustees of the National Maritime Museum, Greenwich between pages 208 and 209

One of the instruments which Frobisher took on his 1576 voyage was a Horizontal Plane Sphere made by Humphrey Cole. John Davis considered it one of the navigator's necessary instruments (The Seamans Secrets, 1595). It was used for fixing positions by bearing and distance, or, if the navigator was a skilled surveyor, for triangulation survey work. This one is interesting for its outer graduation dividing the circle into 360°, its inner graduation of the rhumbs of the winds, and those of 'The Geometricall Square' used in survey work. The geometrical square was a primitive scale for finding distances. Even after triangulation was introduced in the middle of the sixteenth century, surveyors continued to be chiefly interested in distances and heights rather than angles. A quadrant, or quarter of a geometrical square, will usually be found upon quadrants intended for use in survey work, and a double quadrant on the lower half of the back of planispheric astrolabes. The sides of the quadrants are usually divided into 12, 60, 100 or 120 divisions, the more numerous sub-divisions being a refinement of the instruments of the sixteenth and seventeenth centuries. They correspond to imperfect tangent and cotangent scales.

This planisphere forms the base of Humphrey Cole's Theodolite of 1574 which was derived from Waldsmeuller's holometrum of 1512 with the addition of a nautical compass, a development probably first made by Gemma Frisius about 1530. He used a separate compass. In Cole's instrument the compass forms an integral part of the instrument about which the vertical semi-circle rotated.

LVI(b) Armillary Sphere by Humphrey Cole, 1582. By courtesy of the Department of Natural Philosophy of the University of St. Andrews facing page 209

Inscribed 'Humphrey Cole fecit 1582', it measures 18 inches overall height. In the centre of the base support is a ring for a plumb-bob (missing). The compass box is engraved in the interior with the four quadrants of the compass and contains a rod-type compass needle with a brass capital. The planisphere is on the projection of de Roias (1550). Frobisher's instruments for the voyage of 1576 to the North-West included 'a great instrument of brasse named Armilla Tolomei or Hemispherium' by Humphrey Cole. (See Appendix i0B.)

LVII Luke Foxe's Circumpolar Chart of 1631. By courtesy of the Trustees of the British Museum facing page 224

*I have also placed a Polar Map or Card, that this Discoverie may be the better understood, and for that I did desire to give satisfaction by Demonstration of all treated of in the Booke; for, otherwise, another projection could not have contained it but at unreasonable diversity, and because I cannot des-
Plate

cribe all the Names in Fretum Hudson, of Capes, Islands, and Bayes at length in Letters, in respect of the smallnesse of the Degrees of Longitude, I have inserted them in a table by the letters of the Alphabet, as thou shalt find, beginning with A, b, c, d, and tracted my owne way and discovery forth and home in small prickes. Luke Foxe. From Kingston upon Hull, this first of January, 1635. This chart projection shows admirably the reason for the 140-year attempt of the English to find either a North-West or a North-East Passage to the Orient—it would be so much shorter and quicker than by way of the Cape of Good Hope. Note the typical way in which Foxe’s track is pricked on the chart.

LVIII  Edward Wright’s Chart of the N.E. Atlantic on Mercator’s Projection from Certaine Errors of Navigation (1599). By courtesy of Henry C. Taylor between pages 224 and 225

This is the earliest printed chart on Mercator’s projection. It should be compared with the Hatfield MS, chart of the same area, also on Mercator’s projection, with which it has much in common. (Pl. LXI.) The Course of the Earl of Cumberland’s ship in 1589 is pricked off on the chart. This chart should also be contrasted with Hood’s plane chart of 1592 covering the same region. (Pl. XLIX.) (See Appendix 18B.)

LIX  The First Printed Table of Meridional Parts for every 10 Minutes of Latitude. From Wright’s Certaine Errors of Navigation (1599). By courtesy of Henry C. Taylor facing page 225

‘A correction of Errors.
‘Till the Printer had thus farre proceeded, I was purposed to have published the whole Table before mentione, in such sort as I had made it, (supposing a Meridian of the nauticall Planisphere to be diuided, beginning at the equinoctial) into such parts whereof a minute of the equinoctial containeth 10,000, and setting downe by which of these parts euery minute of latitude is to be drawne, till you come within a minute of the Pole.
‘But upon further advice it was thought more meet to abridge the same as followeth, to euery tenth minute, & to cut off throughout the Table the three first figures towards the right hand, meaning not at this time to trouble thee with more then mought be of vse, for the true diuiding of the Meridian in the Sea Chart into degrees, and sixe parts of a degree, without sensible error which may be sufficient for the greatest sort of Sea Charts or Maps, that hitherto hue beene vse.
‘This Table is diuided into two columns, whereof the first containeth degrees, and tens of minutes, of the Meridian of the nauticall planisphere, beginning at the equinoctial. The second column containeth acqual parts of the same Meridian, beginning likewise to be numbered from the equinoctial: (of which parts euery minute of the equinoctial is vnderstoode to containe 10.) and sheweth how many of these parts are answerable to any degree or Decade of minutes of latitude, in the nautical Planisphere or Sea Chart.’

LX  Mercator’s Projection as described by Edward Wright in Certaine Errors (1599). Drawn from a sketch by the author facing page 232

‘Suppose a spherical superficies with meridians, paralels, rumbs, and the whole hydrographicall description drawn to bee inscribed into a concave cylinder, their axes agreeing in one. Let this spherical superficies swell like a bladder, (whiles it is in blowing) equally always in every part thereof (that is as much in longitude as latitude) till it apply, and joigne itselfe (round about, and all along) also towards either pole into the concave superficies of the cylinder, each parallel upon this spherical superficies increasing successively from the equinoctial towards eyther pole until it come to be of equal diameter with the cylinder, and consequently the meridians still widening them selves, til they come to be so far distant every where ech from other as they are at the equinoctial. Thus it may most easily be understooode how a spherical superficies may (by extension) be made a . . . plaine . . . superficies . . .’
Plate
LXI  MS. Chart of the N.E. Atlantic on Wright’s (Mercator’s) Projection. By courtesy of the Marquess of Salisbury facing page 233

This chart, preserved in the muniment room at Hatfield, has notable similarities to Wright’s engraved chart of the N.E. Atlantic, including the Azores, contained in the 1599 edition of Certaine Errors. It seems highly probable that it is English, of the late sixteenth century, and the oldest surviving MS. chart on Mercator’s projection. It has been reproduced in facsimile in E. M. Tenison’s Folio of Charts of Elizabethan England. It is described at Hatfield as: Chart of the English Channel from Portsmouth, with the soundings marked to Ushant, & of the coast of Spain to Cape St. Vincent, with the Azores. MS. No. 52 in Maps, Charts & Plans No. 2. Hatfield House. It measures 21 x 14½ inches. (See Appendix 18.A.)

LXII  Printed Chart of the Strait of Gibraltar, 1595. This chart is in William Barentszoon’s Nieuwe hercuynghe ende Caertboeck van de Midlandsche Zee, of 1595, and the French edition, Description de la Mer Méditerranée, 1609, in which the same plates were used. By courtesy of Henry G. Taylor facing page 248

Note the double network of rhumbs and the two compass roses, one for meridional compasses, as used by the Mediterranean seamen, and one for the common sea-compass of the northern seamen. In this the compass needle was affixed to the fly so as to allow for variation. Except for the double network of rhumbs the charts were close copies of much older charts, showing little change from those of the fourteenth century.

LXIII  12-Inch Dip Ring of the Seventeenth Century. By courtesy of the Department of Natural Philosophy of the University of St. Andrews facing page 249

Note the raised rim for retention of the glazing.

LXIV  Chart of the Thames from Wagenaar’s The Mariners Mirrour (?1588). By courtesy of the Lords Commissioners of the Admiralty facing page 264

This chart should be compared with the later Blaeu charts of 1612 (see Pl. LXXVI), and 1625 for changes in the shoals, improved delineation of the coast and the increased buoying and beaconing of these difficult waters.

LXV  The Winds and Currents of the Atlantic. (See Appendix 26.) Adapted by the author from an Admiralty Chart by courtesy of the Controller of H.M. Stationery Office and of the Hydrographer of the Navy facing page 265

LXVI  Champlain’s Illustration of the Log, Log-line, Log-board, etc., 1632. Champlain, Les Voyages de la Nouvelle France Occidentale, Paris, 1632. By courtesy of the Lords Commissioners of the Admiralty facing page 280

The artist has drawn the detail of the manner of attaching the pin to the stray-line in order to form the crow’s foot incorrectly. It has been suggested that the line was probably rove through the log-chip in the direction opposite to that shown and that the pin was attached to the stray-line at a distance from the end suitable to form a crow’s foot when the pin was plugged into the socket. (See Appendix 31.1)

LXVII and LXVIII  A Model Log and Journal of the Early Seventeenth Century. ‘Sir Thomas Roe’s Journal during his Embassy at the Court of the Mogul.’ (B.M. Add. MS. 6115.) By courtesy of the Trustees of the British Museum between pages 280 and 281
Plate

Of The Log or Table of Courses Sir Thomas wrote: 'The 6: of March 1614 at 7 in the morning: ye Lizard Bering N.W.b.N.5 Leaug off: I began this Course.' The Journal of Observations according to ye Table of Course was an expansion of summary entries in the log. (See Appendix 21.) Not all masters kept such excellent journals as did the accomplished amateur navigator Sir Thomas Roe, first English plenipotentiary to India. Captain Peyton's journal of the voyage (B.M. Addl. MS. 19, 276) had a margin for comments, a narrow column for dates, and a wide one for all courses, observations, winds, etc. These were logged in narrative form across the page. Roe's longitude was estimated from the meridian of the Lizard, as far as the Cape of Good Hope. Then the Cape of Good Hope became the prime meridian.

LXIX Four Sea Astrolabes. Sixteenth and Early Seventeenth Centuries. By courtesy of the Trustees of the National Maritime Museum, Greenwich, of the Department of Natural Philosophy of the University of St. Andrews, and of the Curators of the Albert Institute, Dundee and the Museum of the History of Science, Oxford facing page 281

Only ten actual specimens of the mariner's astrolabe have been found in all the world's collections. Their present location and probable country of manufacture are: *1. Dundee, Albert Institute, 1555. (Portuguese?) *2. Greenwich, N.M.M., c. 1585. (Spanish?) *3. Denmark, Kronborg Museum, 1660. (French?) *4. Oxford, History of Science Museum, c. 1600. (Spanish?) *5. New York, Hoffman Collection (Decd.) 1603. (French?) *6. Japan, Tenri University, before 1610. (Portuguese.) *7. St. Andrews University, 1616. (English.) *8. Sweden, Skokloster Castle, 1626. (French?) *9. France, Caudebec-en-Caux Museum, 1632. (French.) *10. Portugal, Coimbra University, c. 1650. (Portuguese.) The first and earliest of these instruments is a very recent discovery of remarkable importance. (See Pl. XIX (b).) The St. Andrews specimen is, by its great weight and size, and its precision, the peer of all known examples; its maker, Elias Allen, was the finest instrument maker of his day. Asterisk (*) indicates those shown in this plate.

LXX Ivory Presentation Backstaff or Davis Quadrant of c. 1695. By courtesy of the Trustees of the National Maritime Museum, Greenwich facing page 296

Though made of ivory and dating from the last decade of the seventeenth century it is typical in design and detail of wooden Davis quadrants of the first quarter of the century. Observe the sighting vane with sighting hole on the large 30° arc, the horizon vane with horizon slit, and, on the 60° arc, the shadow vane. The arcs are graduated, as was common by 1630, with a Zenith Distance—complement of the altitude—scale. The 60° arc is graduated to degrees. For use the shadow vane was set to within 15°—30° of the estimated meridian Zenith Distance. The observation was completed by the adjustment of the sighting vane. The diagonal scale enabled readings to be taken accurately to within 2'. If the shadow was cast by the upper edge of the shadow vane 16' was added to the observation to allow for the sun's semi-diameter, if the lower edge cast the shadow 16' was subtracted. The small radius of the 60° arc brought the shadow vane close to the horizon vane and so ensured that a sharp shadow line was cast. The direct reading of the Zenith Distance simplified the computation for finding latitude.

LXXI Evolution of the Nautical Cross-staff Down to 1631 Drawn from a sketch by the author facing page 297

LXXII The Diagonal Scale and the Nonius Scale. From Captain George Waymouth's MS., The Jewell of Artes, of 1604. By courtesy of the Trustees of the British Museum facing page 312

The diagonal scale was probably devised by Richard Chancellor about 1550; the nonius was devised by Pedro Nuñez about 1540. The nonius was not a practical scale for seamen as its readings had to be converted into minutes. The diagonal scale seems to have been adopted by them fairly generally from the end of the sixteenth century when improved instruments
Plate

and declination tables came into use and tables of corrections for height of eye and refraction were prepared. It enabled much more accurate readings to be taken than hitherto. A general rule for reading a diagonal: First count how many concentric circles there are. There are usually 6 or 10. Then see how many diagonal lines are drawn within the limits of one degree. There are usually 2 or 3. Then multiply the number of concentric circles by the number of diagonals in 1°, divide the product into 60 (the number of minutes in a degree). The quotient gives the number of minutes that each intersection increases by and is more than the preceding one. The nonius is often erroneously referred to as a vernier, but Vernier published his invention in 1631, Nuñez his in 1542 in *De Crepusculis*. By drawing a series of arcs (Nuñez drew 44) inside and concentric with the arc of a quadrant, and by graduating the outermost arc into 90 degrees and the inner ones into progressively fewer equal divisions (Nuñez divided his into 89, 88, 87 and so on, the 44th inner arc being divided into 46 equal divisions), it was possible to ensure that the alidade would cut, more or less accurately, one of the 45 arcs.

The resultant reading was either in degrees, exactly, or in arcs and equal divisions of arc. Conversion to minutes and seconds was not really difficult, but it was a task few navigators, if any, were prepared to tackle. If, for instance, the alidade on a full nonius cut the arc divided into 55 equal parts at the 45th division, the angle measured was \( \frac{45}{55} \) of 90° = 90° × \( \frac{9}{11} \) = \( \frac{810°}{11} \) = 73° 7'.

\[ \frac{7 \times 60°}{11} = \frac{420°}{11} = 38° \frac{2°}{11} = 2' \times 60° = 11°. \]

Answer 73° 38' 11". On nonius scales with fewer divisions the same method of conversion was employed.

LXXIII Title-Page of Edward Wright's *Certaine Errors in Navigation*, second edition, 1610. By courtesy of the Trustees of New York Public Library facing page 313

Note the illustrations of Edward Wright's Quadrant, Universal Rings for finding variation, and his World Chart on Mercator's projection. The chart, it will be observed, includes 'Terra Australis' and 'The South Land Yet Vknoune', features omitted in the World Chart of 1600. The possibility of a N.W. Passage is evident beyond Hope Sanderson and west of Fretum Davis. To the North-East the advantages of a N.E. Passage are clear from the supposed shape of China. A Dip-circle, Sea-Astralse, Cross-staff, Compasses, Armillary Sphere, Rutter and Astralse are clearly delineated.

LXXIV Title-Page of the Second Part of *The Mariners Mirrour* (1605). By courtesy of Henry C. Taylor facing page 328

The title-page of the first part of this edition is identical with that of the English edition of 1588, except for the elimination of the reference to the exploits of Howard and Drake, and the substitution of *Jodocus Hondius excudit ann. 1605*. Two copies only of this edition are now known.


This superseded Ashley's translation of Wagenär's *The Mariners Mirrour* (1588), the second English edition of which, that of 1605, had Dutch letterpress and English charts. This frontispiece gives a lively picture of instruction in the art of navigation in Holland in the first decade of the seventeenth century. In the foreground from left to right are a compass, running-glass, various charts (including a paradoxical one), another 'wagonner', a universal astrolabe. The men on the left are discussing a sea-astrolabe, those behind are measuring off a distance from a chart in a 'wagonner'. At their feet is a rutter; a celestial globe is in front of them, and next to it is a terrestrial globe on which a master-pilot is demonstrating. A mariner measures off a distance on it, watched by another. Behind them two more mariners are poring over a plane chart. On the right a cross-staff with three crosses is being explained to two boys.
Plate

LXXVI Chart of the Thames Estuary in Blaeu’s The Light of Navigation, 1612. By courtesy of the Trustees of the British Museum between pages 328 and 329

This forms the left-hand page of a double-page chart of the Thames Estuary and East Anglian coast, first published in Holland in 1608. On comparison with Ashley’s chart in The Mariner’s Mirror of twenty years before it will be noticed that there are more buoys and leading marks, that approach courses are now included, that shoals are better defined and that the coast is less distorted for pilotage purposes. The more numerous rhumbs are indicative of the increased navigational as distinct from pilotage importance of the chart. De Spieits, the Spits so often mentioned in rutters, is now marked by a buoy.

LXXVII Page 104 of Book One of The Light of Navigation (1612). By courtesy of the Trustees of the British Museum facing page 329

Sailing directions are given for the coast between Start Point, Devon, and Portland, Dorset. The following pages treat, in order, ‘Of marine depths and fashions of grounds which men finde when they come out of the sea, to seek out the Chanel between Hey sant and the Sorrels [Ushant and the Scillies], taken out of the search made by Adrian Gevutson of Haerlem’; ‘Of the falling and running of the streame about these landes’; of, ‘What moone maketh high water at these places’; of, ‘At what depths you may see these coun treys’; and of, ‘How the countreys lye distant from each other’. Considerations of, ‘How these places are distant from other coun treys’, and of, ‘Under what degrees [in what latitude] these Coun treys lye’, complete the section.

LXXVIII West Indische Paskaert by William I. Blaeu, c. 1630. By courtesy of the Bibliothèque royale de Belgique, Brussels facing page 344

The earliest known printed chart of the Atlantic on Mercator’s projection. The Prime Meridian passes through Funchal, Madeira. The degrees of longitude are numbered eastward from the Prime Meridian (360°). The mythical islands of the Atlantic have been omitted. Printed on vellum, it measures 78 × 99 cm.

LXXIX Thomas Hood’s Sector. From The making and use of the Geometrical Instrument called a Sector (1598). By courtesy of the Trustees of the British Museum facing page 345

The diagonal scale enabled readings down to 10° to be accurately read off. This Sector was designed primarily for the instrumental solution of mathematical problems involving proportions in survey work.

LXXX Title-page of Edmund Gunter’s The Description and use of the Sector (1624). By courtesy of the Trustees of New York Public Library facing page 360

Notice Gunter’s cross-staff and the compasses and straight-edge (with Gunter’s line on it) in the hands of the man in the top right corner; the Gunter’s quadrant in the hands of the man below him; bottom left the observer using Gunter’s cross-bow; and top left the man using Gunter’s Sector; above him a celestial globe with dust-cap. A Gunter’s cross-bow is preserved in the seventeenth century Wrangel Collection of navigation instruments at Skokloster Castle, Sweden.

LXXXI Edmund Gunter’s Sector of 1605 or 1606. From De Sectore & Radio (1623). By courtesy of the Trustees of the British Museum facing page 361

Gunter designed this Sector in 1605 or 1606 primarily for the solution of navigational problems. It was the precursor of the slide rule and, at a time when logarithms had not yet been invented, greatly expedited calculation. Each side of the closed sector is depicted.
ILLUSTRATIONS

Plate

LXXXII Chart Title, Scale of Distances and Ornament to
A Chart in Blaeu's The Sea Mirrour (1625). By courtesy of the
Trustees of the British Museum facing page 376

Observe the faithful representation of a sea-astrolabe, hour-glass, lead and line, cross-staff, vellum chart, and compasses with which to measure distances and courses and to prick the traverse.

By courtesy of Henry C. Taylor facing page 377

From the chart of New England ("I had taken a draught of the Coast, and called it New England") drawn by Captain John Smith in 1614 and included in his The Generall Historic of Virginia, New England & the Summer Isles . . . to this present 1624, London, 1624.

LXXXIV An Early Stuart Navigator's Instruments of Pirotage, c. 1631. By courtesy of the Trustees of the National Maritime Museum, Greenwich, England facing page 472

A representative collection of instruments of pilotage used by the navigators who took the early colonists to America and the West Indies, and who established the trade with India.

Compass
Mounted in gimbals in a square compass-box, fitted in a portable binacle with a lantern inside.
(18th century similar to 16th century.)

Lodestone
(17th century)

\[\text{\begin{tabular}{l}
\text{Traverse Board} \\
\text{(17th-19th century)}
\end{tabular}\begin{tabular}{l}
\text{Telescope} \\
\text{(18th century similar to 17th century)}
\end{tabular}\begin{tabular}{l}
\text{Ring Dial} \\
\text{(16th century)}
\end{tabular}\begin{tabular}{l}
\text{Nocturnal} \\
\text{(17th century)}
\end{tabular}\begin{tabular}{l}
\text{Two pairs of Compasses} \\
\text{(17th century)}
\end{tabular}\begin{tabular}{l}
\text{Pocket Dials} \\
\text{(16th century)}
\end{tabular}\begin{tabular}{l}
\text{Log-line reel} \\
\text{(17th-19th centuries)}
\end{tabular}\begin{tabular}{l}
\text{Lodestone in Brass Case} \\
\text{(16th century)}
\end{tabular}\text{\end{tabular}}\]

Examples of the Lead and Line and Dipsie Lead and Line, the fundamental instruments of pilotage for an oceanic navigator approaching land, have been omitted only because of the dictates of space. The Log-chip, Log-line and Stray-line have been omitted for the same reason.

LXXXV An Early Stuart Navigator’s Instruments of Navigation, c. 1631. By courtesy of the Trustees of the National Maritime Museum, Greenwich, England facing page 473

A representative collection of navigational instruments used by navigators who took the early colonists to America and the West Indies, and established the trade with India.

Celestial Globe
(Mercator’s, 1551)

Mariner’s Astrolabe
(c. 1585)

Terrestrial Globe
(Mercator’s, 1541)

Davis Quadrant
(17th century)
Plate

Cross Staff
(17th century)
(with 60° Cross)

Battery of 1 Hr. Glasses
(17th century)

Two Pairs of Circular Compasses
(17th century)

Charts
(17th century)

Gunter's Scale
(17th century)

Brass
Quadrant
(17th century)

Dial Watch
(16th century)

The Mercator's Globes though obsolescent by 1631 might well have been carried. They measure 16 inches in diameter. The Mariner's Astrolabe too, was obsolescent, being superseded by the Davis Quadrant; like the brass Quadrant it was useful when the horizon was obscured. The quadrant is seventeenth century. The Cross-Staff and Davis Quadrant are of late seventeenth century manufacture and are in ivory, being a presentation set. They are, however, otherwise similar to pear-wood instruments of the early seventeenth century. (See Pls. LIII and LXX.) The Battery of Running Glasses is of the seventeenth century. It will be noticed that the glass on the left has got out of step with the rest. The navigator would therefore take the mean time of the other three. The Circular Compasses are seventeenth-century and for use with the globe. The MS. Waggoner is actually one of fifty years later, but it is a typical seventeenth-century production. Indeed on Drake's last voyage of 1595-6 a similar Waggoner was compiled and survives, in Paris. The Waggoner shown is Description of the South Sea by B.S. Made by William Hack, Wapping, 1684. It is often known as the Buccaneer's Waggoner. There is a copy (Sloane MS. 44) in the British Museum as well as at Greenwich. Page 34/70 is opened. It depicts the Gulf of Vallona on the Caribbean Coast of Panama. On the right-hand page is inscribed: 'On this Bank was the Almirant of the King of Spaine Castaway in the year 1631.' The Charts of paper or parchment were normally kept rolled. As the Gunter's scale has been included Gunter's Sector, which preceded his scale with its logarithmic lines, has been omitted.

LXXXVI  CAPTAIN JAMES'S CHART OF HIS VOYAGE FOR THE DISCOVERY OF THE N.W. PASSAGE IN 1631-32. By courtesy of the Trustees of the British Museum  facing page 488

Unlike Foxe's chart of this region James's is on Mercator's projection. The distortions in higher latitudes caused by this projection can be clearly seen by comparison with Foxe's circumpolar chart on a zenithal equidistant projection (See Pl. LVII). He called the distortions 'unreasonable diversity'. The names of the headlands, bays and islands reflect the hopes and frustrations of the N.W. explorers and commemorate their names and those of the merchants and nobility who financed their voyages. The mythical Buss I. and Friesland between England and Greenland will be noticed. As in James's chart Cape Farewell is charted several degrees too far to the southward, evidence of the difficulty of accurate navigation in northern waters. None of the explorers hitherto had been able to observe the latitude of the Cape, few besides Davis had seen it; knowing its presence they had preferred to give it plenty of seasroom.

LXXXVII  SIGNIFICANT ENGLISH VOYAGES OF THE SIXTEENTH AND EARLY SEVENTEENTH CENTURIES. Drawn from a sketch by the author  facing page 489
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An Accidence

For yong Sea-men.

The Coxon hath
The trumpeter hath
The Sailers, two or one is a half
The Boyes a single share.
The Lievetenant what the
Captaine will give him, or as
they can agree.

They use to appoint a
certaine reward extraordinar-
y to him that first descries a
Sayle if they take her, and to
him that first enters her.

For to learne to obserue
the Altitude, Latitude, Lon-
gitude, Amplitude, the vari-
ation of the Compass, the
Sunnies Azimuth and Almi-
canter, to shift the Sunne and
Moone, and to know the
Drydes, your rooms, pricke
your card, & lay yonr Com-
passe, get some of those
bookes, but praeticfe is the
best.

Mr. Wrights errors of Navi-
gation.

Mr. Taps Sea-mans kallender.
The Art of Navigation.
The Sea Regiment.
The Sea-mans secrets.
Wagganour.
Mr. Gunters workes.
The Sea-mans glasse for the
skale.
The new attracter for variatio.
Mr. Wright for the use of the
Globe.
Mr. Hewes for the same.

E3 Good
INTRODUCTION

In the year 1626 Captain John Smith, sometime Governor of Virginia and Admiral of New England, published in London a slim quarto volume called ‘An Accidence or The Path-way to experience Necessary for all Young Sea-men, or those that are desirous to goe to Sea...’.

It was not the first book from his pen. Virginia, settled successfully in 1607, owed its permanency to the skill, resolution, valour, and energy with which he had nursed it through the first years of settlement. When he had left in 1609, the colony, more than once in the throes of death, was convalescent. Three years later Richard Pots, Clerk of the Council at James Town, Virginia, and W. Phettipplace, Gentleman, wrote of Captain Smith’s departure: ‘What shall I say? But thus we lost him that, in all his proceedings, made Justice his first guide, and Experience his second, that loved actions more than words, whose adventures were our lives, and whose loss, our deaths.’

Since then Captain Smith had spent his enthusiasm and boundless energy in advocating with his pen as well as by word of mouth the colonization of the New World by the English. Yet he was essentially a practical man. An outstanding man of action himself, his motto for others was ‘Practice is best.’ Advising those lacking experience but desirous of learning to be seamen, he wrote, ‘to be a good gunner you must learne it by practice’; and again, ‘to learne’ navigation ‘practice is the best’.

Advocacy of the cause for colonization was one activity, but it was typical of the man that in 1614, on a voyage to the territories known as New England, finding the charts of the coastline ‘no more good then so much waste paper’ he should chart it anew himself and publish it, and so make straight the crooked way for those he hoped would follow after—as six years later the Pilgrim Fathers did.

Similarly the aim of the Accidence was essentially practical. It was to be

1 Captain Smith’s advice to would-be seamen is also contained in: A Sea Grammar, WITH THE PLAIN EXPOSITION of SMITH’S Accidence for young Sea-men, enlarged. Divided into fifteen Chapters: what they are you may partly conceive by the Contents. Written by Captaine JOHN SMITH, sometimes Governour of VIRGINIA, and Admirall of NEW-ENGLAND. LONDON, Printed by JOHN HAUFLAND, 1627.

2 The full title of Captain John Smith’s Accidence is: AN ACCIDENCE OR The Path-way to EXPERIENCE, necessary for all Young Sea-men, or those that are desirous to goe to Sea, briefly shewing the Phrases, Offices, and Words of Command, Belonging to the Building, Ridging, and Sayling, a Man of Warre; And how to manage a Fight at Sea. Together with The Charge and Duty of every Officer and, their Shares: Also the Names, Weight, Charge, Shot, and Powder of all sorts of great Ordnance. With the use of the Petty Tally. Written by Captaine JOHN SMITH sometimes Governour of Virginia, and Admirall of New ENGLAND. LONDON; Printed for Jonas Man, and Benjamin Fisher, and are to be sold at the signe of the Talbot, in Aldersgate streete. 1626.

3—A.O.N. xxxiii
a manual to aid would-be colonists on the long sea-passage that they had
to make in order to reach America; and it was to aid the 'many young
Gentlemen and Valiant spirits of all sorts desirous to trye their Fortunes
at Sea' in the war with Spain.

Captain Smith was a pioneer in more ways than one. He was persuaded
to print the Accidence because, as he put it, it was 'a subject I never see
writ before'. Conscious of professional jealousy, he was quick to add that
he wrote it 'not as an instruction to Marriners nor Sailers ... But as an
introduction for such as wants experience, and are desirous to learne what
belongs to a Seaman ...'

When he wrote his Accidence for Young Sea-men, and later when he ex-
panded it into his Sea Grammar, he eschewed the subject of navigation,
contenting himself with the advice that 'to learne to obserue the Altitude,
Latitude, Longitude, Amplitude, the variation of the Compasse, the
Sunnes Azimuth and Almicanter, to shift the Sunne and Moone, and to
know the tydes, your roomes [rhumbs], pricke your card, and say your
Compass, get some of these bookes, but practise is the best'.

'Mr. Wrights errors of Navigation.
Mr. Taps Sea-mans kallender.
The Art of Navigation.
The Sea Regiment.
The Sea-mans secrets.
Wagganour.
Mr. Gunters workes.
The Sea-mans glasse for the skale.
The new attracter for variatiō.
Mr. Wright for the use of the Globe.
Mr. Hewes for the same.
   Good Sea Cards
Two paire of compasses
An Astrolabe quadrant
A crosse staffe
A backe staffe
An Astrolabe
An Nocturnall.'

It is from a study of the books and the instruments listed by Smith that
most can be learnt about the art of navigation in Elizabethan and early
Stuart times. And not least amongst the virtues of his own two books is to
be counted the fact that they are the first English books to record what
were considered to be, as indeed they prove to be, the most valuable manuals
and accessories for the budding and the practising navigator of those days.

I undertook the work that follows because it deals with a subject which
I had never seen treated before. Like John Smith, I have written it not as
an instruction for mariners or sailors but as an introduction for such as are
desirous to learn what belonged to a seaman in the days when Englishmen
first ventured upon the ocean seas, taking for their motto that brave one of
Robert Thorne of Bristol, in 1527, 'there be no land unconquerable nor
sea innavigable'.

What instruments, what books, tables, charts, and other navigational
aids had they? We shall see. We shall see, too, what contributions they
made towards the advancement of the art of navigation during Elizabethan
and early Stuart times. We shall examine the conditions and influences
under which their works arose. Remembering that their object was always
practical, we shall consider why these works were called for, why they were
produced, when and by whom; and, in order to assess their value, we shall
first ascertain what was the common navigational practice in Europe up to
the middle of the sixteenth century, when the English first took to oceanic
navigation.

But we must not forget that the books they wrote and the instruments
they wrought were the handiwork of men, for, as Richard Eden, the trans-
lator of the first manual of navigation to be printed in English, wrote: 'it
is decent to commend those Citizens that by theyr industry of bodye or
mynde have done greate affayres, and have wylyngly obeyed good lawes'.
Many of them were men famous in their generation, whose names today are
still remembered and revered, of whose lives much is known. But of others,
only their works remain. Yet, like John Aspley, they held, 'We are not
born for ourselves only, but . . . those that traffique in the deepe, and have
their business in great waters, those that are unto this Island as a woodden
wall, the Sea-chariots, and the horses of England; these. I say, may claime
justly to the fruits of our labours. . . .'
Holding to that creed, they gave ungrudgingly of their best.

But what of the men who used the tools that they made and sailed the
ships that they built? These men had for an example Richard Chancellor.
He, in the year 1553, bound with Sir Hugh Willoughby on the first great
voyage of discovery that was essentially English in inspiration and in exec-
cution, was met on his way by tales of the terrors and dangers of the
Arctic Seas beyond the North Cape of Norway. But 'persuading himself
that a man of valour could not commit a more dishonourable part than,
for fear of danger, to avoid and shun great attempts, he was nothing at all
changed or discouraged . . . remaining stedfast and immutable in his
first resolution' to find the North-East Passage to Cathay.

Some there were like Captain John Smith (if that active, erstwhile
Governor of Virginia ever indeed did relax) who could say:

Sleepe after toyle, port after stormie seas,
Ease after warre . . . doth greatly please.

1 _The Arte of Navigation_ translated 'out of Spanyshe into Englyshe by Richard
Eden', 1561, from the _Arte de Navegar_ by Martin Cortes, Seville, 1551.

2 John Aspley's _Speculum Nauticum, A Looking Glasse for Sea-men_ (1624).
Dedicated to 'The Worshipfull The Master Wardens, and Assistants of the Trinity
House in Deptford Strand'.
INTRODUCTION

Some there were like Sir Hugh Willoughby and his enduring companions who left only their frozen bones to mark their resting place.

But of many more, Richard Chancellor amongst them, Hawkins, the illustrious Drake, John Davis, Henry Hudson, who gave his name to New York’s teeming river, and a whole host unnamed, the poet of their age, Will Shakespeare, wrote the epitaph:

Full fathom five thy father lies;
Of his bones are coral made;
Those are pearls that were his eyes;
Nothing of him that doth fade,
But doth suffer a sea-change
Into something rich and strange,
Sea-nymphs hourly ring his knell:
Ding-dong.
Hark, now I hear them—ding-dong-bell.
ACKNOWLEDGMENTS

Some years ago Mr. Henry C. Taylor, of New York, suggested to me that the historical significance of the navigational books and manuscripts of the sixteenth and early seventeenth centuries in his library, particularly their contribution towards the successful colonization of America by the English, which formed the beginnings of the United States of America, would provide the theme for a short essay of considerable interest. From that seed this book has grown and taken shape. Its completion also is due, in the first instance, to the unfailing interest of Mr. Taylor in the progress of my researches, and to his ever-ready help and advice. Moreover, without full access to his remarkable library of books and manuscripts relating to the early colonization of America and the navigational techniques used and developed, the task of writing this book would have been both more difficult and less congenial.

To the late Mr. Bonner Smith, when Admiralty Librarian, and to the late Monsieur D. Gernez of Versailles, I am indebted for much practical encouragement in the pursuit of my earliest researches.

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To Dr. James A. Williamson I am peculiarly indebted: it was through his writings on Tudor maritime enterprise that my interest in the Elizabethans and their navigational problems was first aroused.

D. W. WATERs

Jolyons,
Bury,
West Sussex.
1958.
ADDRESS TO THE GENTLE READER

EXCUSE me, gentle reader if oughte be amisse, straung paths ar not
trode al truly at the first: the way muste needes be combrous, wher
none hathe gone before. where no man hathe geuen light, lighte
is it to offend, but when the light is shewed ones, light is it to amend.
If my light may so light some other, to espie and marke my faultes, I
wish it may so lighten thē, that they may voide offence. Of staggeringe
and stomblinge, and vnconstaunt turmoilinge; often offending, and sel-
dome amending, such vices to eschewe, and their fine wittes to shew that
they may winne the praise, and I to hold the candle, whilst they their
glorious works with eloquence sette forth, so cunningly inuented, so finely
indited, that my bokes maie seme worthie to occupie no roome. For
neither is mi wit so finelie filed, nother mi learning so largely lettered,
nother yet mi laiser so quiet and vnincōbered, that I maie perform iustlie so
learned a laboure or accordinglie to accomplishe so haulte an enforcement,
yet maie I thinke thus: This candle did I light: this lighte haue I kindeled:
that learned men maie se, to practise their pennes, their eloquence to
adaunche, to register their names in the booke of memorie I drew the
platte ruelie, whereon they maie builde, whom god hath ended with
learning and liuelihood. For liuing by laboure doth learning so hinder, that
learning serueth liuinge, whiche is a peruers trade. Yet as carefull familic
shall cease hir cruelle callinge, and suffer anie laiser to learninge to repaire,
I will not cease from travaile the path so to trade, that finer wittes maie
fashion them selves with such glimpsinge dull light, a more complete woorke
at laiser to finisshe, with inuencion aгрeeable, and aptnes of eloquence.

And this gentle reader I hartelie protest where errooure hathe happened
I wissh he redrest.'

This address is from Robert Recorde's The Pathway to Knowledge,
London, 1551, the first English book on geometry. The address is no less
sincerely that of the author of the present work, penned in these times
when 'liuing by laboure doth learning so hinder'.
Part I

THE DEVELOPMENT OF THE ART OF NAVIGATION IN EUROPE IN THE FIFTEENTH AND EARLY SIXTEENTH CENTURIES

‘What can be a better or more charitable deed, than to bryng them into the way that wander: What can be more difficulte than to guyde a shyppe engoulsed, where only water and heaven may be seen.’

Martin Cortes, 1551. (Richard Eden’s translation, 1561.)
Chapter One

THE ART OF PILOTAGE

'Gentle mariners one a bonne vyage
Howse up the saile and let God steer.
in ye bonaventure making your passage
It is ful sea, the wether fair and cleer
The nepetides shall you nothing dore
a seeboord mates, S. george to bore
Mary & John ye shall not need to feer
but with this book to go safe thorow.'
Robert Copland, 1528–50?

The Elizabethan scholar Dr. John Dee, one of the first, if not the first of English scholars to teach the art of navigation, defined it, in 1570, in these simple terms: 'The art of navigation demonstrateth how by the shortest good way, by the aptest direction, and in the shortest time, a sufficient ship... be conducted.'

It is a good definition, and it is as good a definition of the modern navigator's art as it was of the Elizabethan navigator's of 1570. It comprehends in a small compass all the factors of time and space, distance, direction, speed, and seaworthiness, which govern the calculated movements of a ship. But in doing so it leaves so much the more to the imagination or knowledge of the reader. Of what did the art of navigation consist? And how did the Elizabethans practise it? Again let us get brief answers to these questions from a contemporary author. This time it is not from an Englishman that we shall get the most succinct replies, but from the manual of navigation published at Antwerp, in 1581, by a Flemish teacher of the art,1 Michiel Coignet, whose words are later paraphrased in one of the most popular English navigation manuals of the later seventeenth and early eighteenth centuries, Seller's Practical Navigation or an Introduction to the Whole Art.

'Nous appelons comunément l'art de naviguer la science de bien et seurement gouverner et diriger par regles certaines le nauire de l'un port à l'autre', wrote Michiel Coignet, following closely the definition of Dr. Dee. We can translate this definition freely as, 'We commonly call the art

1 Coignet, M., Instruction nouvelle des points plus excellents & nécessaires, touchant l'art de naviguer (1581). The full title will be found on p. 154.

The first navigation manual printed in English was a translation of the Spanish manual; Breue compendio de la sphera y de la arte de nauegar—con nuevos instrumentos y reglas—exemplificado con muy subtiles demonstraciones: compuesto por Martin Cortes natural de burjalos en el reyno de Aragon y de presente verino de la ciudad de Cadiz: dirigido al invictissimo Monarcha Carlo Quinto Rey de las Hesperias etc. Señor Nuestro. (Seville, 1551).
of navigation the science of well and safely steering and directing a ship by certain rules, from one port of call to another.’ ‘Cette pratique’, he continues, ‘est repartie en deux, a sçauoir en la navigation cômune et la navigation grande.’ As Seller put it a hundred years later, ‘Practical Navigation . . . consists of two general Parts, First, That which may be called the Domestick or more common Navigation (I mean Coasting or Sailing along the Shore) . . . Secondly, That which may more properly bear the Name and principally deserves to be entitled the Art of Navigation, . . . that Part which guides the Ship in her Course through the Immense Ocean, to any part of the Known World. . . .’

In short, the art of navigation in Elizabethan and Stuart times comprised the art of pilotage or coasting—Coignet’s ‘la navigation cômune’; and oceanic navigation—‘la navigation grande’. Both were referred to indiscriminately as an art or as a science, and for the present we will leave open the question whether both or either practice deserved to be termed a science. Michiel Coignet adds a great deal more about pilotage; not so much about oceanic navigation.

‘La navigation cômune’, he continues, ‘ne se sert d’autres instrumêts, que de l’expérience, de l’aiguille, et de la sonde.’ That is, ‘Pilotage uses no other instruments than experience, the compass and the lead.’

‘Car l’entièrscience de cette navigation commune ne consiste en autre, qu’à bien et parfaitement conoistre tous les caps, ports, et riuieres, comme iceuix se montrent et s’apparaissent en mer, quelle distance il y a entre eux, quelle route ou cours ils tiennent, aussy a quel rumb de Lune la maree y est plaine ou basse, le cours & descente de toutes eaux, auecque la qualité, profondeur & fond d’icelles. Ce que principalemenc (comme dessus est dict) s’apprend par experience, et instruction des anciens Pilotes bien exercitez.’ Which we can render as, ‘This is because the whole science of this form of navigation—pilotage—consists in nothing more than in knowing perfectly by sight all the capes, ports, and rivers met with, how they rise up and how they appear from the sea, and what distance lies between them, and what route or course, or rather bearing, they have one from another; also in knowing on what rhumb (bearing) of the moon high and low tide occur and the ebb and flow of the waters; and in knowing the depth and nature of the bottom. These are all principally things (as was said before) which are taught by experience, and the instruction of old and well-tried Pilots.’ Whereas, ‘La navigation grande se sert outre les pratiques susdites, de plusieurs autres regles fort ingenieuses et instrumens prins de l’art de l’Astronomie et Cosmographie. . . .’ That is, ‘Oceanic navigation on the other hand, employs, besides the above-mentioned practices, several other very ingenious rules and instruments derived from the art of Astronomy and Cosmography.’ Or as Seller put it later, rather more precisely, coasting ‘employs the Mariners Compass and Lead, as the chief Instruments’, while ‘the Masterpiece of Nautical Science’ is

1 Seller, Practical Navigation (1717) (first ed. 1669).
to determine 'in what place the Ship is at all times both in respect of *Latitude* and *Longitude*: this being the principal care of a Navigator... To the Commendable Accomplishment of which knowledge, these four things are subordinate Requisites:

\[
\text{viz.} \quad \begin{cases} 
\text{Arithmetick} \\
\text{Geometry} \\
\text{Trigonometry, and} \\
\text{Astronomy.}
\end{cases}
\]

We may conclude, then, that by Elizabethan times navigation consisted of two fairly distinct arts, pilotage and oceanic navigation. One, pilotage, was empirical and depended primarily upon experience and the observation of terrestrial objects. The other, oceanic navigation, was fundamentally scientific and depended primarily upon calculation and the observation of celestial bodies. A pilot's ability was measured by the skill with which he conned his ship in coastal waters, from cape to cape, and by his knowledge of the off-shore soundings and sea-bed, and his familiarity with sea-marks and land-marks, tides and estuarine shoals. Of the navigator was demanded the same skill and, over and above this, the ability to direct the ship's course and fix the ship's position when far from land by instrumental observation of heavenly bodies and mathematical calculation.

Today, with his modern navigational aids and education, the ordinary navigator can both pilot and navigate his ship in all the waters of the world. The pilot is almost a rarity, his activities being confined to peculiarly treacherous waters in the approaches to important ports. Until the latter half of the sixteenth century the ordinary master of an English ship was still typified by Chaucer's

'A SHIPMAN was ther, woning fer by weste: 
For aught I woot, he was of Dertemouthe ... 
A daggere hanging on a laas hadde he 
About his nekke under his arm adoun ... 
... of his craft to rekene wel his tydes, 
His stremes and his daungers him bisydes, 
His herberwe and his mone, his lodemenage, 
Ther was noon swich from Hull to Carthage. 
Hardy he was, and wys to undertake; 
With many a tempest hadde his berd been shake. 
He knew wel alle the havenes, as they were, 
From Gootland to the Cape of Finistere, 
And every cryke in Britayne and in Spayne; 
His barge y-cleped was the Maudelayne.'

Nevertheless, from early in the sixteenth century the growth of the Royal Navy, the gradual increase in the size of merchants' ships, small though

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1 Chaucer, *Canterbury Tales*, Prologue (c. 1390), lines 390, with omissions, to 410, from Skeat, W.W., *The Complete Works of Geoffrey Chaucer* (1949); lodemenage = pilotage; Britayne = Brittany; barge = ship.
they still were, the silting up of many of the older ports, the growing importance of London as a port and naval base, and the consequent increased use of the wide shoal-infested, tide-tortured reaches of the lower Thames had led to the establishment of officially recognized bodies of licensed pilots. Although the distinction between port pilots and sea-going pilots can be traced back many centuries earlier, it can be said that from early Tudor times it was officially recognized that port pilots were properly those who, to quote an early seventeenth-century authority, ‘(upon coasts and shores unknown unto the Master), were employed for the conduction of ships into roads and harbours, or when they were to pass over bars or sands’; whereas ‘the charge and duty of the Master of a ship was to undertake the conduction of her to the places and ports whither she was bound, and to shape all such courses as might best conduce there unto . . . .’

Thus in the first half of the sixteenth century we find strictly regulated port pilotage organizations established at Kingston upon Hull, Newcastle upon Tyne, and Bristol, as well as at London, whose pilots controlled the movements of ships within the respective port boundaries. In Elizabethan times, that is in the latter half of the sixteenth century, there developed two sorts of master: the master who was essentially a coastal and short sea-route pilot—like Chaucer’s shipman—and the master who was an oceanic navigator. They were the practitioners of two distinct arts, though, unlike the master-pilot, who could not navigate in the ocean sea, the master-navigator could pilot his ship in the familiar waters off his native shores, and required a pilot only when entering or leaving harbour or off unfamiliar foreign shores. But by Stuart times—the first quarter of the seventeenth century—the master-navigator had become almost a specialist in oceanic navigation, at any rate in the view of at least one Elizabethan sea-captain. Comparing Elizabethan and Stuart masters Sir William Monson in his old age vowed ‘that since I served in the Narrow Seas I find so great a difference betwixt the masters of that time and this that I may compare it to an ancient art, that in long continuance of time has been forgotten and lost for want of use. The masters in those days were either ignorantly adventurous, or in this Time providently cautious . . . because their breeding has not been to sail amongst sands, or in seas so narrow that . . . that wind which is secure upon one shore is death upon another; and tides that sometimes are advantageous to them, at other times may prove dangerous. . . . ’ To remedy this state of affairs Monson called for ‘expert and skilful pilots that make the Narrow Seas their daily trade and practice’.

In short, by then the pilot, the coaster or channeller, and the navigator had


become pretty clearly established as distinct types of seamen having accomplishments peculiarly their own. It had happened in the space of a lifetime. For whereas the pilot’s art—in the broad sense of the word—was immemorially old, in the sixteenth century the navigator’s had only a few score years of age.

The English seaman under the early Tudors traded in the waters of north-west Europe as far as Iceland for fish, the Low Countries for fine cloths and Rhenish wines, Bordeaux and the Biscay ports for woad, used in dyeing, and fine French wines, and to Portugal and Spain for fruits, wax, iron, and again wines. In exchange he carried wool and cloth, tin and hides.¹ The great manufacturing centres of the world were the Lombardy plain in Italy, and the Low Countries. The goods of the Italian craftsmen, and the wines and silks of Italy were brought chiefly in foreign bottoms, those of the Low Countries in French and Flemish as well as English ones. The naval stores—timbers for masts and spars, hemp for rope, pitch and train-oil for seams, bottom coating and grease—and grain came from the Baltic in the ships of the Hanseatic League. English seamen rarely penetrated the Baltic or extended their voyages to the Atlantic islands of Spain and Portugal—Madeira, the Canaries, and the Azores—or to the Mediterranean. Theirs was essentially a home trade, a coastal trade. They were practised in the art of pilotage only. Their ships were very small, mostly under 100 tons, and were in the early years still chiefly clinker built, that is with overlapping strakes. Although in the first half of the sixteenth century the stronger Mediterranean carvel build, under the influence of Italian shipwrights brought in by Henry VIII, displaced the clinker build, the merchant ships, despite subsidies, did not greatly increase in size. As late as 1626 an inventory of ‘all the ships and barques, belonging to the Port of Bristoll’ listed only four ships between 250 and 200 tons, and twelve between 200 and 100 tons, compared with twenty-six between 100 and 20 tons.² Of the many others engaged upon the foreign trade but captured by pirates in the preceding twenty-five years, most were under 100 tons. The smaller English merchant ships in the first half of the sixteenth century were single-masted and rigged with fore-and-aft sails—a jib and a sprit sail—or a single square sail. Either rig was simple to work and required only a small crew. The larger vessels were square-rigged only, or ‘cross-sailed’ as it was termed, with three masts and a bowsprit. The fore and main masts each carried a course and a top-sail, the bow-sprit a sprit-sail; all these were ‘cross-sails’; the mizen mast carried a lateen-sail. This rig remained typical of merchant ships well into the eighteenth

¹ Hunter H. C., How England got its Merchant Marine, 1066–1776 (1935), contains valuable summaries and extracts of English mercantile legislation designed to build up the merchant and royal navies. The extent and volume of the English carrying trade at various periods can be ascertained from this valuable work. The standard work on the subject is Cunningham, W., The Growth of English Commerce and Industry (1903).

century. The running rigging of these ships was coarse and clumsy by modern standards and heavy to handle. The result was that rather large crews were carried; numbers were also an advantage in the event of a struggle with pirates, still common enough, even in home waters. At the close of the sixteenth century the Dutch introduced many improvements in the efficiency of the rigging which the English merchantmen were slow to adopt—to the handicapping of their carrying trade. An idea of the crowding of crews can be gained from the fact that the Elizabethan and Stuart warships, which, of course, were more heavily armed for fighting, carried roughly one man to every 2 tons of displacement. Thus a warship of 100 tons would carry a crew of fifty. Before the 1580s the scale had been one man to every 1 ½ tons of displacement. For ground-tackle the ships carried, according to size, from two to nine iron anchors of a pattern closely resembling the modern Admiralty pattern anchor; that is consisting of a shank with two arms at the crown forming an arc of a circle and a stock passed through the shank below the anchor ring and at right-angles to the plane of the arms. The stout cables were of tarred Baltic hemp or of finer stuff from the Mediterranean now known as Italian hemp. The cables were short and the anchors by modern standards light, so that their holding qualities were poor. There was, however, a steady improvement in ground-tackle in the sixteenth century, the length of the cables being increased to 100 or 120 fathoms; and later, in the seventeenth century, the weight of the anchors was steadily increased.  

The merchant ships were not the only English ships sailing the seas of north-west Europe in the first half of the sixteenth century. In addition to the fishing vessels, which we can consider as part of the merchant navy, there were the warships of the Royal Navy. In this, always excepting the special galley fleets of the Mediterranean states, the English were unique. The Royal Navy, though its roots run further back into history, was the creation of the Tudors, and essentially of Henry VIII. Whereas other states in north-west Europe relied upon hiring or requisitioning armed merchant ships for battle by sea, the Tudors relied upon a Royal Navy of ships designed specifically for war, for the defence of the realm and offence of the enemy. 2 By the creation in 1545 of the Navy Board, whose business it was to provide and administer the Royal Navy under the direction of the senior executive officer, the Lord Admiral, Henry VIII gave the Royal Navy both permanence and individuality. What is more, whereas in the fifteenth century it had been the merchant ships which had led the way in improvements in ship construction, design, and rigging—when ships of up to 1,000 tons were built—the creation of a royal fleet with royal dockyards and administrative officers to maintain it meant that the Government of the country was not merely paternally interested but was directly

2 Oppenheim, M., Administration of the Royal Navy, 1509–1660 (1896), is a masterly work on the administrative and material development of the Royal Navy in the sixteenth and seventeenth centuries.
involved in ship-building and the seaman’s art in general; not least in the art of conducting a ship from one port to another. From Tudor times two parallel developments are apparent in English seamanship through the direct influence of the Crown; these were improvements in ship-design and improvements in the art of navigation. Thus the establishment of the Royal Navy was a most important maritime measure, and its effects were quite out of proportion to the number of ships involved. For instance, although Henry VIII built, bought, or seized in prize numerous ships of from 100 up to 1,000 tons during his reign, at his death the royal fleet mustered only twenty-eight ships of 100 tons and upwards; again in Elizabeth’s reign the fleet that defeated the Spanish Armada in 1588 contained only twenty-four royal warships of over 100 tons, the largest being of 1,000 tons. Nevertheless these few ships had a great influence. The fact is that, although bounties continued to be paid to merchants to build larger and therefore more seaworthy and potentially more powerful ships, the financial responsibility for innovation in ship-design was taken over—had had to be taken over—by the Government in the interests of the nation, not so much from slow-acting economic considerations as from the urgent problems of fighting efficiency. The merchant was quick to recognize this and was content to follow and adapt where his forbears had had to lead and experiment. But the sixteenth century was an age of transition, and we still find private men, like Sir Walter Raleigh, building a great ship of improved design, and selling it to the Government, as he did the Ark Raleigh, Lord Howard of Effingham’s Ark Royal in the Armada fight. But of more direct concern to our subject is the fact that, having ships of its own, the Government was very much concerned in the problem of their preservation from the dangers of the sea. Hitherto its sailors had been obliged, like merchant seamen, to rely upon natural sea-marks; but in the sixteenth century, as we shall see, the Crown took steps to provide special sea-marks in dangerous coastal waters, and to obtain seamen competent to conduct its ships.

For long there had been Fraternities of the Sea at the more important ports. These were organizations of shipmen which appear to have been responsible, amongst other business, such as the welfare and conduct of their fellows, for the selection and supervision of pilots for their ports. From 1512 to 1514 England and France were at war. It was essentially a naval war waged with royal ships. Though the actions seem trifling enough now, it is significant that it was in 1514 that Henry VIII established the Corporation of the Trinity House of Deptford Strand ‘for the advancement and benefit of navigation and commerce . . .’ and for the training, licensing, and regulation of Englishmen in pilottage. Experience had shown that many foreigners had learnt the secrets of the channels to our ports and turned their knowledge to the advantage of the French.¹ Other similar corporations were set up during his reign at Kingston upon Hull and

Newcastle upon Tyne. Apart from Portsmouth, where the first dry-dock in the world had been built in 1495, the royal dockyards were all on the Thames or on the Medway, which flows into the Thames estuary. It is therefore not surprising to learn from ‘An Act concerning Sea-marks and Mariners’ passed in 1565, the eighth year of Elizabeth’s reign, that ‘the Master, Wardens, and Assistants of the Trinity House of Deptford Strand, being a company of the chiefest and most expert masters and governors of ships’, had been charged, not only ‘to foresee the good increase and maintenance of ships, and of all kind of men traded and brought up by watercraft’, but also with ‘the conduction’ of the ships of the ‘navy royal’.

When Henry VIII had licensed the Corporation of Trinity House, he had done so to safeguard the royal as well as the merchant ships from loss by hazard or default, but experience showed that his measures needed strengthening. This was the purpose of the Act of 1565, for from it we find that ‘By the destroying and taking away of certain steepleys, woods, and other marks standing upon the main shoreys, adjoining to the sea coasts of this realm of England and Wales, being as beacons and marks of ancient time accustomed for seafaring men, to save and keep them and the ships in their charge from sundry dangers thereto incident: Divers ships with their goods and merchandise, in sailing from foreign ports towards this realm of England and Wales, and especially to the port and river of Thames, have by the lack of such sea-marks of late years miscarried, perished, and lost in the Sea, to the great detriment and hurt of the Common Weal, and the perishing of no small number of people.’ As a consequence the Act extended the authority of Trinity House to set up and maintain, out of shipping dues it was entitled to levy, as many beacons, marks, and signs for the sea as seemed necessary on the sea-shores and heights, as well as in the approaches to ports, of England and Wales. Furthermore it prohibited, under penalty of a fine of one hundred pounds, the destruction of steepleys or conspicuous trees used as recognized beacons.

The early Tudor seaman, then, besides having the familiar features of capes and bays to direct him had also the time-honoured use of church steepleys and conspicuous trees and, for leading marks into estuarine channels and ports, artificial beacons of timber or stone; but it was not until Elizabethan days that he had artificial coastal beacons. In channels to ports, besides landmarks, he had buoys, their laying and maintenance, like that of the artificial beacons, being vested in the Crown through the Lord High Admiral, who could levy ‘buoyage’ as well as ‘beaconage’ to defray their cost; although generally he, or the deputy to whom he granted it, farmed out these dues. The buoys, which were of wood, were of two sorts: barrel-shaped ‘tuns’; and cone-shaped ‘can-buoys’. The latter had the base of the cone uppermost; the apex, as the strongest part, was used as the point of attachment for the moorings.

The first lighthouse was established in Henry VIII’s reign at the entrance to Newcastle upon Tyne. It was not until the seventeenth century that light-
houses became more numerous. Their increase was hotly debated in James I’s reign, the argument against them being that they facilitated a sudden invasion by an enemy.¹

As we have seen, the English great ships were chiefly royal warships, and very few in number. All were conducted by men who had learnt their art in the mercantile school. The great ships, and this is true of all great ships until well into the eighteenth century, were none too seaworthy, and confined their cruising to the fine-weather months, roughly April to October. The merchant shipping, on the other hand, sailed all the year round. Indeed, for generations the English ships of the ancient and valuable Bordeaux wine trade had braved the autumnal storms and winter gales of the Channel and the Bay of Biscay in order to ply their trade to the best advantage by bringing in the heady wines of the new vintage demanded by palates denied finely flavoured foods in winter. Not until 1532 was the practice prohibited by legislation to put an end to the mounting toll of losses. Nevertheless, the bulk of English seamen were, and continued to be, inured to the hardships of the sea at all seasons of the year. They were essentially small shipmen, and their masters, pilots. On the whole they specialized in various carrying trades; the men of Bristol traded like those of Southampton, chiefly to the south-west with the French and Spanish Biscay ports and the Atlantic ports and islands of Portugal and Spain. The men of Southampton also specialized in the cross-Channel trade, and some, like the London men in that with the Netherlands. The men of the other East Coast ports—Harwich, Yarmouth, Kingston upon Hull, and Newcastle, to name the biggest—occupied themselves in the Baltic trade (the little there was), in that of the Netherlands, and also in the fish-carrying trade between Scandinavia, Iceland, and their home ports.

By long experience the English ship-masters knew their particular waters well, their coastline, land-marks and sea-marks. In addition they had certain aids, whose importance increased greatly, once they sailed in unfamiliar seas. Then indeed, apart from seamanship, that is to say, ship-handling skill, such aids were all-important.

If he was literate, the ship-master prized a rutter. This was a small pocket-book in which was recorded the magnetic compass courses between ports and capes (he often termed the ship’s course ‘the caping of the ship’); the distance between them, stated in kennings or distances of 20 miles (in Scottish waters 14 miles), the distance at which it was reckoned a man could discern the coastline; the direction of flow of the tidal streams; the time of high-water on days of new or full moon at important ports, headlands and channels, that is to say the establishment of the port or place; and the soundings or depth of water and nature of the sea-bed in the Soundings west of the Sleeve or English Channel, in the Sleeve itself, and in the approaches to ports.

The oldest English rutter known would seem to date from the early

fifteenth century and to be based on much older lore. This rutter gives the sailing directions for the circumnavigation of England and for the voyage to the Strait of Gibraltar. The first two-thirds contains the names of places on the coasts and their bearing from one another; as, 'Lizardds and Saint Mary sands of Cille est and west but beware the gulf' [Wolf Rock]; the direction of the flood and ebb, 'in the fairway between Start and Lisart the cours is est and west'; land-marks such as 'the parish steeple'; and the establishment of the ports, 'all the havens be full at a west and south-west moone betwene Start and Lisarte'. The last third of the rutter contains the soundings and nature of the sea-bed; as, 'And ye come out of Spayne ... till ye come into Sowdyng, And yf ye have an C. fadome depe or els $\frac{xx}{iiij.x}$ than ye shall go north till the sonde ayen in Ixxij. fadome in feir grey sondë ... between Clere and Cille.'

These rutteres were written originally in manuscript on vellum or scraps of paper by the pilot himself from notes he made over a pot of ale with some other ship-master in a sea-port tavern. They were copied, mislaid, collected together again, and perhaps bound up to form a little leather book of ill-arranged, often conflicting information. Nevertheless the rutter was the ship-master's vade mecum. To this day the careful pilot compiles his own note-book. Only about half a dozen of these manuscript rutters (Italian, portolani; Portuguese, roteiros; French, routiers; Flemish, lees-kaerten) dating from before the early sixteenth century are known. But in the middle of the fifteenth century the art of printing was developed by John Gutenberg of Strassburg, and by 1480 over one hundred towns in Europe had printing presses. The first rutter to be printed in north-west Europe appears to have been Le routier de la mer ..., ascribed to Pierre Garce and printed at Rouen between 1502 and 1510. In the next century and a half it ran through over twenty editions. The oldest printed rutter known is an Italian portolano printed in Venice in 1490.

In 1528 'a sad ingenious and circumspect Mariner of the Citie of London ... beeing in the toune of Bourdewes bought a prety booke Imprinted in the French Language called the Rutter of the Sea'—probably

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2 'And coming out of Spain [steer the courses given] until you reach the Soundings [the 100-fathom line]. Then if you find 100 fathoms depth, or 90, sail north until you sound in 72 fathoms and bring up fair grey sand between Cape Clear [cape of S.W. Ireland] and the Scilly Is.' is a free rendering of these directions.

the edition of 1502—'containing many proper feates of his science'. He brought the book home with him and gave it to a London book publisher, Robert Copland, for translation and publication. *The Rutter of the Sea* was the first printed rutter in English, and the sailing directions it gave were those for the Bordeaux wine trade and to Cadiz.

The rutter starts with: 'Of the tydes, that is to wit, the flood and Ebbes fro the race of Sayne [south of Ushant] into Flaunders’ to which are devoted three and a half pages, and continues, devoting from one to four pages to each of the sections, with:

Courses to the race of Sain into Flaunders and how the tides toward Brittain beareth;
Routes and courses fro the race of Sayne into Flaunders;
Entrings and Harborowes of the coste of Normandy;
Floods fro Sylley and England into Flaunders;
Routes from Silley and England into Flaunders;
Entrings and Herborows all along the coste of England;
How the portes & havens of England, Britain and normandy doo lye how many leygges fro one to another;
Soundinges that ye shall finde co-ming fro Spayne Leuante, or Portingale to seek Ushant;
The kennings from Syllaye and England unto Flaunders;
Floods and Ebbes fro the foreland or cape of cornwailles into wales all a long by the sea coste;

and ends with the

judgments of the Ile of Aulcron,

that is, with the recognized mercantile law of the sea in north-western waters.

In 1541 another section was added to the rutter: ‘The Rutter of the Sea for the North Part’.1 This was based on the English manuscript rutter of the early fifteenth century already referred to, and covered the circumnavigation of Scotland from Leith southward to the Humber, from Leith northward to Duncansby Head in Caithness, thence around the north and west coast of Scotland to the Mull of Kintyre, Mull of Galloway and the River Solway. Each section showed the direction of the tidal streams, time of flood and ebb tides, the kennings, of 14 miles distance, from cape

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1 The English printed rutter referred to is: The Rutter of the Sea with the Hauens Rodes, Soundings, Kennings, Windes, Floods, and Ebbes daungeres and coastes of diuers regions with the lawes of the Ile of Aulcron, and ye judgments of the Sea. With a Rutter of the North added to the same. [Translated by Robert Copland from the French of Pierre Garcie, with omission of the woodcuts of land-marks in the original and a prologue added, ?1550. First printed 1528 without the Rutter of the North. No copy is known of the 1528 ed. The Rutter of the North was compiled by Richard Proude, and printed in 1541, and based on the rutter of 1408 (anonymous). See Appendix 1. The earliest printed Dutch rutter is one of 1532].
to cape, and the havens, roads, sounds, and dangers on the route. The information it contained was more complete and better arranged than in the earlier printed part dealing with the Channel, Bordeaux, and Straits routes. This can be explained by the fact that it followed hard upon a voyage of circumnavigation of his realm made by King James V of Scotland in the summer of 1540. The voyage was made under the direction of a well-known Scottish pilot, Alexander Lindesay. The compiler of *The Rutter of the North* doubtless had access to the manuscript of Lindesay’s more up-to-date rutter. However that may be, by the 1540s the English ship-master had the use of a printed rutter covering the seas around England and Scotland and the route to the Strait of Gibraltar. Unlike most other ship-masters, however, he was still generally dependent upon the written word for guidance. The French and Portuguese manuscript and French and Dutch printed runters of this time included drawings or crude woodcuts of headlands and strips of the coast to assist in identification.

The use of manuscript runters of northern waters continued side by side with the use of printed ones for another half century at least, while English runters for foreign seas, except when they were embodied in printed journals or narratives of voyages, remained—with one exception—exclusively in manuscript until well into the seventeenth century.

Robert Copland listed the navigational instruments needed by a master-mariner as ‘the carde, compas, rutter, dyall and other which . . . sheweth the plat . . .’. It is possible that Robert Copland referred to a manuscript rutter with charts when he listed a ‘carde’, for there is in the British Museum just such a sixteenth-century *Booke of the Sea Carte* (B.M. Add. 37,024). This manuscript book, besides having its contents clearly set out in titled sections with the subject-matter arranged in an orderly manner, contains sea-cards of the waters of north-west Europe. These sea-cards were not charts in the modern sense. They were little outline maps with the names of ports and a compass rose and radiating lines or rhumbs by means of which the master-mariner could fairly accurately gauge his course across Channel to his port of destination. The third book of *The Booke of the Sea Carte* contains four of these cards, namely: Scotland; the East Coast of England, Flanders, and Holland; southern England from Cardigan Bay in Wales to the Channel; and Ireland, the Irish Sea, and western England.

It has been said that the English were ignorant of the use of charts until John Cabot, who was an Italian pilot, came to England at the end of the fifteenth century. This may well be, for it was not until Henry VII’s reign that Englishmen in search of trade penetrated the Mediterranean, where they might feel the need for charts. The seamen of the South and West Coast ports certainly knew of sea-cards long before this for the Venetians, who with the Catalans were the leading chart-makers until the sixteenth century, had sailed annually for centuries to the shores of England in their great Flanders galleys to fetch for the looms of Lombardy the peerless wool of England. You may certainly trace the limits, if not follow the
growth, of their trade, by the gradual extension northwards of the coastlines delineated on their charts, which, unlike the 'sea cardes', were bearing and distance charts of considerable accuracy. All semblance of accuracy, however, if further delineation is attempted in them, ends north of the Wash, and of the Scheldt in Flanders. Scotland, Denmark, Scandinavia, and the whole of the Baltic when shown are most crudely represented until well into the sixteenth century. The inference, that the northern seaman did not use a chart, is clear. The accuracy of this inference is vouched for not only by Michiel Coignet's omission of the use of the chart in his definition of the pilot's art but also by words of the first Englishman to write and print a book on the practice of navigation, William Bourne. In his book, *A Regiment for the Sea*, first published in 1574, Bourne says that the ship-master should 'be a good coaster, that is to say, . . . knowe every place by the sight thereof', as Chaucer said his ship-master of Dartmouth did in the fourteenth century, and understand ocean navigation for which 'the use of the Sea-Cardes is most necessary'. Furthermore, four years later, in the third impression of his book, occurs a most scathing indictment of the ancient mariner, the ignorant 'coaster', the prejudiced 'Channeller', as he calls him. 'The nature of a number of men is to dislike of all things not done by themselves', declared William Bourne somewhat bitterly, therefore

I doe hope that in these dayes, that the knowledge of the masters of shippes is very well mended; for I have knowen within this 20 yeeres, that them that wer auncient masters of shippes hath derided and mocked them that have occupied their cardes and plattes . . . saying: that they care not for their sheepes skinnes, for he could keep a better account upon a boord . . .

1 Andrews, H. C., 'Scotland in Portolan Charts'. *Scot. Geog. Mag.*, Vol. 42. (The first chart of the Baltic was a wood-cut one of 1543 by the Dutch hydrographer Cornelis Anthonisz.).

2 A Regiment for the sea Conteyning most profitable Rules, Mathematical experiences, and perfect knowledge of Nauigation, for all Coastes and Countreys: most needeful and necessary for all Seafaryng men and Trauellers, as Pilotes, *Mariners, Marchaunts &c.* Exactly deuised and made, by William Bourne. Imprinted at London, by Thomas Hacket, and are to be solde at his shop in the Royall Exchaunge, at the Signe of the Greene Dragon. [1574]. [STC 3422 The title-page of the Huntington Library copy; that of the Paris copy has 'imprinted at London for Thomas Hacket, etc'.].

3 William Bourne's 'Preface to the Reader' in the *Regiment for the Sea*, of which the first edition was probably printed and published in London in 1574. This is from the 1577, unauthorized edition. The title reads: A Regiment for the Sea: Conteyning most profitable Rules, Mathematical experiences and perfect knowledge of Navigation, for all Coastes and Countreys: most needful and necessary for al Sea faryng men and Trauellers, as Pilotes, *Mariners, Marchaunts, etc.* Exactly deuised and made, by William Bourne. Imprinted at London, nigh vnto the three Cranes in the Vintree, by Thomas Dawson and Thomas Gardyne, for Iohn Wight. [1576] [STC 3423], [1577] [STC 3424].
He concludes, paraphrasing Robert Copland of half a century earlier, 'if they should come out of the Ocean Sea to seeke our Channel to come unto the River of Thames; I am of that opinion that a number of them doeth but grope as a blinde man doth . . .'.

In short the English ship-master, in common with the seamen of more northern waters and the Baltic, at this time rarely if ever used a 'sea-carde', let alone a larger chart or 'platte'; he relied for finding his way about almost exclusively on his rutter. The second book of the Booke of the Sea Carte, for example, gives the sailing directions for a voyage from London to Land's End (spelling modernised).

(i) The Courses of Tides from the Thames to the Cape of Cornwall (Land's End)
   . . . from the Cape of Cornwall to Scilly it floweth west-south-west and east-south-east . . .
(ii) Floodes and ebbes from Thames to Dover, from thence westward to the Cape of Cornwall
     . . . At Dover the moon south full sea . . .
(iii) Courses from the Thames to the Cape of Cornwall
     . . . The cape of Cornwall and Lizard, be east-south-east and west-north-west . . .
(iv) Kennings from the Thames to the Cape of Cornwall
     . . . from Lizard to the Cape of Cornwall one kenning . . .
(v) Sounds and dangers from the Thames to the Cape
     If ye will be in the Downes cast anchor at vi or vii fathoms . . .

Besides certain tide-tables the book also includes 'The Mariners Prognostycacion gathered out of Ptolome, Arystotelle, Plini, Virgill and other natural philosophers'. In this are recorded the signs and tokens of the sun, moon, and stars at various times and seasons; of winds, thunder, and lightning; and of rainbows and the look and the sound of the sea. Thus 'Of Winds', the writer notes: 'A sudden calm in the sea after great wind signifieth the wind to change, or then the same wind to increase and grow'—that most dreaded sign for the seaman in a storm; and 'Of the Sea' he writes, 'The rock and sands of the sea, making murmur, or sounds without, and not on shore, signifieth great storm to come. . . . The sea froth appearing in divers places, with bellowing of the water signifieth evil weather for many days after.' The emphasis is wisely on dangers to come, but, at the last, relief is promised by 'the dolphin fish swimming and leaping often-times above the water . . . in the time of a storm . . .', for that 'betokeneth calm and fair weather'.

Among other aids to the ship-master was an annual almanac containing the calendar with the phases of the moon and telling him which would be moonlight nights, and giving also an annual prognostication of more general interest. With the spread of the art of printing in Europe such works had become fairly numerous by the end of the fifteenth century, although in
England the first almanac was not printed until 1503, and then it was a crude translation of a French work. The *Kalendayr of shyppars* included not only a calendar and a description of the universe—on Ptolemaic lines—but also numerous moral precepts of a wise and homely nature; its popularity was immense, and it passed through many editions. This one apart, almanacs fell broadly speaking into two types: those intended for the astronomer, physician, scholar, and student, and those designed for use by less erudite people, or humbler folk, amongst whom we must include the ship-masters. The simpler almanacs were generally printed as broadsheets for posting up on a wall or ship’s bulkhead, or as sextodecimo volumes for the pocket. The broadsheets contained the calendar and brief information showing the moonlight and dark nights, and a forecast of the weather; the pocket almanacs contained the same information as the broadsheet, but on fuller lines. The true almanac was a larger work, and consisted essentially of a table giving the chief astronomical events of the year, and the terrestrial events dependent upon them. These included the conjunctions and opposition of the sun and moon for the year, tables of the sun’s declination, the positions of a few stars, the rules for using the North Star, and the rules or ‘declaration’ for the compilation of the calendar. The day ran from noon to noon, and the year from the vernal equinox, March 11th. Frequently the almanac covered a period of years.

It was not until 1539 that the calendar and the almanac were issued together for popular use. Quite distinct from the calendar and the almanac proper was the prognostication. Until an Act of 1541 against sorcery was repealed in Edward VI’s reign, English prognostications were rare. Even when they became more numerous they were generally confined to the incidence of the weather and diseases. The authorities frowned upon the forecasting of disasters, though phenomena such as comets or eclipses naturally called for more dramatic handling. Later, from 1571, the publication of annual almanacs and prognostications was controlled by a patent which confined their issue to two London printers, Watkins and Roberts. By this time the annual or common almanac had taken the form it generally adhered to for the next century. It then comprised the ecclesiastical calendar; the canons of phlebotomy, bathing, purging, etc.; the anatomical man showing the influences of the signs of the zodiac on the body; the tables of the positions of the moon in the zodiac; the phases of the moon; and the distances by road between towns in England. By then too, the prognostication, with a separate title-page, was always annexed to the almanac. Besides forecasting the weather and happenings based on astrology, the prognostication after 1571 frequently listed the fairs held all over England, information intended for chapmen which might prove useful also for the itinerant ship-master. In the sixteenth and seventeenth centuries such annual or common almanacs were in everybody’s pocket. They took the place of the modern pocket diary—indeed, even in the sixteenth century some had blank pages for entries. In the absence of modern illuminants their lunar tables were particularly useful. Many almanacs
had tide-tables, sometimes in the almanac itself, sometimes in the prognostication. These gave the 'ebbs and fluddes' for various stretches of the English or Channel coast, and very often rules for finding the daily times of high water. Indeed such a tide-table appeared in the earliest annual almanac in book form printed in England. A decade later Anthony Askham’s annual almanac for 1553 contained rules for finding the time by the stars specially compiled for mariners (though it had no tide-tables), and this almanac incidentally was the first to follow the practice of starting the year on 1st January.¹

Of the instruments used by the early Tudor ship-master, probably the most ancient was the lead and line for finding the depth of water. His forbears had needed it before ever they felt the need for determining direction. The first necessity for the seaman in the opaque waters of the northern seas, with their varying depths caused by the rise and fall of the tide, is a means of finding how much water he has under his ship and of detecting the presence of hidden rocks and shoals. This he did with the lead and line. Michiel Coignet, it will be recalled, considered it one of the two chief instruments of the pilot, and he did so because just as the pilot could fix his position by the contours, colour, and texture of the coast, so when out of sight of land, or when off-shore in poor visibility, he could locate himself, as fishermen still do, by the contours, colour, smell, taste, and texture of the sea-bed. To the seaman whose voyage took him out of soundings the lead and line was again an indispensable instrument. Soundings was the name he gave to the waters west of the English Channel, between Ireland and Brittany, and covering in that region what is known as the continental shelf. The shores of the continents and larger islands of the world do not descend in a continuous slope from the coast-line to the ocean-bed. On the contrary, from the shore-line the sea-bed slopes, here steeply—as off Spain and western Ireland—there gently, as to the west of the English Channel—to a depth of about 100 fathoms, then plunges precipitously, thousands of fathoms deep—'deeper than did ever plummet sound'—to the ocean-bed. The outer edge of the continental shelf, the line where the continental slope thrusts abruptly up towards the surface of the sea, is thus clearly defined by the 100-fathom line and can be found with considerable accuracy by a deep-sea lead and line—a fact of the utmost value to a mariner approaching the waters covering the continental shelf. At some points, as off the west and south-west coasts of Ireland, and off all the coast of Spain and Portugal, the edge of the continental shelf is found only ten or twenty miles from the coast, at others it is hundreds of miles to seaward—from the Lizard it lies distant 200 miles on the arc of the south-west quadrant. On a voyage from England to Spain a ship passed out of soundings when some 100 miles south-west of Ushant and entered them

again only a score of miles—when within sight, by day—of the north-west coast of Spain. It was a hazardous land-fall. Returning from Spain the direction made good and the progress made could be estimated only by eye during the passage across the Bay of Biscay, until soundings were struck to the south-west of Ushant, Scilly or Cape Clear. The lead and line then gave warning—the first and the most timely—of Soundings having been reached and of the dangers of shallow seas, rocky coasts, and tide races ahead; but it also gave, from the evidence of the nature of the sea-bed brought up on the lead, an indication of the ship’s position in relation to the coast, and consequently, if the evidence had been interpreted aright, of the course to be steered and of the soundings to be expected in order to make a safe landfall off a chosen stretch of coast. We have seen that the earliest rutter gave the pilot such information, and in Robert Copland’s the mariner approaching the English Channel from Spain is warned that, after coming into Soundings:

When ye be at lxxx fadome ye shall finde small black sande and yee shalbe at the thwart of lezarde.

When ye be at lx or lxv ye shall finde white sande, and white soft woormes And ye shall be very nigh to Lezard.

Although the earliest illustration of a lead and line is found in the frontispiece of the Spieghel der Zeeverd of Lucas Janszoon Wagenaer, first published in 1584, and the earliest English descriptions of the lead and line date from the 1620s, the very fact that illustrations and descriptions fit the leads and lines used by seamen to this day points to the conclusion that those used by the English seaman of the early sixteenth century were similar. He used one of two sorts, according to the depth of water. In deep water, when he thought he was approaching the shore, he used the deep-sea or dipsie lead and line. According to Captain John Smith, who described it in his Sea Grammar of 1627, this consisted of a ‘a long plummet, made hollow, wherein is put tallow’, attached to a thin line 150 fathoms in length, marked first at 20 and then at every 10 fathoms with so many small knots in little strings fixed to each mark. Sir Henry Mainwaring in his Seaman’s Dictionary, written between 1620 and 1623, but not printed until 1644, gave the dipsie lead a weight of 14 lb., and the length of the line as 200 fathoms. He described the ‘arming’ of the lead as being with ‘hard white tallow’, except when used on an oozy sea-bed, when white woollen cloth with a little tallow formed the arming. Both Smith and Mainwaring are agreed that the sounding lead used in shoal water, that is in depths of less than 20 fathoms, weighed as it does today, 7 lb., and was a foot long. The line was thicker than the dipsie line, and was marked

1 See Pl. III.
2 Life and Works of Sir Henry Mainwaring, Vol. 2. N.R.S., Vol. 56, contains the ‘Seaman’s Dictionary’ which Mainwaring wrote between 1620 and 1623 as a guide for the Lord High Admiral, the Marquis of Buckingham; it was first published in 1644 by order of Parliament for use in the fleet.
at 2 fathoms and 3 fathoms with black leather, at 5 and 15 with white cloth, at 7 with red cloth, and at 10 with leather. The modern line differs only in that 13 fathoms is marked with blue cloth, and 17 with red, but the 20-fathom mark is two knots in a piece of string—the 20-fathom marking of the dipsie line. To use the dipsie lead the ship was hove-to, and the sounding was taken either from the pinnace or the lead was taken forward to the eyes of the ship, and the line coiled down at intervals all along the weather side of the deck to the poop. One of the crew was stationed at each coil. When the lead was hove overboard, each man as his coil ran out called to his fellow abaft him, ‘Watch, there, watch’, and as the line came up and down and ceased to run out the depth was taken, either so many fathoms or ‘No bottom’, under the eyes of the master. The sounding line, being short, could be used under way. ‘Soundyng ledes with lynes’ were important items in the ship’s stores of the royal ships.

Probably the next oldest instrument the ship-master used was his compass. The mariners of the ancient world centred round the Mediterranean and Black Sea had used books of sailing directions, known as a periplus, ‘a sailing-round’ or ‘port-book’. The directions they used were related to the winds, for with their simple square sail the seamen of ancient times were dependent upon a following wind for making headway. They evolved eight principal directions or ‘winds’, as they called them. North they identified by the Pole Star and its guards, which they saw over the mountains—Tramontana to the north. East and west they identified by the sun’s direction at sunrise and sunset and intermediate directions by the nature or supposed source of the winds. The Greeks, who were the seamen of the Roman empire, seem to have transmitted their lore, probably through the warring and trading activities of the Byzantine empire, to the seamen of the nascent city states in Italy of the early centuries of our era. In the eighth and ninth centuries the Arabs overran much of the Mediterranean littoral and introduced the lateen-sail, a form of balanced lug-sail by means of which the seaman could make headway towards the direction from which the wind was blowing. In the tenth and eleventh centuries the Norsemen overflowed from their northern coasts and penetrated the more highly civilized Mediterranean, bringing with them too a means of making good a course towards the direction from which the wind was blowing, the bowline. By means of the bowline a square sail could be trimmed around towards the wind and its luff, or leading edge, drawn tight, so that an efficient sail area was formed. By means of these two inventions, the

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1 The latter is the time-honoured method in the sailing merchant service today and there is no reason to suppose it has changed in the centuries. Journals and narratives of the early seventeenth century refer to sounding from the pinnace.

2 Documents and Inventories of Henry VII, N.R.S., Vol. 8, e.g. ‘The Mary Fortune... Soundyng ledes with lynes. Also the seed Robert Brygandyne hath payed for ii Soundyng ledes pryece the peece xijd—ijs and for iii Soundyng lynes to the same ij of them at ixd a peece xvijd and oon at viijd—iis ijd. ...’
lateen-sail and the bowline, the seaman was freed from the tyranny of the following wind. The consequence was that to exploit their advantages a more reliable and constant direction pointer than the sun, stars, and winds became an urgent need. So it was, in all probability, that the magnetic compass came into its own at sea. The Norsemen had divided the compass of their horizon originally into four directions or quarters, now called the cardinal points, North, East, South, and West, based no doubt upon the bearing of the sun at midday, sunrise, and sunset, and upon the Pole Star, and its guards, which was then about 8 to 10 distant from the pole. Since the directions were only general the amplitude of the sun, the amount by which the sun rises and sets north or south of true east and west, and the polar distance of Polaris did not greatly matter, and no doubt was allowed for roughly according to the season of the year and the approximate time of the day or night. The rising of the sun due east and its setting due west at the equinoxes, in March and September, was probably well known. By the fourteenth century, to judge from written notes, but the thirteenth century to judge from the rhumb (direction) lines on the oldest surviving chart, the seaman's horizon had been divided into thirty-two directions or, as he called them, 'rhums of the winds'. Almost everywhere the northern names for direction had been adopted—North, South, East, and West, and their various combinations to denote the twenty-eight intermediate directions—but the classical practice of referring to directions as 'winds' had continued in the Mediterranean and had been adopted by northern seamen also.

We do not know who invented the magnetic compass, nor when it first came into use at sea, nor where. It seems to be fairly well established that it was a European invention, and most probably a Mediterranean one. Tradition associates it with the Italian port of Amalfi. One thing is certain, it was in use amongst northern and Mediterranean seamen in the twelfth century. Its use anywhere before that cannot be established. It is perhaps not without significance that the earliest records of the compass should date from within a century of the start of the first crusade (1097); that it was not until after the first-known mention of a compass (1187) that any significant force of crusaders, other than Italian ones, made their way to the East by sea (this was in 1190 when Philip Augustus and Richard Coeur de Lion initiated great sea-borne crusading expeditions from northwest Europe); and that amongst the Italian ports which by then had longestablished carrying trades in the Mediterranean was Amalfi, whose ships carried, amongst other cargoes, magnetic iron ore from the mines in Elba. In short, the twelfth century, which saw significant developments in ship design, may well, under the stimulus of the crusades, have also seen the magnetic compass first brought into use at sea by men of Amalfi.

It is probable that originally the compass consisted of a piece of magnetic

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ore—a lodestone (literally ‘way-stone’) placed on a piece of wood and floated in a bowl of water when the mariner wished to check the wind direction by finding the direction of north in thick weather or on dark nights. By 1187 we have the description in Alexander Neckham’s *De Utensilibus* of a needle transfixing a piece of reed so that when floated in a bowl of water it indicated the four cardinal points. From his description in *De Naturis Rerum* it appears to have been used at sea only in foul weather, and then only for checking wind direction, as distinct from the ship’s course. For this there were practical reasons. From the earliest times the pilot had set his course by trimming his sail to the wind, and had coned the helmsman in terms of wind direction, while the helmsman had subsequently steered so as to keep this trim of sail. With her full-cut square sail the ships of both northern and Mediterranean seamen could do little more than run before the wind. Consequently the pilot thought traditionally in terms of wind direction, a practice which even the introduction of the lateen-sail and the bowline, since it was made (almost certainly) at a time when compasses were not in use, gave no cause for abandoning. The aid which the pilot felt in need of on starless nights and in thick weather was consequently one which would enable him to check the direction of the wind. The primitive lodestone and magnetic needle, floated by a reed in a bowl of water, enabled him to do just this—and no more for, being free floating, it quickly moved towards the side of the bowl and, on contact with it, became deflected from the direction of north. In a small craft in rough weather such an instrument could enable only the general direction of north to be gleaned by a snatched glance; nevertheless, this, it must be emphasized, was sufficient for the pilot’s purpose of gauging the wind direction.

The essential accompaniment to the magnetic needle was a lodestone with which to magnetize it and with which to keep it magnetized, for iron loses its magnetism unless specially treated, and knowledge of this was still a mystery. The earliest mention in English records of lodestones appears to be in the inventories of 1410–12 of the *Plenty* of Hull, which had ‘1 sailing piece’, and of the *George* for which ‘12 stones, called adamants, called sailstones, were bought for 6s in Flanders’.  

A certain amount of art was involved in sensitizing the needle. The pilot could either rub it on the lodestone before floating it or, and this was more dramatic, he could float the needle in the bowl and then magnetize it by induction. To do this he held his lodestone close to the edge of the  

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bowl: as the floating needle swung towards the stone he moved the stone round the bowl. Faster and faster he swung it until he was drawing the needle round too at a good pace. When he judged the right moment had come he snatched the stone away. Bereft of its attractive influence the needle stopped circling and settled in a north-pointing direction. Such actions smacked of wizardry to the uninitiated. The pilot therefore was jealous of his art.

Besides the floating needle Alexander Neckham had also described a compass consisting of a needle rotating on a point. Thus by the close of the twelfth century the main elements of the sea-compass had been evolved. By 1218 a compass, we learn, was considered 'most necessary for such as sail the sea'. By 1269, from a treatise written by a Frenchman, Pierre de Maricourt, we know that a form of compass had been developed which enabled the pilot to check the ship's course relative to magnetic north, and to take bearings. This was a dry, not a wet, compass. That is to say the compass bowl was not filled with liquid. The compass needle was mounted within the bowl on a vertical axis with a pivot at each end. The bowl was fitted with a graduated verge ring. This compass marked a further technical advance; so did a non-magnetic pin fitted at right-angles to the compass needle. By this device the moments of inertia in the two vertical planes passing through the needle at right-angles to each other were equalized. Without it the compass would have been useless in a vessel in a seaway for, under the influence of its own rolling and pitching motion the needle would have tended to turn into the plane of the ship's roll. It is probable that this compass had been developed some time earlier, because in 1270, only the year after Pierre de Maricourt wrote his treatise, Louis IX of France, after six days of storm during his crusading voyage from Aiguesmortes, on the south coast of France, to Tunis, demanded to know the ship's position and was shown it on a chart to be in Cagliari Bay, Sardinia. Now such charts were drawn by plotting the compass bearings and estimated distances between places, and the oldest surviving example, which can be dated about 1275—only five years after Louis IX's experience—displays such technical excellence that it is clearly the product of a long-established skill. In short, the use of magnetic compasses designed to take magnetic bearings of objects and places from ships had been well established by the last half of the thirteenth century. An Italian ship inventory of 1294 included, indeed, 'two charts, a pair of compasses, and two lodestones'. Whether by then the next step had been taken and a graduated card had been attached to the compass needle, in place of the engraved verge ring described by Pierre de Maricourt, is as yet unknown.

But from the excellence of the contemporary distance and bearing charts it would seem probable that it had. The result of this development was, of course, that it was no longer necessary to orientate the compass bowl to the needle in order to find compass directions. The compass was now self-indicating in all directions.

While this was a logical development, in view of the now consistent use of charts by Mediterranean seamen, it was not easily made, for it was no easy matter to devise a simple, strong yet sensitive instrument which, despite the violent rolling of a vessel in a cross sea, the heavy jarring shocks as she pounded into a head sea, and all and every alteration of course that the master might put her through, would point steadily to north. The solution demanded originality tempered by technical skill and balanced by a nice sense of practical requirements. When the problem had been solved the accuracy and frequency with which bearings could be taken was increased, and ship-masters carried an instrument sufficiently reliable and accurate to justify their ordering the helmsman on occasion to steer by it instead of by the trim of the sails. This practice necessitated having the compass permanently before the helmsman at a height and in a position where it would be constantly visible to him by day and by night. At the same time it had to be protected from the elements and from the ordinary hazards of ship-board activities. As a result the binnacle or bittacle, as it was often called, in early days, came into use. We first find binnacles mentioned in English ship inventories of 1410–12. A binnacle—whatever may have been its detailed form and construction in those days—was essentially a portable wooden chest in which the steering compass was stowed, and which could be secured to the deck before the helmsman, care being taken to ensure that the centre of the compass-fly lay in the fore and aft centre-line of the vessel. The front panel of the binnacle could be removed so that the compass, secured to a shelf within the binnacle at a height suitable to the helmsman, could be kept constantly in view by him. By night the compass was illuminated by a candle lanthorn placed beside it in the binnacle, a fact which is confirmed by a German monk who made a voyage to the Holy Land as a passenger in a three-masted galley in 1483. By these means the helmsman was able to check by day and by night both the direction of the ship’s head and the trim of his sails. In this task he was continually supervised in Mediterranean and in all Iberian ships by the master or his mates, using a compass in a binnacle on the poop for the purpose.¹

In the fifteenth century an apparent error in compasses began to be recognized; compasses were observed to point not to the north, towards the Pole Star, but to the east of north. By now the daily circumpolar move-

III. The Lead and Line.
IV. Edward Fiennes, Lord Clinton and Saye, Lord High Admiral, and the Sea-compass, 1562.
The 3. part.

and lykewise the Rose; that it decline not to one parte or other. And if it be quicker then it ought to be, then make the point that it goeth upon somewhat blunter.

The 5. Chapter, of the effecte

or property that the compasse hath to Northwestynge, or Northeastynge whereby is knowne the variation of the compasse.

Any and divers are the opinions that I haue haerde, and also read in certain writers of later partes, as touchinge the Northeastynge, and Northwestynge of the compasse. And yet mee seemeth that none doth touche the prick, and finde the lykke. They call it Northwestynge, when the needle

V. Compass-fly and Needle of 1545.
VI. The Compass of Variation, 1597.
ment of the Pole Star was known to many seamen, and was being made use of by the Portuguese pilots, but this phenomenon of variation, as the continual ‘casting’ of the north point of the compass was known, was a new discovery. By the Mediterranean seamen and cartographers the discovery of the discrepancy between true and compass north, even if appreciated before the late fifteenth century—which is very doubtful—was left alone. In Flanders, however, where, with the growth of trade, the manufacture of lodestones and compasses seems to have flourished from the fourteenth century, the compass-makers of the latter half of the fifteenth century, if not earlier, corrected their compasses for the variation observed in north-west Europe. This they did by so mounting the compass card or ‘fly’, to give it its contemporary name, on the compass needle that when the needle pointed to magnetic north the compass fly indicated approximately true north. For doing this the northern compass-makers, who all soon copied the Flemish ones, have been censured.1

Certainly in later years this led to a lot of confusion, and probably shipwrecks, but at the time it was not an unreasonable thing to do, for the northern ship-master, it will be recalled, did not use a chart. In the Baltic, indeed, it appears that as late as the last decades of the fifteenth century he did not even use a compass. Then he was used to steering with a rudder and a lead.2 Free of the restrictions imposed upon Mediterranean compass-makers by a complementary and traditional art of chart-making, the Flemish compass-makers were at liberty to make innovations in the instruments they made. Perhaps they were prompted by the practice, common in north-west Europe since the middle of the fifteenth century, of

1 The main authorities consulted are: Chapman, S.; Harradon, H. D.; May, W. E.; Mitchell, A. C.; Hewson, J. B. This last’s History of Navigation (1951) does not incorporate the researches of recent years. Mitchell’s researches are embodied in a fully documented critical examination of the origin of the compass which concludes: (I) That while it is possible that the Chinese were acquainted with the directive property of the magnet by A.D. 1093, they made no further use of that property for at least two hundred years thereafter. (II) That there is no evidence of the origin of any such knowledge among the Arabs, and it is improbable that they transmitted any information on the matter to Europe, their earliest mention of the compass being nearly half a century after its first mention in Europe. (III) That the compass was in use in western Europe by A.D. 1187, and taking into consideration the fact that the directive property must have been discovered much earlier, it is probable that a knowledge of that property and its application in western Europe was of independent origin and as early as, if not earlier than, that in China. Mitchell also points out that variation was used in portable sun-dial compasses of Nuremberg by 1450, and that Columbus used a Genoese and a Flemish compass on his second voyage of 1493–6.

2 Nordensköld, A. E., Periplus (1897), p. 106, quotes a Spanish envoy’s experience of sea travel in the Baltic in 1578 where he said, ‘the natives never use any other chart than a small written book’, i.e. a rutter. Nor was the use of the compass customary. Spekke, A., ‘The Eastern Baltic Coast up to the 16th century’, Imago Mundi, Vol. 5, cites Fra Mauro, a fifteenth-century voyager’s statement ‘per questo mare non se navega cum carte ni bossola ma cum scandaso’. That is, they use neither chart nor compass, only a lead for navigating.

5—A.O.N.
engraving the variation upon the increasingly popular traveller's pocket sundials—foerunners of the modern wrist-watch. This enabled the dial to be orientated accurately and consequently the correct local time to be found. Similarly, the ship-master who used his compass-fly as a sun-dial would find the time more accurately when the fly was off-set. Whatever the source of inspiration, we find in northern waters that the compass fly was off-set in azimuth anything from half a point—5°1'—to a whole point and a half—17°—to the west of the compass needle in order to compensate for the easterly variation of the compass in the particular waters in which it was intended to be used. In the Mediterranean, on the other hand, where for generations mariners had constantly used a compass in conjunction with a bearing and distance chart as well as with a rutter, variation was not allowed for by adjustment of the fly. As in the modern compass, the north point of the fly was aligned with the north point of the compass needle. Such a compass was often described in the sixteenth century as a meridional compass. At first sight the use of the meridional compass would appear to have involved the mariner of southern Europe in the problem of applying a correction for variation to every course he steered or bearing which he took when using his chart. But he knew what he was doing. He did not apply any such corrections normally, for the appropriate correction for variation was allowed for in the traditional layout of the chart which dated from the days before variation had been suspected. Consequently he had merely to read off the course on his chart which would take him to his destination, and in order to reach it, steer that course as indicated by his compass.

There are occasional crude illustrations of the mariner's or sea-compass on maps of the fifteenth century, indicating that it then consisted of a round box and a fly similar in form and layout to those in common use in the sixteenth, seventeenth, and eighteenth centuries. If not the earliest detailed illustration, certainly the earliest illustration of an English sea-compass dates from 1562.1 The compass is shown held proudly in the left hand of Edward Fiennes, Lord Clinton and Saye, Lord High Admiral of England, who is wearing his badge of office, a golden 'call' or whistle, while the forefinger of his right hand rests on the compass box's outer edge, pointing significantly at the fleur-de-lis marking the north point of the fly.

It is in the third, and oldest, of the books listed by Captain John Smith on the art of navigation that the earliest description of the manner of making the mariner's common sea-compass is to be found. The similarity between this description—contained in Richard Eden's translation of 1561 of Martin Cortes's Arte de Navegar of 15512—and the compasses

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1 See Pl. IV.
on the frontispiece of Anthony Ashley's *The Mariners Mirour* of 1588, with an illustration in William Barlow's book *The Navigators Supply* of 1597, and an actual steering compass of the eighteenth century (in a portable binnacle) in the National Maritime Museum at Greenwich, makes it clear that all are typical of the best sea-compasses in use in England throughout the period, and that this is equally true of the compass held in the Lord High Admiral's hands in 1562. The description 'Of the maykyng of the Maryners compass for Navigation' occurs in the third chapter of the third part of Cortes's manual of navigation. We learn that on a circular piece of chart paper, four to six inches in diameter, were painted the compass points or 'winds'. The Italian seamen still often used a compass marked with the initial letters of the eight principal winds traditionally recognized in the Mediterranean, namely, T for Tramontana (north), G for Greco (north-east), Levante (east), S for Sirocco (south-east), O for Ostro (south), A for Africo (or Libeccio) (south-west), P for Ponente (west), and M for Maestro (north-west). Levante (east) was indicated not by the initial letter but by a cross. The northern compass, however, as already explained, was by now always marked with the thirty-two points still used today, and one of the first tasks of the young seaman was to learn 'to say' or, to use the modern expression, to 'box' his compass, starting from north. On all compass-flies the east point was marked with a cross, and this custom persisted into the eighteenth century. The north point was indicated by a *fleur-de-lis*, as it is to this day, a device which appears to be a formalized rendering of the thin isosceles triangle used by the fifteenth-century Italians and the Catalan eight-rayed star, imitating the stars in Ursa Minor, of which the Pole Star or Polaris is the most conspicuous.¹

Underneath the fly was attached the compass 'wire' or needle. This was glued on with paper, and consisted of a length of iron wire, originally of the length of the circumference of the fly but bowed double and pinched together at each end until its length equalled the diameter of the fly. It thus formed an elongated hoop through the centre of which, and of the fly, a brass cone, known as the 'capital', was pushed. On this the fly could pivot. The compass box consisted of a round wooden box turned out of the solid, half the diameter of the fly in height, covered with glass, sealed in by resin, and fitted with a detachable wooden base, in the upper centre of which was fixed the brass 'pin' or pivot, for the fly.²

Before assembly the compass needle or 'wires' were 'fed' by being touched with 'the face of the stone', that is, with the lodestone which formed part of every pilot's outfit. The lodestone he kept in a brass filigree case, which could be locked, and hung up by a chain well clear of the compass when not required for feeding it. This had to be done fairly

¹ Winter, H., 'What is the Present Stage of Research in regard to the Development of the use of the Compass in Europe?', *Research and Progress*, Vol. 2. See PIs. V and VI.
² See PIs. IV and V.
frequently, for the wires, being generally of soft iron, lost their magnetism after a while. To feed his compass the pilot lifted his stone from its case, rapped it sharply, so that (as he supposed) small bearded ‘icicles’ appeared at its north end, ‘whereon’, Martin Cortes laid down, ‘you shall rubbe the poynct of the iron as you wolde whette a knyfe: and so shall certen of those beards of the stone cleave and sticke faste to the iron’. This done he mounted the fly on the pin and tested it for ‘quickness’, blunting the end of the pin should the fly prove too lively. He then secured the base, complete with pin and fly, to the compass box. If the compass were to be used for steering or conning the ship, it was mounted in gimbals in another wooden box, either round or square, before being placed in the binnacle, in the construction of which only wooden nails were used.1 Gimbals—the word perhaps comes from the Old French gemel, a twin—are two brass rings which move within each other, each perpendicular to its plane, in such a manner that despite the movements of the ship in a seaway the compass suspended in them is kept level and the movement of the compass-fly is thus greatly reduced.2 Cortes, who completed writing his book in 1545, appears to be one of the earliest authorities to mention gimbals. It is reasonable to suppose that gimbals were introduced with the practice of conning a ship by the compass, and consequently that they were in use in the fifteenth century. Pedro Nuñez mentioned them in 1537.

The degree of accuracy and the finish of the compass varied widely. The master mariners no doubt took good care to see that the instrument they bought was of the finest materials and craftsmanship, but the coasting pilot’s compass, if it was not his own rough and ready manufacture, was often crude enough. Writing in 1597, William Barlow, in The Navigators Supply,3 specifically warns mariners against the ‘errors that dayly are committed in the making and framing’ of the common sea-compass ‘such as are in common use, and are sale-ware for Masters and Pilots’. The errors he describes must make a seaman’s flesh creep to read: the fly unequally divided; the wires of the fly imperfectly joined, eccentrically mounted, rusty, roughly cut, and, to level up the fly, daubed with wax; the capital set on the fly eccentrically, likewise the pin in the base on which it pivoted; the glass cover cracked or gnarled, ill-cut and, worse, set into the cover with excess of resin; the gimbals so imperfectly made ‘that you should offer a Tinker discredit to compare his works with this’; the riveting of the gimbals done with iron; iron nails holding gimbals in position; and iron nails used in the making of the very binnacle. In spite of these strictures we find him still writing in 1616 that amongst Englishmen and others

1 Documents and Inventories of Henry VII, N.R.S., Vol. 8. The Marie of the Tours (1485). ‘Compass iiij, Rennyng Glasses j, Soundyng leeds j, Bitakles j.’
2 See Pl. VI.
3 Barlow, W., The Navigators Supply (1597). The full title will be found on p. 216.

An excellent example of a crudely made sea-compass is in the National Maritime Museum, Greenwich. It is a Portuguese fisherman’s of the turn of this century.
‘the compass needle . . . is . . . so hungerly and absurdly contrived, as nothing more’, so that we may suspect that in the early part of the sixteenth century many compasses were no better.¹ We know that in twelfth-century ships the compass was illuminated at night. From the Sea Grammar we know that in Captain Smith’s time for night use a special ‘dark compass’ was provided. On the fly of this type the points were painted in black and white only, and not in the usual bright, but at night indistinct, colours. That wooden pins were used in the construction of the best binnacles of the sixteenth and seventeenth centuries shows that deviation—the compass error induced by the presence of iron—though not named was appreciated. Indeed Captain Smith says treenails were used ‘because iron nailes would attract the Compasse’; Cortes implies this.

Whether before the 1580s a lubber’s line was marked on the compass box to indicate to the helmsman the position of the ship’s head in relation to the fly is not clear. Cortes does not mention it. The earliest mention of such a mark on the compass bowl appears to be that in the Spaniard Zamorano’s navigation manual of 1581, a later edition of which was translated into English and published in 1610.² Until it was introduced—and it was the increased size of ships that made it necessary—the helmsman used the masts or stem for a guide. From the accounts and inventories of Henry VII’s royal ships we learn that the ‘Kynge’s ships’ at the close of the fifteenth century carried, according to their size, from two to four compasses as part of their equipment, and it would appear that this was the usual establishment throughout the sixteenth and early seventeenth centuries.³

² Edward Wright’s Certayne Errors in Navigation (2nd ed.), 1610, contains a translation of a Spanish navigation manual of 1588 describing the use of the lubber’s line at night.
³ Edward Wright got a friend to translate Compendio del arte de navigate, del Licenciado Rodrigo Camorano. Impresso en Seville, Año 1588. It is almost identical with the first edition of 1581—in the 1588 edition a compass rose is substituted for a circular diagram showing thirty-two radial lines representing the rhumbs of the winds—Compendio de la arte de navigate, de Rodrigo Camorano, en Seville, Año 1581. (The date in the colophon is 1582.)

In Chapter 17 this reads in the translation: ‘The Sea Compasse is . . . a round box of wood . . . within two hoopes of latin . . . fastened within a square box, or a round . . . placed . . . in the midst of the pup of the ship where the bittacle standeth in a right line, which passeth from the boltsprit by the midst of the mainmast to the puppe, it serueth continually to governe the ship by mowing of the rudder, till the winde or the line of your compasse, towards which we desire to shape our course, stand directly towards the prow or boltsprit of the ship. They use also for the night to marke a point within the inner part of the inner box, which in respect of the capitell of the compasse [the pivotal point of the fly] may stand directly towards the prow of the ship: And alwaies in guiding the shippe, you must take heed that the said point be continually joyned with the winde of the rose towards which you intend your course.’

Whatever its faults, and they were often many, in the early sixteenth century the sea-compass was, with the lead, unquestionably the English ship-master's most vital instrument. This is not to say that he no longer used the stars as guides. As in earlier times, he used the Pole Star, the *stella maris* or *Tramontana*, easy to find by its terminal position in the tail of the Little Bear, for finding the north. But if it was still for long the cynosure of the lodeman's eyes on many a black and stormy night, the lodestone could justly claim:

I guide the Pilots course,
his helpynge hande am I.
The Mariner delights in me,
So doth the Marchaunt man.1

The ship-master used the compass not only as a direction indicator but also as a rough time-piece. 'It hath beene an ancient custom among Mariners to devide the Compasse into 24 equall partes or howers, by which they have used to distinguish time,' explained John Davis, at the end of the sixteenth century, 'Supposing an East Sunne to be 6 of the clocke, a South-east Sunne 9 of the clocke, and a South Sunne 12 of the Clocke, etc.,' and he gives in his *Seamans Secrets* a diagram of a compass rose so marked.2 This practice arose from the lack of mechanical time-keepers and from the impracticability of using sun-dials on board ship. Some method of time-finding was necessary in order to determine the state of the tide. The Mediterranean seaman was little affected by tides. But on the Atlantic coasts, and much more on the northern coasts, the rise and fall of the tides and the changes in direction of the flowing of the tidal streams were important considerations for the ship-master. He was particularly concerned with knowing the times of high- and low-water at each port of call, the depth of water at those ports at those times, and the direction of flow of the tidal streams likely to be experienced between them. Few ports had public clocks. Like the smaller house-clocks introduced into the houses of the wealthy early in the sixteenth century and the little watches—little more than rich men's novelties—public clocks erred by anything up to an hour in the day. All had to be regulated by sun-dials, and because of their errors had only an hour hand. Over any length of time sand-glasses

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1 Norman, R. *The Newe Attractive* (1581). The full title will be found on p. 153.
2 The Seaman's Secrets.

Devided into 2. partes, wherein is taught the three Kindes of Sayling, Horizontall, Paradoxall, and sayling upon a great Circle: also an Horizontall Tyde Table for the easie finding of the ebbing and flowing of the Tydes, with a Regiment newly calculated for the finding of the Declination of the Sunne, and many other most necessary rules and Instruments, not heretofore set forth by any.

Newly published by John Daws of Sandrudge, neere Dartmouth, in the Countie of Devon. Gent.

Imprinted at London by Thomas Dawson, dwelling at the three Cranes in the Vinetree, and are these [sic] to be solde. 1595.

See also Appendix No. 3.
were equally unreliable. This rise and fall of the tides had been associated with the motions of the moon for many centuries. The earliest surviving tide-table, compiled by the monks of St. Albans in the thirteenth century, gives the times of high-water at London Bridge on each day of the moon's age, but without a sun-dial this was useless for seamen. They accordingly hit upon the practice of recording the times of high-water according to the age and compass bearing of the moon. For simplicity and ease of memory they noted the times of high-water at the various ports on the days of full and new moon—at 'full and change'—in terms of the compass bearing of the moon at the moment of high-water. This, since the highest highwaters or spring tides were found to occur at about full and change, became the establishment of the port. Thus the establishment of Dieppe, for example, was expressed as 'Dieppe is North-North-West and South-South-East', that is 'High-water occurs at Dieppe on days of full and new moon when the moon bears North-North-West or South-South-East' (10.30 p.m. and 10.30 a.m.); and high-water occurred on days of full and change at ports on the English coast 'betwenee Start and Lisarte (Lizard)', according to the oldest English rutter, it will be recalled, 'at a west and south-west moone' (4.30 p.m. and a.m.); and 'at Dover', ran the Booke of the Sea Carte, 'the moon south—full Sea' (noon and midnight). If he arrived off a port whose establishment he knew, on a day other than that of full or change, the seaman had to calculate the time of high-water. This was because owing to the different motions of the sun and moon successive high tides normally occur at intervals of about 12 hours and 24 minutes. Thus in the 24-hour solar day there is a daily retardation in the times of high-water of 48 minutes or 4 hours. In a lunar month of 30 days (more nearly 29½ days) there is thus a complete cycle of tides. The daily retardation can thus be expressed as 34 or 4 of an hour. This was the retardation recorded in the St. Albans tide-table, and in Portuguese tide-tables. But this was not a convenient figure for the northern seaman, who had frequently to compute the tide and do so with the aid of the 32 points of his compass. He therefore often adopted a daily retardation of 42 = 3 hour or 45 minutes. By this means he was able to calculate quite accurately enough for practical purposes the daily change in the time of high-water by the compass bearing of the moon —the chief arbiter of the tides—and thus the time of high-water. Accordingly he adhered to the practice of marking his fly in hours, as explained by John Davis, making each point worth 45 minutes of time. When he knew the establishment of a port all he had to do to find the time of high-water on a particular day was to find from his almanac the age of the moon and add the daily retardation—one point for every day of the moon's age. Suppose that high-water at a port coincided with the moon's meridian passage at full or change, then the establishment of the port was North and South, that is, noon and midnight. As each point was worth 4 hour, the two daily highwaters were deemed to occur at intervals of about 12 hours apart, 16 points.

As each day the cycle of high tide retarded one point—45 minutes—according to the compass clock, when the moon was eight days old high-water occurred at West and East, that is to say, at six in the morning and six in the afternoon. However, by using a daily retardation of 45 minutes instead of the more accurate 48 minutes, at the end of fifteen days the compass clock was one point out. This error was generally remedied by starting on the same point on the sixteenth day.\textsuperscript{1} When the daily retardation of 48 minutes was used each day of the moon’s age was taken as equal to a retardation of one compass point and three minutes.

Some idea of the accuracy of the establishments and of this rule is afforded by comparing the establishment of Dover with a modern tide-table. Dover’s establishment was given as North and South—high-water at full and change at midnight and noon. On 9 March 1940 the moon was 29.7 days old and high-water occurred at Dover at 11.47 p.m. On the 10th, when it was just under one day old, high-water at Dover occurred at 12.05 p.m. On 18 March, when the moon was eight days old, high-water occurred at 5.47 p.m. According to the rutters and the rule for calculating the time of high-water by the compass rhumbs and the moon’s age, it was at 6 p.m.\textsuperscript{2}

The establishment of the various ports was given in the ship-master’s rutter in the course of the sailing directions, generally for high-water, though sometimes the bearing of low-water was given instead. The haphazard arrangement was far from convenient for a ship-master sailing on a route with which he was not very familiar. In the first half of the sixteenth century a Breton of Conquet, G., probably Guillaume, Brouscon, who issued simple almanacs for farmers, hit upon the idea of issuing tide-tables for the often more or less illiterate seamen, which enabled any port’s establishment to be picked out at a glance. For his tide-tables he drew rough outline charts of the coasts between Biscay, the Channel, and Irish Sea, wrote in the names of the ports on the coastline, drew a compass rose on the sea area, and linked the various ports by weaving lines to the compass point of their establishment. In addition he included eight circular diagrams, one for each of the cardinal points in half the compass. In the centre of each diagram he drew an eight-point compass rose orientated so that the point or rhumb of establishment was at the bottom.\textsuperscript{3} Around the compass rose he drew four concentric rings divided into 29 equal parts corresponding to the 29 lunar days. The outer circle indicated the moon’s


\textsuperscript{2} The phases of the moon for March 1940 are from Brown’s \textit{Nautical Almanac}, Glasgow (1940), and the times of high-water at Dover from \textit{The Admiralty Tide Tables, Part I}, 1940, Section A. London (1939).

\textsuperscript{3} See Pls. VII and VIII.
VII. Establishment of English and Irish Ports, c. 1545.

VIII. Circular Tide-tables for Ports with Establishments of South-south-east and South. High water on days of full and change at 10:30 and 12:00. Brouscon’s Tide-tables and Almanac of c. 1545.

5°—A.O.N.
The instrument thus ended and brought to perfection, when you desire to know the hour, you shall turn the index of the lesser sundial in the which is written the name to that part of the great sundial where is marked the day in the which you desire to know the hour: And then use your face towards the north, you shall make the head towards the heighth of heaven, at the 10. of April.

IX. A Nocturnal of 1545.
X. A Traverse Board.
XI. The Rule of the North Star, and Distance to Raise or Lay 1 of Latitude and the Almanac for January and February, in Brouscon's Tide-tables and Almanac of c. 1545.
age, and its divisions were numbered clockwise, from the bottom, from 1 round to 29 (1 was also numbered 30). The circle next to, and inside, that of the moon’s age contained eight symbols, four representing the phases of the moon, and four the states of the tide—springs or neaps. The next inner circle contained the time, in hours and quarters of the hour, of high-water on each day. The innermost circle contained the times of low-water. By counting the lunar month as consisting of 29 days the cumulative error caused by the use of 45-minute differences of time instead of 48 was neatly eliminated. A calendar of the age of the moon accompanied the tide-tables, from which, knowing which one was appropriate for the establishment of the port, and knowing the age of the moon, it was simplicity itself to find the time of high- or of low-water.

Sometimes the illiterate seaman was aided in the elucidation of such tide-tables by the symbolic representation of place names. Such a printed English tide-table of 1569 survives and probably had been included in an almanac.¹

An interesting feature of Brouscon’s tidal diagrams is that he showed the spring tides, that is the highest and lowest tides that occur twice each lunar month when the moon is full and new, as occurring two days after new and full moon. Comparison with modern tide-tables shows this to be correct. Brouscon’s tide-tables, because of their simplicity and ease of working, were extremely popular, and at least one Englishman, John Marshall, copied them, adding an explanation of their use. A transcript of his, dedicated to the Earl of Arundel, is in the British Museum.²

It is to be observed that the depth of water shown in the ruttlers for various places rarely discriminated between the depth of water at spring tides and at other tides. For instance, when the moon is in its first and third quarters the rise and fall—the range—of the tide is smaller than at spring tides. The difficulty of discriminating between the different ranges of tide was caused by the lack of a common zero or basic depth of water to which the tidal range could be related. The establishment of such a level was too difficult for the times to be general, although a simple example of such differences occurs in the tide-tables of an almanac of 1569.³ On the other hand, the effect of wind on the time of high-water was often noted for certain places. For instance, in Robert Copland’s printed rutter high-water at spring tides in the Somme was noted as occurring at ‘moone in the south’, that is at noon or midnight, but ‘with nep tides, and northe winde the moone in the south-south-east ful se’, that is with neap tides a north wind caused high-water to occur an hour and a half earlier.

¹ A verie plaine and perfecte table, etc., 1569. (B.M. Bagford Fragments. Harl. 593719).
² See Appendix No. 3.
³ Hubrich, Joachim, An Almanack and Prognostication for the yere of our Lord God, 1569.
What no rutter included was the strength of the tidal stream, and we may mention here that such information, though English navigators had started to collect it early in the seventeenth century, only began to be included in sailing directions in the latter part of the eighteenth century. On the other hand from the earliest times it had been recognized that the flood stream did not cease to flow off-shore at the time that it did inshore, that is at the time of high-water inshore. For example, in the English Channel the flood-stream which flows up-Channel towards the Dover Strait is extremely complex. It continues to flow in mid-Channel when inshore the tidal stream has already turned, the ebb set in. Similarly the ebb continues to flow down-Channel in the offing when inshore the flood has already set in. In the upper part of the Channel near the Dover Strait the flood continues to flow some three hours after high-water, and the ebb for three hours after low-water. For the ship-master crossing the Channel or, instead of caping, sailing in mid-Channel, this difference, which was greatest in the Straits, was obviously of importance. The phenomenon was known, and explained, by the expression that the tides in the offing flowed ‘one under other’ for a period measured in fractions of a tide. Thus if the flood in the offing flowed for three hours longer than it did inshore, it was said to flow tide and half tide; tide, half and half-quarter meant it flowed for five points —3½ hours longer: ‘by longer is not meant more hours’, explained Mainwaring, whose explanation appears to be the earliest, ‘but thus: if it be high water at the shore at twelve o’clock, it shall not be high water in the offing till it be three o’clock (which is the compass and time for the running of half a tide).’ The further explanation was that, while the flood was flowing thus in the fairway, the ebb was flowing beneath it, close to the ground.

Tidal knowledge, then, was rough by modern standards, but for the times generally good enough, though it was not uncommon for ships to run aground ‘from mistaking of the tide’, even in well-known ports. Lack of knowledge of the strength of tidal streams was a frequent source of error, but it was one which could only be avoided by long experience of ship-handling in the waters concerned.

Although the mariner could use his compass in sunny weather as a clock or crude sun-dial, its horizontal position rendered it extremely inaccurate in these northern latitudes. Only at the times of the equinoxes, in March and September, does the sun rise due east at six o’clock, and set due west at six in the evening. In midsummer, for instance, ‘for us in England (the Sunne having his greatest North declination) it is somewhat past 7 of the clocke at an East Sunne, and at a South-east Sunne it is past 10 of the clocke’, to quote John Davis’s explanation in his Seamans Secrets. In midwinter the sun rises at eight, south of east, and sets at four, south of west. Except therefore at the equinoxes, in spring and autumn, the mariner’s compass was an extremely unreliable time indicator. At night, until the latter part of the sixteenth century, the English seaman was not much better off. Although he could tell the time by the stars he had almost
certainly to do so without the aid of the instrument—the nocturnal—which the more sophisticated southern seaman used.¹ The Little Bear was a favourite time indicator. Nightly it swung anti-clockwise around 'the axis of the world', pivoting about Polaris, the Pole Star, the last star in its long curved tail. At the head of its body the bright stars ½ (Kochab) and γ served as pointers. By the position of the 'Guards' (in practice, of Kochab) the time could be estimated. Making a wider sweep around the heavens, yet never dipping completely from sight, was the constellation of the Great Bear, the 'Plough' or 'Great Dipper', with its two pointers, the bright stars Dubhe and Merak, which could be used to as good effect as those of the 'Little Dipper', particularly if Polaris and the Little Dipper were obscured. To an observer the sun appears not only to take part in the general rotation of the stellar system but also to have a slower motion of its own through the stellar system, doing a complete orbit in a year. Each day it seems to slip back a little, slantwise across the celestial sphere. Life being regulated by solar time, the same stars rise a little earlier on each successive night. In other words the sidereal day, the day measured by reference to the stars, is three minutes and fifty-six seconds shorter than the (mean) solar day. This complicates time-finding by the stars, for to an observer watching the skies each night the Guards appear in a slightly different position at the same solar hour, having slipped back slightly in their circuit. For instance, early in March the Guards of the Great Dipper are in line and high above the Pole Star at midnight. In mid-June they are due west of it at midnight, early in September in line below it at that hour, and three months later due east. Thus to an observer regarding them at the same solar hour each night they appear in the course of a year to move anti-clockwise right around the pole, or as time-keepers to lose an hour every fifteen days. Where in March they indicated midnight, a month later, in April, their same position will indicate ten o'clock, in May eight o'clock, in June if they are visible, six, and so on. No doubt the keen ship-master of early Tudor days memorized the rules giving the positions of the Guards at midnight during the year, and could judge the time within an hour at most seasons, or from the middle of the century referred to an almanac, such as Anthony Askham's, containing rules for finding the time.² Both methods were rough and ready, though good enough in general, for the ship-master rarely had need to measure time accurately in hours and minutes for purposes of calculation. Mostly he caped his way about the seas: not always, however; it was then that he had need of a time-keeper, and he used a sand-glass, either an hour or a half-hour glass, to enable him to keep a check on the distance sailed. He did not use it for measuring his speed—this he judged by eye—but having done so he could, by aid of the sand-glass, reckon how far he had run, or, more usually, how soon he reckoned to make his landfall. He started his hour-glass or 'rynnyng

¹ See Pl. IX. He could and sometimes did use his compass as a moon-dial.
² Askham, A., An Almanache . . . Very pleasant for mariners and sea men, etc. (1553).
glass’ at noon when the sun bore due south and appeared highest in the heavens. Once again, this was only a rough check, for the sun appears to hang in the heavens at its highest point, and its change of bearing is not rapid to the unaided eye, particularly when its northerly declination is great, as in summer.

The ship-master also needed a sand-glass (Robert Copland’s ‘dyall’, a corruption of the Latin diurnalis = relating to a day) for gauging the passage of the watches for the relief of the hands and the running of the ship’s routine. For this purpose he kept an hour-glass or, as was customary by the seventeenth century a half-hour glass, hung in the binnacle under the eye of the helmsman, who turned the glass each time the sand ran out and marked the passage of the time by ringing the ‘Watche belle’ at each half-hour, sounding one stroke for every half-hour that had passed of the four-hour watch.²

Besides needing the running-glass for keeping a record of the distance run, the ship-master needed it for keeping a record of the courses steered in order to estimate the course ‘made good’ during the watch. Although, until the latter part of the sixteenth century, the English ship-master rarely used any form of chart, indeed despised the use of any such aid, we know from William Bourne that in the 1550s the ‘auncient masters of shippes’ reckoned that they ‘could keep a better account upon a boord’ of the way they had sailed. Robert Copland, writing in 1528, did not mention ‘the board’ as a necessary instrument, probably because it was only necessary when not caping. In the Bordeaux wine trade, of which he was thinking in particular when he wrote, the masters did mostly cape. When out of sight of land, however, for any appreciable time, as on a voyage to Portugal (to follow the coast of France and northern Spain all the way would have been uneconomic even in those days), or on the return voyage when the persistently northerly winds experienced off the coast of Portugal often forced him to work his way homeward with a long sweep out into the Atlantic, the ship-master had to keep a reckoning. He kept a ‘dead reckoning’. That is, he estimated and recorded the way his ship had gone, taking into consideration not only her mean speed and course but also the effect of wind and tide, of waves and of the waywardness of his ship. He kept a record of the course steered on a ‘traverse board’, William Bourne’s ‘boord’. ‘Upon the Binnacle is also the Travas’, explained Captain Smith in his Sea Grammar, ‘which is a little round boord full of holes upon lines like the Compassse, upon which, by the removing of a little sticke, they keepe an account, how many glasses (which are but halfe hours) they steare upon every point.’

Mainwaring in his Seaman’s Dictionary of the 1620s explains further

¹ Documents and Inventories of Henry VII, N.R.S., Vol. 8, p. 323, gives The Mary Fortune . . . ij Compaseys and a Rynmyng glasse . . .
THE TRAVERSE BOARD

that it 'is for him at the helm to keep (as it were) a score ... to save the Master a labour, who cannot with so much curiosity watch every wind and course so exactly as he at helm, especially when we go by a wind, that is sail with a following wind, and the wind veers and hauls'.

In the traverse board illustrated, rows of holes at the base enabled the estimated—or measured—speed to be recorded each half-hour by the insertion of a peg in the appropriate hole, but these were almost certainly not a feature of traverse boards before the introduction of the knotted log line probably about 1600.1 Even so, finding the speed was not the task of the helmsman, who was partly between decks where he could see best how the sails drew. By Captain Smith's death it would appear, however, that the most capable navigators did use such an addition to the traverse board for logging their speed. It will be noticed that the thirty-two compass points each have eight holes, one for each half-hour of the watch. Every two hours or at the end of the watch the master reckoned, by sighting the pegs, the mean course steered, and noted it, together, if he were well skilled, with the distance he reckoned the ship had run, in chalk on a board or slate. He then cleared the traverse board for the next watch. That masters began increasingly to use a traverse board in the sixteenth century is indicated by the absence, after the middle of the century, of references to distances in kennings and the regular use from that time of leagues as measures of distance. A kenning could not be related conveniently to the ship's speed; a league could. A league in northern waters was 3 miles, and this was something that could be gauged, for the ships commonly sailed 3 to 4 miles in the hour.2 If the master were particularly well advanced in his art, he probably possessed a 'marteloio' copied from some Italian, French, or Iberian pilot. Italian and Catalan pilots had been using such traverse tables, drawn on charts, since the thirteenth century. Andrea Bianco, a famous Italian cartographer and a captain of a Venetian galley in London, in 1448, has left one on one of his charts.3 When obliged by the unfavourable direction of the wind to tack frequently, the pilot could calculate his dead reckoning much more accurately with the aid of this table. It enabled him to calculate the distance made good along the course necessary to bring him to his intended landfall. But English pilots who practised these refinements of navigation were rare in Tudor England before Elizabeth's day. If any used a traverse table, it was more probably the later Portuguese and Spanish 'Rule to Raise or Lay a Degree

1 See Pl. X.
2 Hues, R., *Tractatus de Globis et corum usu*, London, 1594 (translation in, Hak. Soc., Ser. 1, Vol. 79), refers to vessels in the latter part of the sixteenth century on voyages to the Cape of Good Hope sailing a degree a day—60 miles in 24 hours, and this is confirmed by plotting the tracks of ships of the period as recorded in their journals.
of Latitude', which gave the distance that had to be sailed on a given course in order to raise or lay a degree of latitude.¹

¹ 'The rule to Raise or Lay a Degree' was the formula:

\[
\text{distance} = \frac{\text{difference of latitude}}{\text{cosine (course)}}
\]

Given \(17\frac{1}{2}\) leagues = 1, then to raise or lay one degree of latitude on the following courses the distance shown opposite them had to be sailed:

<table>
<thead>
<tr>
<th>Courses</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>North and South</td>
<td>17(\frac{1}{2}) leagues</td>
</tr>
<tr>
<td>1st point 11° 15'</td>
<td>17(\frac{1}{2}) '</td>
</tr>
<tr>
<td>2nd point 22° 30'</td>
<td>19 '</td>
</tr>
<tr>
<td>3rd point 33° 45'</td>
<td>21 '</td>
</tr>
<tr>
<td>4th point 45°</td>
<td>24(\frac{1}{2}) '</td>
</tr>
<tr>
<td>5th point 56° 15'</td>
<td>31(\frac{1}{2}) '</td>
</tr>
<tr>
<td>6th point 67° 30'</td>
<td>45(\frac{1}{2}) '</td>
</tr>
<tr>
<td>7th point 78° 45'</td>
<td>89(\frac{3}{4}) '</td>
</tr>
</tbody>
</table>

The early rules were often in error as much as 2\(\frac{1}{4}\) leagues on some points. See Pl. XI.
Chapter Two

THE DEVELOPMENT OF THE ART OF NAVIGATION

"... here do I not say that Navigation is not a thing of antiquity... But I say that I am the first that have brought the arte of Navigation into a brief compendiousness, giving infallible principles and evident demonstrations, describing the practice and speculation of the same, giving also true rules to Mariners, and shewing waves to Pilotes, by teaching them the making and use of instruments, to knowe and take the altitude of the Sunne, to knowe the tides or ebbings and flowings of the sea, howe to order their cardes and cōasses for Navigations, giving them instructions of the course of the Sunne and motions of the Moone; teaching them furthermore the making of Dyalles both for the day and for the night, so certen, that in all places, they shall shewe the true hours without defaute. And have likewise declared the secrete propertie of the lodestone, with the mater and causes of the Northeastinge and Norwesting (commonly called the variatio of the compass) with also instrumentes therunto belonging."

Martin Cortes's Epistle Dedicatory to Charles V. (The Arte of Navigation... by Martin Cortes. Translated out of Spanyshe into Englyshe by Richard Eden, 1561.)

The art of navigation was developed out of the art of pilotage to meet the needs of the oceanic explorers and seamen who wished to find their position when out of sight of land, and to ascertain the location of new lands when they first discovered them or attempted to return to them. The Italians, situated centrally in the Mediterranean, had for centuries been the link between East and West. Under the impetus of the crusades they had built up great commercial empires based upon the carriage of goods by water between Italy and the Black Sea and Levantine ports in the east, and between Italy and the Lowlands of Flanders and the Fens of England in the north-west. Apart from force of arms the power and wealth of the Italian Republics, of Genoa and Venice in particular, depended upon the skill of their shipwrights, seamen, and pilots. In the thirteenth century a Genoese expedition had pushed south down the coast of West Africa and rediscovered the Canaries. Early in the fourteenth century the Portuguese had enlisted the services of Genoese pilots to create a navy and explore to the southward. The Azores, 700 miles to the westward of Lisbon, had been newly discovered. The Canaries were colonized in 1402, the Azores thirty years later. Under the inspiration of Prince Henry the Navigator (1394–1460) the push to the southward was continued in an endeavour to turn the flanks of the Moslem 'infidels', and so open up new marts. By 1481 the equator had been crossed, and seven years later the Cape of Good Hope rounded, and the southern route to the Indies revealed.
From 1497 when Vasco da Gama made the first voyage to India by this route the Portuguese traded regularly with the trading posts they rapidly established in the Indian Ocean and East Indies.

Although the ability of man to navigate, ‘to conduct a ship’ over the waters of his known world, has determined the extent of his trade, it has been the ‘sufficiency’ of his ship that has determined its volume, and that has made long sea voyages economically possible. The skill of the shipbuilder and the wares of the ship-chandler have been vital ingredients in the development of the art of navigation. The Italians, as might be expected from their long history of successful maritime commerce, were the master-shipwrights of the western world in the fifteenth and early sixteenth centuries. Indeed the stage of development already reached by western shipbuilders had much of their inspiration and experience behind it. Even in the fifteenth century the length of the oceanic voyages down the coast of Africa made bulk an essential feature of the ships that were to perform them economically. The size was necessary to enable stowage room to be sufficient for the carriage of cargoes large enough to be profitable. The long Atlantic coastline of Africa afforded few safe watering places and few places where supplies could be got for the crews; the ships, accordingly, had to be self-sufficient in food and water. As the running gear was inefficient, and piracy prevalent, large crews had to be carried, and consequently large quantities of stores. The science of food preservation was very imperfectly understood. The best containers were found to be casks. Even so, unscrupulous suppliers or incompetent storage meant that much of the food became putrescent before it could be eaten; wine went sour and water stagnant. Dietetics were likewise not understood. In the short voyages in European waters men fed on ships’ stores for only a few days, then ate on shore fresh food and fruit. At sea fresh food and fruit perished before an oceanic passage had been half completed. Scurvy set in, and the crews sickened and died. On shore there was little or no regard for hygiene, and in the summer disease stalked the narrow streets. At sea uncleanliness meant certain death on a long voyage. All this had to be learnt painfully by bitter experience, and taught by the experienced to ignorant and heedless men. Discipline had to be strict. These are aspects of the art of navigation often overlooked, but the master-pilot who overlooked them, no matter how great his skill as a pilot, sooner or later came to grief. As William Bourne put it,1 ‘the maister of shippes in Navigatiion . . . ought to be such a one as can well governe himselfe, for else it is not possible for him to govern his company well . . .’; and as Captain John Smith further advised,2 ‘he that desires command at Sea, ought well to consider the condition of his ship, victuall, and company . . . for there is no dallying nor excuses with stormes, gusts, overgroune Seas, and leeshores, and when their victuall is putrified it endangers all. . . . Many suppose any thing is good enough to serve men at sea. . . . A Commander

2 Captain John Smith, *A Sea Grammar* (1627).
at sea should do well to thinke the contrary, and provide for himsellfe and company in like manner.' The wise one did. Not least amongst the reasons why the English under the early Tudors were ignorant of oceanic navigation was that they not only lacked the skill with which to build 'sufficient' ships, but were ignorant too of the hygiene, discipline, and logistics necessary for successful oceanic voyaging.

The pioneer explorers of the fourteenth and fifteenth centuries had been essentially pilots—masters of the art of pilotage—finding their way at sea primarily by observation of terrestrial objects while in sight of land, and by observation of the ship's course as indicated by the compass for the short periods that they were out of sight of land. But as their voyages lengthened, and when winds were unfavourable, they had had to practise the art of calculation, using the simple traverse table already described, in order to ascertain their mean course. They had also observed as they progressed southwards the Pole Star dropping lower and lower in the northern horizon astern. On such voyages its altitude had served as a rough guide to position. Almost insensibly astronomy and cosmography had been called in to their aid. That the earth was a sphere was common knowledge to the Christian scholars in the middle ages who calculated the Church's calendar, and to the Jewish cosmographers who advised the Mediterranean seamen. Early in the thirteenth century a text-book on the doctrine of the sphere, Sphaera Mundi, had been written by an Englishman, John Hollywood (Sacrobosco). It was in print in 1478, and a Portuguese translation was used by the Portuguese explorers. The possibility of the circumnavigation of the earth had been explained in the fourteenth century by Sir John Mandeville in his Travels, but, as he wrote, '... for that it asketh so long tymne and also there are so many perils to passe ... few men assay to go so, and yet', he added, 'it might be done'. The classical explanation of the cosmos known as the Ptolemaic was common doctrine to the learned schoolman and pilot.1 It supposed the earth to be fixed to the centre of the world, and that all the celestial bodies moved around it in their daily and yearly revolutions. The world consisted of elementary and celestial parts. The elementary part consisted of four elements, earth and water which made up the sphere or earth on which man dwelt, air which encompassed the earth, and fire which filled the space between air and the sphere of the moon. These four elements were subject to continual change one into another. Enclosing them were eleven concentric spheres, each one solid yet transparent. In order, outwards, these spheres were those of the seven planets: the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn. The eighth sphere was the firmament, and in this sphere were embedded the fixed stars. The ninth sphere was the crystalline Heaven or Second Mover; the tenth was the Primum Mobile or First Mover; the eleventh, added by the schoolmen, 'the Imperial Heaven, where God and His

1 Almost every navigational work of the sixteenth and seventeenth centuries contains a description of the Ptolemaic system. It remained standard into the eighteenth century.

6—A.O.N.
Angels were said to dwell'. This, like the earth, was immovable. The First Mover revolved from east to west in twenty-four hours, and by the violence of its motion carried all the other spheres, except that of the Imperial Heaven, around with it. Its axis formed the poles. Now, at the equinoxes the sun is on the celestial equator, the line on the celestial sphere equidistant from the poles. But the point on the celestial equator of this equinoctial rising marked by the fixed stars undergoes a slow change, known as the precession of the equinoxes, which returns on itself every 26,000 years—reckoned in those times to be 36,000 or 49,000 years. This motion was explained by the crystalline sphere having, in addition to its diurnal east-to-west motion, a slow west-to-east motion, which it transmitted to the firmament carrying the stars. Hence the crystalline sphere was also known as the Second Mover. Each of the seven spheres of the planets also had, in addition to the east-to-west motion imposed by the First Mover, a contrary west-to-east motion. This, which was their own and made around their own orbit, accounted for their wandering in the heavens. The orbital period of the moon was a month, of the sun a year, that of Saturn as long as thirty years. That is, thirty years elapsed before he returned to the same position relative to the fixed stars. The orbit of each of these wandering bodies was inclined to the plane of the celestial equator, and as each one circled in its course it 'declined' northward and southward among the fixed stars. The most important orbit, that of the sun, was called the ecliptic, since only on it did eclipses take place. Its inclination was about 23°. The five wandering stars, the planets, like the moon, had been observed to confine their motions within a belt 12° wide, 6° wide on either side of the ecliptic. This celestial girdle was known as the zodiac. The zodiac was divided into twelve signs, or sections, each 30° long. Six of them, Aries, Taurus, Gemini, Cancer, Leo, and Virgo, were northern signs, and measured northern declination; the other six, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, and Pisces, the southern signs, measured southern declination. They took their names from the various constellations against which the sun had been seen to rise in its annual westward movement through the heavens along the ecliptic when the zodiac was first devised. At the spring or vernal equinox the sun had risen in line with Aries. Accordingly the first point of Aries had been taken as the datum point of the ecliptic. Owing to the precession of the equinoxes, the sun no longer rose at the vernal equinox in line with Aries. However, the point of its rising was still called 'the first point of the constellation of Aries', and the position of the sun in the heavens, its declination each day of the year, was given according to its position in the zodiac. It was recognized by scholars that the four seasons and the variation of the length of the natural day in different parts of the earth were caused by the sun's declination. They also understood the causes of eclipses.1 By the early fif-

1 Taylor, E. G. R., *Ideas on the Shape, Size and Movements of the Earth* (1943) is a valuable brief treatise on the subject from classical times to the eighteenth century. See Pl. XII.
teenth century the division of the world into parallels of latitude north and south of the equator was already marked on some maps. Meridians of longitude, lines passed through the poles to indicate position east and west on the surface of the globe, were also sometimes drawn. This was in maps as distinct from charts. The works of Ptolemy, recently translated from the Greek by Byzantine scholars who had fled with them before the advancing Turks, were the source of these innovations.

Parallels of latitude indicate angular distance on the earth’s surface north and south of the equator, measured from the earth’s centre. Meridians of longitude indicate angular distance east or west of a selected prime meridian on the earth’s surface, also measured from the earth’s centre. The art of the navigator consists in determining as precisely as possible with the scientific instruments and information at his disposal the angular position of his ship north or south of the equator and east or west of his prime meridian. By means of this art, whether he be within sight of land or not he can be reasonably sure of his position on the earth’s surface. The problems that the voyages of discovery of the fifteenth century gave rise to involved those of developing instruments for measuring the movements of celestial objects and recording them, of devising simpler instruments and data suitable for use at sea, and mathematical systems of calculation whereby seamen could observe the position of celestial objects, and then calculate their ship’s angular position on the globe.¹

The great scientific achievement of the Portuguese pioneers was that they brought together and systematized navigational lore; and it was upon this approach to a scientific system of navigation that their discoveries depended. The problem facing them in their southward advance down the African coast was how to determine their position more accurately than by dead reckoning. At first they used the Pole Star. But the Pole Star did not indicate the true elevation of the pole. In the late fifteenth century it was about 3½° away from the pole, revolving about it in twenty-four hours. Today, owing to the precession of the equinoxes, it is barely 1° distant from the pole.² If the navigator was to determine his latitude by the Pole Star, he had to make a correction according to whether it was above, below, or to one side of the celestial pole.³ He determined the height of the pole by observing the position of the Guards of the Little Bear as they swung around the Pole Star. A system for determining the correction to be supplied to an

¹ See Fig. 1.  
² See Fig. 2.  
³ See Fig. 3.
THE PRECESSION OF THE EQUINOXES

Observe the polar distance of Polaris in A.D. 1000 (about 7°) and in 1955 (about 1°). In 1500 Polaris had a polar distance of about 31°.

The Guardians of Ursa Minor and Ursa Major are conspicuous.
observation of the Pole Star, known as 'The Regiment of the North Star', was devised, and from the latter half of the fifteenth century formed part of the navigator's fund of knowledge. The earliest written directions surviving are in the *Regimento do estrolabio e do quadrande*, dated 1509? (first edition 1495?). 'When the guards are on the West Arm the North Star stands above the Pole one degree and a half', is one of the rules.¹ If the navigator had just taken the altitude of the Pole Star, he would accordingly subtract $1^{\frac{1}{2}}$" from his observed altitude in order to find his latitude.

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**Fig. 3**

THE THEORY OF THE RULE OF THE NORTH STAR

It would appear that a simple instrument to show the rules mechanically was in use in the fifteenth century, though the earliest detailed description of one in print appears to be contained in Martin Cortes's *Arte de Navegar*, written in 1545, published in 1551. This (retaining the nomenclature of the earlier instrument which had contained a human figure as a pointer) consisted of a disc or volvelle marked with the four cardinal points termed also 'The Head', 'The Foot', 'The Right Arm', and 'The Left Arm', with an inner circle drawn on it marked with the degrees of correction to be applied to the Pole Star to find the true pole.² The navigator rotated a pointer in the form of a trumpet, marked with the seven stars in the constellation of Ursa Minor, until it coincided with the position of Ursa Minor, holding the instrument up meanwhile and sighting the Pole Star through a hole in the centre. Martin Cortes's particular pattern was a singularly good one, as it clearly showed the rotation of Ursa Minor, including the Pole Star, around the true pole. Unfortunately he used the astronomer Werner's erroneous (1541) Polar Distance of $4^\circ9'$ instead of the

¹ Brown, L. A., *The Story of Maps* (1949) is a somewhat erratic work on the development of cartography. It has helpful material on navigational matters such as 'The Rule of the North Star' quoted. It has a valuable bibliography. See also *The Book of Francisco Rodrigues*, Hak. Soc. Ser. 2, Vol. 90, where an early Portuguese navigation manual is reprinted and translated.

² See Fig. 4.
seamen's more accurate 3° 30' of that time, which, however, he included in the text, so that he unwittingly condemned his navigators to faulty observations.

Altitudes had been taken at sea in the fifteenth century by means of the quadrant, and the astrolabe. Of these the quadrant was the first to be adapted for use by seamen.¹ As used by the astronomers who advised the pilots sent out by Prince Henry the Navigator from 1415, it consisted of a quadrant of a circle, in wood or brass, graduated on the arc from 0° to 90° and fitted with two sighting vanes along one edge and a plumb-bob suspended from the apex. The altitude of the heavenly body (at first the Pole Star) seen through the sighting vanes was indicated on the arcuate scale by the plumb-line. It was not a practical instrument for shipboard use, but in the mid-fifteenth century, when the voyages were being made

¹ See Pl. III. Earliest known use of quadrant by mariner, 1460, of astrolabe, 1481.
down the African coast, this did not matter, for it was quite practicable for the pilot to go on shore to take his observation. The quadrant had the great advantages of simplicity of manufacture, a large scale, and the possibility of being used in the simple manner suited to the pilots’ limited mathematical knowledge. The pilot was as yet accustomed to using only bearing and distance charts, which had no latitude scales. At first, therefore, he was taught to use his quadrant as a means of measuring his linear distance south (or north) of his port of departure, generally Lisbon. He was taught to observe the altitude of the Pole Star at his port of departure when the Guards were in a given position and to mark this elevation on the quadrant scale, as indicated by the plumb-line. Subsequently during the voyage he observed the Pole Star when the Guards were in the same position and marked on the scale where the plumb-line now cut it. He was taught that every degree division represented 16½ leagues of 3 miles to a league. He was thus able to check by observation the distance sailed south (or north) of his datum port—if there were three divisions between the datum mark and that of his latest observation, he was 50 leagues south (or north) of his datum port. When in the middle of the century the Azores and Madeira were colonized it became the practice to mark the quadrant with the altitude of the Pole Star (with the Guards in a given position) at various points on the coast or at the islands, and the pilots then sailed down the coast to the ‘altitude’ and, if they were seeking one of the islands, having reached it, ran down this altitude to the westward to reach their landfall. As their mathematical ability increased, a latitude scale was added to their charts and they were taught how to convert their altitude observation by means of the rule of the North Star into observed latitude. But, as already remarked, the quadrant was not an instrument suitable for shipboard use, and with the growth of oceanic voyaging the need for suitable shipboard instruments became urgent. As pilots were now accustomed to working in degrees of altitude and latitude it seemed that they might now be able to make use of instruments such as the cross-staff and the astrolabe, both of which instruments, not requiring a plumb-bob, could be used at sea. They were, however, much more complicated than the navigator needed, being graduated to serve the astronomer and astrolger in making their observations.

In 1484 King John II of Portugal formed a commission to tackle the urgent problem of position-finding by navigators at sea and in the southern hemisphere, where they no longer had the use of the Pole Star. The result of their work, tested off Guinea in 1485, was simplified solar tables, derived from those (1473–78) of the Jewish astronomer Zacuto of Salamanca, enabling the daily declination of the sun to be calculated. ‘The Regiment of the Sun’ enabled the navigator to use the sun as a means of latitude determination.

He could thus find his angular position south of the equator as well as north of it astronomically.

Like the early Pole Star observations, the first solar ones had been used by pilots for checking their linear distance north or south of a port of departure. Declination had been ignored. A noon observation had been made, at say Lisbon, on the day of departure, and on several following days during the voyage. The angular differences observed had been converted into leagues and used as the measure of the northing and southing made good. But this method, pilots had been warned, was confined to the first few days' sailing from the 'datum' port. After that the cumulative effect of the daily change in declination rendered such observations useless. The next development had been the tabulation of the sun's noon altitude on each day of the year at Lisbon, and other 'datum' ports. By this means a pilot, on observing the altitude of the sun at noon, could compare it with that at the nearest convenient datum port, determine the angular difference, convert this into leagues and so find his linear distance north, or south, of the selected datum port. He had thus still been spared the problem of allowing for solar declination—but at the price of being able to use his solar observations only as a check on the distance run north or south from the last known position, and then only provided that his track from that was roughly north or south. Clearly, as soon as he began to round the curve of the Guinea coast, and while he was sailing along the thousand miles of coastline running east and west in the Gulf of Guinea, his solar observations, if converted into leagues, were grossly misleading. The same applied to any voyages that might be made to the westward. The crossing of the equator in 1481 made the preparation and use of solar declination tables imperative if Africa was ever to be rounded and the sea route to the East found out. So the tables were prepared and the pilots were taught to apply declination to their solar meridian altitude observations. By this means they were able for the first time to find their latitude in any part of the world.

When finding the latitude by Polaris the navigator had learnt to apply the rule of the North Star in such a way that he eliminated the effect of the rotation of Polaris around the celestial pole and thus found the true elevation of the pole above the horizon. The angular distance between the pole and the horizon was, he learnt, the same as the angular distance between his place of observation and the equator, measured from the centre of the earth—in a word, his latitude. This is because, owing to the vast distances of Polaris (and of all stars) from the earth, and because of the relatively minute size of the earth, the angle made by Polaris and an observer's horizon on the earth's surface is, for all practical purposes, the same as the angle made by Polaris with the rational horizon passing through the earth's centre. This is the same as the angle, at the earth's centre, between the observer's zenith and the equator, which is the angle of his latitude. Thus, suppose the altitude of the celestial pole be found to be $48^\circ$, then the celestial pole makes an angle of $48^\circ$ with the rational horizon at the
earth's centre. Now the zenith is, by definition, 90° overhead from the horizon. Therefore the distance between the celestial pole and the zenith, the zenith distance, is $90\,^\circ - 48\,^\circ = 42\,^\circ$. But the celestial equator is also, by definition, 90° distant from the celestial pole. Consequently the zenith must be 48° distant from the celestial equator. As the zenith is vertically above the observer's position on the earth's surface, the observer must be in latitude 48°, that is 48° from the equator. In short, the angle between the

![Diagram](image)

**Fig. 5**

**THE THEORY OF THE DETERMINATION OF LATITUDE BY OBSERVATION OF THE POLE STAR**

Altitude of the Pole Star, corrected by the Rule of the North Star, 48°, therefore latitude of observer is 48° N.

celestial pole and an observer's horizon is the same as the angle between the celestial equator and the observer's zenith, consequently it is equal to his latitude.¹

To find the latitude by the sun the navigator was taught to find the altitude of the sun by observation of its meridian passage, when its height above the horizon is greatest, and to write this down. He was then taught

¹ See Fig. 5.
how to look out the sun's declination for that day in his 'Regiment of the Sun', and to write that down beneath the entry of the sun's observed meridian altitude. He had now to consult certain written rules instructing him how to convert these astronomical data into his angular position north or south of the equator. The rules depended upon whether he was north or south of the equator, whether the sun's declination was north or south of the celestial equator, and whether it was greater or less than the latitude when both had the same name. The rules were framed so as to determine first the altitude of the celestial equator above the observer's horizon. Having found this he was taught that the result subtracted from 90° gave him his latitude. Thus, for example, if the navigator were well north of the equator, observed the sun's meridian altitude to be 62°, and found its declination to be 20° N, his rules instructed him to subtract the sun's declination from its altitude in order to find the elevation of the celestial equator—in this example he would find it to be 42°—and then to subtract this angle from 90° in order to obtain his latitude—in this example 48° N. Had the navigator taken a similar observation six months later, on looking out his declination he would have found it to be 20° S and he would have had to apply a different rule. In being taught to reduce the sun's observed altitude into terms of the celestial equator's altitude and then to subtract this from 90°, the navigator was really being made to measure the angle between the celestial equator and his zenith, which, as we have seen in discussing the Pole Star sight, was the measure of his latitude. It would therefore have been simpler if the navigator's instruments—quadrant, astrolabe, or cross-staff—had been graduated with zero at the zenith and 90° on the horizon instead of, or, since he might need them for star sights, in addition to, being graduated from zero on the horizon to 90° at the zenith. By this means, as a result of observing the sun's meridian altitude he could have read off the sun's observed zenith distance on the scale on his instrument. The rules of how to apply declination would then have been worded so that latitude was obtained simply by adding or subtracting the declination from the zenith distance. In general the more roundabout method was employed. The explanation for this would seem to lie partly in the fact that the instruments of observation had originally been designed primarily for measuring the altitude of celestial bodies and therefore, on adaption to nautical use, re-

1 These rules were often expressed in very involved terms, and included observation of the direction of the observer's shadow. They can nowadays be expressed by the simple formula, \( l = d - Zm \), where the latitude, \( l \), is expressed as a function of the sun's declination, \( d \), and of the meridional zenith distance, \( Zm \), northern declination and latitude being considered as positive (+ve), southern as negative (−ve), and \( Zm \) as positive or negative according to whether the observation was made towards the north or south.

2 See Fig. 6.

3 By the opening of the sixteenth century some Portuguese navigators were observing zenith distance instead of altitude, and were using appropriately engraved instruments, but the Spaniards, from whom the English learnt so much, do not appear to have done so until much later.
tained this scale; partly in the adaption to nautical use of thirteenth-century Spanish rules originally designed for the determination of latitude by measuring altitude; and partly in nautical tradition, continuance of the practice of observing the sun’s altitude for position-finding although it was

![Diagram](image)

**Fig. 6**

**THE THEORY OF DETERMINATION OF LATITUDE BY OBSERVATION OF THE MERIDIAN ALTITUDE OF THE SUN**

- Sun’s altitude: 62° S.
- Sun’s declination: 28° N.
- Altitude of the equinoctial: 48° N.
- Latitude of the observer: 48° N.

now angular distance from the equator and not linear distance from a ‘datum’ port that was required. The existing astronomical tables expressed the sun’s annual (apparent) motion around the earth in terms of its angular movement, through each of the twelve signs of the zodiac, along the ecliptic.
What the navigator wanted was a record—a prediction—of the sun’s angular position north or south of the equator. Sometimes he was given tables to enable him to convert the sun’s recorded diagonal movement—relative to the celestial equator—along the ecliptic into its vertical movement north or south of the celestial equator.\(^1\) Sometimes the conversion was done for him, the results being tabulated for noon for each day of the year.\(^2\) In either case the most obvious thing to do with the declination when found, since the result was expressed in terms of the sun’s position north or south of the celestial equator, was to treat it as a correction of the sun’s altitude for finding the celestial equator’s altitude. That it could serve equally well as, and be tabulated as, a correction of the sun’s zenith distance for finding the celestial equator’s zenith distance was not generally recognized. The result was that the method of finding latitude from the sun’s meridian altitude was usually more laborious than was strictly necessary. Moreover the rules formulated were not always expressed as clearly as they might have been. In fact, by the sixteenth century the seaman who could call himself a navigator because he could find his latitude by the rule of the Pole Star could no longer do so unless he could apply with equal confidence and accuracy the much more extensive and complicated Regiment of the Sun.

Indeed in order to justify the appellation of navigator he had to have a firm grasp of the theory of astronomical observations for position-finding and, in order to be able to put it to practical use, to be something of a mathematician.

Unlike the Pole Star’s Regiment, which scarcely changed appreciably in a century, the Regiment of the Sun remained reasonably accurate for only about twenty years. It had then to be recalculated. In addition to this, due to the fact that the earth completes its annual motion in about 365\(\frac{1}{4}\) days and not exactly in 365, the sun’s daily position in the ecliptic changes during every cycle of four years: by the sixteenth century, therefore, the best navigators used almanacs with four declination tables. These gave the sun’s declination in leap years and in the first, second, and third years after leap years. Other navigators were content with the simpler single-table type of almanac originally calculated for the leap year March 1475 to February 1476. As the order of accuracy of the four-year tables was to within 5’ to 10’, even this single table was in practice far more accurate than was necessary. The navigator observed without the aid of optical instruments. Telescopes were not developed until 1608, and optical sights later. Open-sight observations at this time by even the most skilled navigator were rarely more accurate than to within half a degree (30’).

The Portuguese Regimento do estrolabio e do quadrante of 1509, already noticed, was a sort of nautical almanac. But besides containing the rule of the North Star, the Regiment of the Sun, a calendar, and declination table for a leap year, it included a traverse table for raising and laying a degree of latitude, and Sacrobosco’s explanation of the universe—De

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\(^1\) See Pls. XIII, XIV and XV.  
\(^2\) See Pl. XVI.
Sphaera Mundi. It was both the first of the printed nautical almanacs and the first of the printed manuals of navigation.

The Arabs had for long used the kamal at sea. The primitive one consisted of nine rectangular boards of different sizes threaded on a length of cord through a hole in the centre. One or other of the boards was held out towards the star to be observed, the end of the cord being gripped between the teeth or in the hand and held close to the eye. The board chosen was that which allowed of the horizon being just seen under the lower edge and the star on the upper. Thus according to the board used, the altitude of the star was known. Later versions consisted of a rectangular board, its length being twice its breadth, threaded on a cord with seven knots along its length. Thus with one kamal fourteen different altitudes could be observed. This simple instrument was first made known to European navigators by the Arabian pilot whom Vasco da Gama employed to cross the Indian Ocean in 1498. It may have inspired the adaptation of the complexly graduated astronomer’s cross-staff for nautical use.
in the early sixteenth century. The mariner's cross-staff consisted of a straight staff, four-square, graduated on one side in degrees and minutes. It was commonly made of pear or boxwood. A wooden cross-piece made so as to slide evenly along the staff formed the other part of the instrument, which was usually about 3 feet long and about \( \frac{3}{4} \) inch in cross-section; greater length caused increased handling difficulties in a breeze. Except that one end was held to the eye, the cross-staff was used like the *kamal*, the cross taking the place of the board, but it had the advantage of having the staff graduated from about 20° to 90°. One method of graduation and of construction can be followed in detail in Martin Cortes's book on navigation, from the English translation of which the drawing showing the method of graduation is copied.\(^1\) He was the first author to publish, for the guidance of seamen, how to make a cross-staff. At the best of times the cross-staff was not an easy instrument with which to take accurate observations. The successful simultaneous sighting of star or of sun's centre and the horizon, done by the rapid blinking of the eye, was a difficult knack to acquire. Add to this the error, known as parallax, caused by the observer not holding the eye end of the staff at the exact spot against his cheek-bone which ensured that its end coincided with the eye's centre, the difficulty of keeping the cross in the plane of the meridian, the vertical plane, throughout the observations; add to that the fact that the shooting of the sun at its meridian altitude was a quite lengthy business entailing the retention of an arm-aching posture and eye-blinding attitude for minutes on end, and something of the skill and long practice that were necessary can be appreciated.\(^2\) The exact time of the sun's meridian passage being unknown, the navigator had to shoot it for some minutes beforehand. As soon as he found that to keep the sun's centre and the horizon just in view he was sliding the cross no longer towards his eye but away from it, he knew the sun had passed its maximum altitude. To gauge this instant was no easier than to retain a steady posture on a heaving deck. As originally developed the cross-staff had definite limitations. It could not be used to sight the sun below 20° of altitude because its graduations ended there, nor in practice above 60° of altitude, although it was graduated up to 90°. The cause was two-fold. In the first place the observer's scan of eye was limited physically to a maximum arc of 60°; in the second place, even if he could shoot the sun above 60°, the graduations on the staff became so small that the slightest error in observation made a difference of degrees to the observed altitudes. Also, it must be remembered, in latitude 40° N, approximately the latitude of Lisbon and the Azores, the sun is already transiting 50° above the southern horizon in the middle of March—the equinoxes. This altitude increases, at first rapidly, with the advancing year. At mid-summer the sun transits 73\( \frac{1}{2} \)° above the horizon. Not until September does it reach the 60°'s again; not until the equinox—23 September—does it transit once again 50° above the horizon. Thereafter, in the winter

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1 See Fig. 7. The earliest reference to a nautical cross-staff is c. 1514.

2 See Pl. XVII.
months, it transits lower and lower over the horizon until, at midwinter, it makes its lowest meridian passage at an altitude of $26\frac{1}{2}$°. Thus in latitudes below about $35^\circ$ N (below $35^\circ$ S, in the winter months) the cross-staff could not be used for solar sights. A navigator in more northern waters could use it in the summer months, however, though not in the winter months, as the following table shows:

<table>
<thead>
<tr>
<th></th>
<th>Sun's Declination</th>
<th>Sun's Meridian Passage Altitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vernal Equinox 21 March</td>
<td>20 N</td>
<td>70 S</td>
</tr>
<tr>
<td></td>
<td>50 N</td>
<td>40 S</td>
</tr>
<tr>
<td>Summer Solstice 21 June</td>
<td>20 N</td>
<td>86\frac{1}{2} N</td>
</tr>
<tr>
<td></td>
<td>50 N</td>
<td>63\frac{1}{2} S</td>
</tr>
<tr>
<td>Autumnal Equinox 23 September</td>
<td>20 N</td>
<td>70 S</td>
</tr>
<tr>
<td></td>
<td>50 N</td>
<td>40 S</td>
</tr>
<tr>
<td>Winter Solstice 21 December</td>
<td>20 N</td>
<td>46\frac{1}{2} S</td>
</tr>
<tr>
<td></td>
<td>50 N</td>
<td>16\frac{1}{2} S</td>
</tr>
</tbody>
</table>

In latitude 60° N the sun's altitude becomes respectively 30°, 53\frac{1}{2}°, 30°, and 61°.

Between roughly 20° N and 20° S, the cross-staff could be used at no season of the year—even at midwinter the sun's altitude was too great.

The medieval astrolabe was an instrument of exquisite workmanship which enabled the astronomer not only to observe the altitudes of heavenly bodies but also to plot their positions and follow their motions in the sky on a planisphere. Essentially it consisted of a brass disc engraved with a stereographic projection of the celestial sphere covered by a net-like plan of the heavens, graduated in degrees around its perimeter, fitted with a suspension ring at its top edge and a rotatable sight bar or alidade at its centre. Stripped of all its astronomical accretions it became a sea-astrolabe. The earliest ones appear to have been of wood, or discs of brass, but an improved cast brass model was later developed. It was a thick, heavy open-work ring of solid brass, to resist corrosion, reduce wind-resistance, and yet gain stability, suspended from a ring, graduated in one quadrant from 0° to 90°, and fitted with an alidade consisting of a bar with two sighting vanes, not so widely spaced as to make sighting difficult, each having a small and

1 On observations made during Frobisher's second voyage to the north-west (1577) we read:

here the North Starre is so much elevated above the Horizon that with the staffe it is hardly to be well observed and the degrees in the Astrolabe are too small to observe minutes. Therefore wee alwaies used the staffe and the sunne as fittest instruments for this use.


2 See Pls. XVII and XVIII.
large sighting hole. To reduce wind resistance further, the size of the astrolabe was kept down to 5 or 6 inches in diameter, even though this had the disadvantage of reducing the size of the graduation and so the accuracy of observations. English navigators, when later they took to the use of the astrolabe, preferred larger ones, 6 or 7 inches in diameter, and with wider-spaced sighting vanes. By then the astrolabe generally had two quadrants divided into 90°, so that the navigator could avoid instrument errors caused by faulty graduation or suspension. By taking sights in succession, using each quadrant, he could check his instrument for error.¹

Once again we are indebted to Martin Cortes for the earliest description of the method of making, graduating, and using the astrolabe. For taking a sight it was suspended not by the thumb but ‘by a threade or lyne’ held in the hand. The navigator used a pair of sighting holes ‘as bigge as may conteyne a great pinne’ for shooting a star, and another ‘so subtile and small as a fyne sowyng needle’ for shooting the sun.²

As indicated by the now numerous almanacs in print, the navigator was no longer confined to the use of the Pole Star at night. The stars, as they steadily rise and set across the night sky, rotate around the pole. Those conspicuous ones whose distance from the pole had been tabulated could be observed at their meridian transits, either north or south, above or below the pole, exactly as was the Pole Star, Polaris. The reason why Polaris was preferred was that it could be observed not only at the time of its meridian transits but, thanks to the rule of the Pole Star, at any time; because it was easy to pick out and easy to identify; because, just like shooting the sun, the meridian transit of stars more distant from the pole meant judging the moment of transit not by the relative positions of Guards but by the change in altitude; because the best time for taking star sights with a cross-staff is at sunset and dawn when the stars are still bright in the heavens and the skyline sharp and clear against the diffused light of the sun, and Polaris was the only star which would probably then be observable: the others might transit hours earlier or later when the horizon was indistinguishable from the night sky; and because the position of Polaris had been pretty accurately observed, the positions of other stars not always so accurately. However, the navigator in low northern and in southern latitudes had no choice. His favourite star was in the Southern Cross, first seen in 1455, for which a ‘Rule’, on the lines of that of the Pole Star, had been evolved, using the Southern Cross itself as a ‘guard’, by John de Lisboa in 1505. The rule was that when the head and foot of the Crozier, as the Southern Cross was often called, were in line with a plumb-line held out before the navigator, the Cock’s Foot was 30° above the south pole. Therefore, having taken the altitude or height of the Cock’s Foot above the horizon, he subtracted 30° from the altitude, the

¹ See Pl. III. The earliest drawing of a mariner’s astrolabe is by Diego Ribeiro on his world planisphere of 1525. Like Cortes’s it was of sheet brass. See Cortesão, A., ‘Notes on the Castiglioni planisphere’, Imm Mundi, Vol. 12.
² See Pls. XVIII and XIX.
XII. The Ptolemaic World System.
XIII and XIV. DECLINATION TABLES, 1545-1688.
Plate XIII gives the first table for calculating the true place of the sun in the Zodiac. The table for the months July (misprinted June) to December is shown. Plate XIV gives the Table of the Equation of the Sun. Whereas Medina in his manual of 1545 gave the sun’s declination in terms of its distance at noon north or south of the equinoctial (see Plate XVI), Cortes retained the customary astronomical method by which it was expressed in terms of the degrees of the signs of the Zodiac—the true place of the sun in the Zodiac. This method necessitated conversion into declination. The method was as follows: in the first table, ‘The Table of the true place [of the sunne]’ (Plate XIII), the month was looked out at the head of the table, the day of the month on the column on the left; then against the day, under the month was given the sun’s position in degrees and minutes of the sign of the Zodiac shown under the month heading; to the degrees and minutes thus found was added ‘The Equation of the Sun’ for the year; this was found in the next table, ‘the Table of the Equations of the Sunne’ (Plate XIV); the sum of the two sets of figures was the true place of the sun in the Zodiac, except that in common or non-leap-years, from the end of February to the end of December 1 had to be subtracted from the sun in order to get the true place. The true place of the sun having been found, the declination was obtained from the third table (Plate XV). This contained at the head the Signs of the Zodiac in which the sun’s declination increased; on the left the degrees of the Signs from 0 to 30, downwards; at the foot the Signs in which the declination decreased and on the right the degrees of the signs from 0 to 30, upwards. If the true place of the sun had been found in minutes as well as degrees the declination had to be obtained by interpolation.
Plate XV gives the third table involved in the calculation of the declination of the sun. Cortes gave the following example:

'In the year 1546 the tenth day of September, the Sunne shalbe in 26.D.38.M. of Virgo [1546 was not a leap-year]: and to the 26 D. presyse, shall correponde 1 D. 36 M. of declination. And to veryfe the declination that commeth to 38 minutes, which is more of the 26 D. (which is one D. 36 M.) to the declination of 27 D. whiche is 1 D. 12 M. The difference is 24 D. Of these you must take such part as is 38 of 60 which are almost twoo terces. Then two terces of 24 are 16 which must be taken of one D. 36 M. which correponde to the 26 D. of Virgo: because the declinations go decreasyng [the sun was approaching the equinoctial on its southerly, autumnal descent], and remayneth 1 D. 20 M. And if the declinations increase, you must addde thereto, as you take away when they decrease.'

Thus the declination was 1 20° N.

*The signs of the Zodiac:*

<table>
<thead>
<tr>
<th>Aries</th>
<th>Libra</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\equiv)</td>
<td>(\equiv)</td>
</tr>
<tr>
<td>Taurus</td>
<td>Scorpio</td>
</tr>
<tr>
<td>(\equiv)</td>
<td>(\equiv)</td>
</tr>
<tr>
<td>Gemini</td>
<td>Sagittarius</td>
</tr>
<tr>
<td>(\equiv)</td>
<td>(\equiv)</td>
</tr>
<tr>
<td>Cancer</td>
<td>Capricorn</td>
</tr>
<tr>
<td>(\equiv)</td>
<td>(\equiv)</td>
</tr>
<tr>
<td>Leo</td>
<td>Aquarius</td>
</tr>
<tr>
<td>(\equiv)</td>
<td>(\equiv)</td>
</tr>
<tr>
<td>Virgo</td>
<td>Pisces</td>
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<tr>
<td>(\equiv)</td>
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<tr>
<td>Año</td>
<td>Mayo</td>
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<td>-----</td>
<td>------</td>
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<tr>
<td>Abril</td>
<td>Mayo</td>
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<tr>
<td>1º</td>
<td>vlí.</td>
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<tr>
<td>2º</td>
<td>vi.</td>
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<tr>
<td>3º</td>
<td>vi.</td>
</tr>
<tr>
<td>4º</td>
<td>vi.</td>
</tr>
<tr>
<td>5º</td>
<td>vi.</td>
</tr>
<tr>
<td>6º</td>
<td>vi.</td>
</tr>
</tbody>
</table>

XVI. DECLINACIÓN TABLE FOR 'ABRIL-MAYO-JUNIO'
2ND YEAR AFTER A LEAP YEAR, 1545.
Libro tercero del altura del Norte.

XVII. Taking a Pole-Star Sight with a Cross-staff, 1545.
Libro segundo.

XVIII. Taking a Meridian Altitude Observation of the Sun with an Astrolabe, 1545.
To take the altitude of the Sunne, hange by the Azimuth on the ringe, and set the Alumbala against the Sunne. Affix a hole to part it downe in the quarter that is grudiate, until the beams of the Sunne enter in by the little hole of the tablet or cased plate, and precisely by the other little hole of the other tablet. Then looke upon the lyne of confidence, and bowe manye degrees at theuyth in the quarter that is graduate, begynneinge to the horizontal line so many degrees of the height hath the Sunne. In like maner shall you doe to take the altitude of any other Starre lookeinge through the grete holes.

XIX(a). Spanish Sea-astrolabe of 1545.
XIX(b). Sea-astrolabe, probably Portuguese, of 1555.
A brief Description of

Here followeth the Mariners Quadrant.

XX(a). The Shipman's Quadrant or The Mariner's Quadrant—Blundeville, 1636.
XX(b). The Shipman's Quadrant of Humphrey Cole's 2-ft. Astrolabe of 1575.
XXI. The Plane Chart's Loxodromes, 1636.
XXII. Chart of 1561 of the Atlantic.
XXIII. The Mediterranean, 1542.
remainder being the elevation of the pole, the latitude. When the Cock's Foot was 30° above the horizon he knew he was on the equator. The charting of the heavens of the southern hemisphere, it may here be remarked, was a task the explorer-navigators of the fifteenth century were the first to tackle.  

The navigator shot the sun when the sky was clear by turning the astrolabe and its alidade until the spot of sunlight from the upper sun-sighting hole fell on the lower sun-sighting hole. He did not peer at the dazzling sun. If the sun was hazed or he was observing a star, it appears that assistants aided him in his observation, one holding the astrolabe, a second reading the index.

The original sea-astrolabe was not a very satisfactory instrument. The users found it impossible to take observations within 4° 5' however little the ship rolls'. But the development of the cast brass model, completed by the middle of the sixteenth century, turned it into a useful instrument. Even so the navigator preferred to go on shore and use it there if he wanted to be sure of his latitude to within half a degree. In tropical waters, for lack of a better instrument, he had to use it, unless he could find a star suitable for a cross-staff morning or evening sight.

While the Portuguese explorations down the coast of Africa had raised the problem of latitude in an acute form, and had resulted in a solution by 1485, the rounding, two years later, of the Cape of Good Hope by Diaz, after he had struck boldly out into the ocean in order to clear the head winds off south-west Africa, had raised another problem, that of longitude. The daring voyage of Columbus in 1492, the partition of the world between Portugal and Spain a year later, and the triumphant voyage of Vasco da Gama in 1497 had made the solution of this problem more urgent.

1 A sixteenth-century English writer on navigation (Blundevile, in his Exercises, 1594) observes:

'The ancient Astronomers . . . did never describe any Starre to be more nigh with the South Pole, than that which is called Canopus, which is a faire bright starre of the first bignesse, and according to the Table of Copernicus, is distant from the South Pole 38 degrees and 4. But those that have sailed in the South Seas of latter daies, have found out other stars unknowne to the ancient Astronomers.'  

M. BLUNDEVILE His Exercises, containing sixe Treatises, the titles wherof are set down in the next printed page: which Treatises are verie necessarie to be read and learned of all young Gentlemen that have not bene exercised in such disciplines, and yet are desirous to have knowledge as well in Cosmographic, Astronomic, and Geographie, as also in the Arte of Nauigation, in which Arte it is impossible to profite without the helpe of these, or such like instructions. To the furtherance of which Arte of Nauigation, the said M. Blundevile speciallie wrote the said Treatises and of meere good will doth dedicate the same to all the young Gentlemen of this Realme, London. Printed by John Windet, dwelling at the signe of the crosse Keies, neere Paules wharffle, and are there to be solde. 1594.

2 The error of early astrolabe observations at sea is quoted from Cabral's voyage of 1500, in Prestage, E., The Portuguese Pioneers (1933), a valuable survey of early Portuguese achievements.

8—A.O.N.
Unfortunately, owing to the revolution of the earth, there is no fixed celestial point of reference such as the pole or equator. How could navigators fix their position in an east and west direction, astronomically? It was realized that the essence of the problem, for which no practical solution was to be found for 300 years, was time. When the sun is overhead at any point on the earth’s surface it is noon at that point and at all points along the meridian running through it. It is noon by local time. At any position east of it, towards the sun’s rising, it is already past noon; west of it, it is not yet noon. If the difference in time could be found, could not this be used to find the position of these places with reference to the one where it was, say, already noon? As the earth in 24 hours rotates through 360°, in one hour it rotates through 15°, in one minute through 15′. Clearly position east and west could be found if time could be accurately measured. This method, first proposed by Gemma Frisius in 1522, we find explained by William Cunningham, the first Englishman to write on cosmography, in his book, The Cosmographical Glasse, written in 1559.1 But the watches he recommended ("such as are brought from Flanders, and we have them as excellently without Temple barre") were accurate to within only a quarter of an hour a day. To determine longitude to within half a degree at the end of a six weeks’ voyage, the error must amount to not more than two minutes in all, or about three seconds a day!

Columbus had tried to find his longitude on his voyages of 1494 and 1504 by finding the difference in time between the occurrence of eclipses based on his observations and the times predicted, probably in Regiomontanus’s Calendarium. But the difficulty in observing eclipses was to ensure that the same moment during the eclipse (which is a long drawn-out occurrence) was observed. Moreover, apart from the fact that eclipses are infrequent, lack of accurate instruments of observation and of a sufficiency of accurate observations over a period of time long enough to establish accurately the laws of the moon’s motions rendered the lunar tables far from accurate. They were to remain so until the eighteenth century.

Another astronomical method for finding longitude attempted was that of the conjunction of the moon and a planet. It has been explained that the First Point of Aries was used as a datum point. Astronomically the half-meridian passing through it served just as the meridian of Greenwich does today for terrestrial longitude. By observing the position and time of transit of planets and stars at the equinoxes, their declination and right ascension, their angular distance measured in time from the First Point of Aries can be recorded in an almanac or plotted on a star map. This makes it possible to find longitude by the occultations of the planets by the moon’s disc, that is by observations made when the declination and right ascension of the moon and a planet are identical.

1 Cunningham, W., The Cosmographical Glasse (1559). The full title will be found on p. 98. See Pl. XII for Cunningham’s illustration of the Ptolemaic system of the world.
William Cunningham gave an example of how he had looked up the positions of Regulus and of the moon, had observed their distance apart, and knowing the rate of change of bearing of the moon to be 35° every hour, had found the difference in time to be 16 minutes, and so his position 4° W of Antwerp. But such methods, apart from the unavoidable inaccuracies of the almanacs, were quite impractical for the ordinary navigator.

Columbus, the Portuguese pilots, and later navigators also tried to determine longitude by observing the change in variation of the compass. From being easterly in the Mediterranean it diminished to zero in about St. Michael's in the Azores, and then became westerly, increasing in amount the farther westward they sailed. They attempted by means of this phenomenon to relate their position east or west in terms of longitude. The difficulty was to find the variation. At first this could only be done, and then only in the middle and lower latitudes, by taking the compass bearing of the Pole Star, rectifying it by the 'Rule of the North Star', and so finding the difference. Meantime the need for accurate direction-finding increased the urgency of determining the variation and by the first quarter of the sixteenth century special instruments and techniques had been evolved for observing the morning and evening amplitude of the sun. But none of these methods, nor of their later refinements, ever gave results sufficiently accurate to determine longitude, even when the longitude of a position of given variation was known. This position, of course, was known only by dead reckoning. The method suffered from fundamental limitations.

Besides wanting to find variation accurately in the hope of being able to solve the problem of longitude, the navigator crossing the oceans needed to be able to determine his true course. Since he found that variation constantly altered during his voyage, if he wished to keep to an observed latitude, he had to relate his direction accurately to true north. This he could do only by means of his compass, and then only if he could correct it for variation. Consequently in order to rectify his course he now found his variation whenever possible. He found it also in order to rectify his bearings when he was fixing his position by compass bearings. No longer could he afford to steer by compass course and fix his position by compass bearing as he had done hitherto, and as the mariners in the Mediterranean and north-west Europe continued to do. If he was to make his landfall successfully after an ocean passage, he had to steer by true and not magnetic courses. One result of this was that if he was wise, he now always aligned his compass needle with the north-south line of his fly. If he did not, on correcting for variation he got terribly confused as to his true course.

Lack of a means of finding longitude made it essential to compute accurately the distance run. The navigator still relied on estimation. To measure time he used a sand-glass or else repeated a series of words, twice if the ship was going slowly. This patter was supposed to be equivalent in time to that measured by a minute or half-minute glass. Gunners in the Navy still did this in the writer's youth at sea. When firing saluting guns they
timed the firing of the salvoes by repeating rhyming lines beginning: 'If I wasn't a gunner I wouldn't be here. Fire One!'

To enable time to be found astronomically at other times besides noon, Gemma Frisius, the brilliant cosmographer to the Emperor, invented an astronomical ring-dial. There were many subsequent variations of this instrument, all seeking to ensure greater accuracy, and they were very popular on shore until superseded by reliable watches in the eighteenth century. At sea, despite all the ingenuity of the designers, they ever remained of little practical value. A typical one consisted of a brass meridian ring with an adjustable shackle and ring to enable it to be suspended at the point equal to the latitude engraved on it. To the meridian ring was pivoted, so that it could be laid flat when not in use, an equatorial or hour ring. In the position of the polar axis was a metal plate with a long slot in it with a sliding pin-hole block adjustable for the sun's declination. This set, and the meridian ring hung in the plane of the meridian, the spot of sunlight fell on the hour on the equatorial circle. Martin Cortes devised a universal dial to meet the same purpose. It was to all intents and purposes a sun-dial and thus of little practical use at sea. Probably under the impetus of the nautical need for time-keeping the art of dialling developed to a high degree in the early sixteenth century, particularly in Germany and Flanders where the finest metal craftsmen and mathematicians lived in close communication with the navigators, cosmographers, and geographers of the rest of the Empire. But all time-instruments depending on the sun suffered from what were for seamen fundamental defects. They had to be aligned accurately, north and south, and set accurately, for latitude, and held stationary. Towards noon the sun's rapid rate of change of bearing made them particularly unreliable. The writer has never succeeded in reading the time more accurately than to within 15 minutes, using a universal ring-dial as a seaman had to do. However, by long practice navigators did estimate time and their speed sufficiently accurately to reach their destinations, though generally not when they expected to reach them.

It was one thing to steer a course, quite another to 'make good' that course. The sixteenth-century ships were very leewardly. No doubt the navigator did what the Dutch navigator Wagenaer recommended in his *Spieghel der Zeevaart* of 1585 should be done, and what continued to be done to modern times—he cast a line astern attached to a piece of lead-weighted wood with a pole in it, and measured the angle of leeway by means of a compass on the poop. As for currents, local ones might be known, though as we have seen their speed was not. The north-eastward drift of the Gulf Stream in the Atlantic was early recognized and later commented upon by the English navigator Frobisher in the course of his

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1 This consisted of three brass rings, one of them with sighting vanes. It is clearly depicted in the portrait of the great cosmographer reproduced in Stevenson, E. L., *Terrestrial and Celestial Globes* (1921), Vol. 1. The ring-dial could also be used for finding latitude.
voyages to the north-west, but again its speed was unknown. All that was known was that it was liable to set ships upon the coasts of Europe before their time.

In an endeavour to help navigators to compute their course between places of known, or at least recorded, latitude and longitude, Gemma Frisius in the 1540s designed a shipman’s quadrant. It seems to have been little used, possibly because of the cartographical error underlying it, probably because of the inexactitude of geographical positions and the lack of a settled prime or zero meridian. As for the prime meridian, some navigators took ‘the westernmost part of Africa’, others ‘St. Michael’s in the Azores’, others again ‘the Canaries’. All differed, and none was definite. Even after years of experimental traverses, at the close of the sixteenth century the position of London, taking the extreme west of St. Michael’s in the Azores for the prime meridian, was 6° 4’ out, Madeira 4° 20’, St. Vincent 6° too far west. As so often, the scientists produced instruments of exquisite accuracy, or theoretical solutions to problems, which were yet useless or little used for lack of the necessary data which would make them practical.

The shipman’s quadrant consisted of a square divided into four equal parts or quadrants by two straight lines which crossed each other at right- angles in the centre and represented the prime meridian and the equator. They also represented the north and south, and east and west rhumbs of a compass fly centred upon their point of intersection, and whose perimeter represented the horizon. Two sides of the square were divided both above and below the equinoctial line into 90° representing north and south latitude, and the top and bottom sides were divided to right and left of the meridian into 90° representing cast and west longitude. Knowing the latitude and longitude of the place where he was, the navigator was supposed to use the quadrant to find the course that should take him to a place of which also he knew the latitude and longitude. He was to find this by subtracting the lower latitude from the higher, and, if the destination lay north of him, stretching a thread (a favourite instrument) across the northern latitude scales at the point corresponding to the difference in latitude. He had then to subtract the lesser longitude from the greater (longitude being measured eastward from the prime meridian through 360°) and marked the difference by another thread stretched between the longitudes scales, using the left-hand scales if the destination lay to the east. Where the two threads crossed was supposed to be the position of the destination. The course to it was supposed to be indicated by the underlying rhumb. The fundamental error in using the instrument in this manner was that a given difference of longitude was treated as being of the same linear distance at different latitudes, whereas because of the convergence of the meridians towards the poles, it is not. Nor was correction practicable by means of the table of the length of a degree in different latitudes given in manuals such as Cortes’s, consequently the course found was incorrect

1 See Pl. XX.
As stated in the previous chapter, the Italian and Catalan pilots of the Mediterranean had for centuries used charts, now known as bearing and distance charts. The earliest surviving one, known as the Carta Pisana, was drawn c. 1275, and is remarkably accurate. By the sixteenth century the charts of Europe extended as far south as Morocco and sometimes the Congo, and as far north as the British Isles and Flanders. Farther north they did not go, as the Mediterranean seaman's trade routes ended there. Farther south they did not extend, as the Portuguese had kept secret since 1504 all their detailed charting south of the Congo, and continued to do so until King Philip II of Spain usurped the throne in 1580. The Italian and Catalan pilots had passed their cartographical skill to the Portuguese. In the century and a quarter after rounding Cape Bojador the latter surveyed and charted about 300 miles of new coast a year, basing much of their eastern information on the charts used by the Arabian seamen.\(^1\) By 1509 they had a chart of surprising accuracy covering the Arabian Sea and the Indian Ocean between the Cape of Good Hope and India and Ceylon.\(^2\) Portuguese pilots served Spain. Like the Italian pilots they taught the Spaniards the arts of pilotage, navigation, and hydrography.

In the fifteenth century the Casa de Guinea e India at Lisbon included an organization equivalent to a modern hydrographic office, at whose head was a cosmographer-in-chief. He was assisted by cosmographers whose business it was to draw and to correct charts and to compile books of sailing directions and, no doubt, as in the similar Spanish organization of the sixteenth century, to assist in the instruction of pilots. By 1508 the Spaniards had established as part of the Casa de Contratación at Seville—their equivalent of the Portuguese Casa de Guinea e India—what was virtually a national school of navigation. It was here that pilots were trained—initially chiefly by the Portuguese—in the new art of oceanic navigation, and, on graduating, were duly licensed. Here too charts were drawn, hydrographic information was accumulated, chart corrections were incorporated in master copies, and, in due course, manuals of navigation were compiled and published. The most distinguished navigators of the age served in its various offices, Amerigo Vespucci, de Solis, Vincente Pinzón, Juan de la Cosa, and Sebastian Cabot—who may have sailed with his father, John, when he sailed from Bristol in 1497 and discovered the New Found Land in the north-west—to name only a few. All these rose in succession to be pilot-major of the institution.\(^3\) Although Martin Cortes was not the first Spanish author to publish a manual of navigation, yet as a

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3 Haring, C. H., *Trade and Navigation between Spain and the Indies* (1918), is a valuable study of the early colonial system of Spain, including the measures taken to ensure the safety of sea-borne goods, and the provision of navigators.
result of the teaching and research work of this officially sponsored and regulated nautical academy, his Arte de Navegar, published at Seville in 1551, is quite the best for fullness of content and clarity of exposition. It is from the pages of his manual that we learn how, amongst other things, the mariner’s chart was made.

For making ‘Cardes for the Sea . . . it shall bee requisite to knowe two things . . . the right position of places’ and ‘the distances that is from one place to another’. Position, Cortes explains, was shown by ‘the windes’, distance on ‘the outline of the coasts’. The charts were drawn upon paper or parchment; if on parchment then usually on a whole sheep’s, goat’s, or calf’s skin, the neck to the left. First the sheet was divided by two black lines in the centre at right-angles, giving length east and west, breadth north and south (but French pilots, like the Arabian ones and the old Romans, put south at the top).

Positions were ascertained by those who had travelled and had ‘well paynted’ patterns ‘of the best and most approved to be true’. These were copied by the use of tracing paper, made from thin paper rubbed with linseed oil and dried, and carbon paper of paper ‘smoked . . . with a lynke or with matches of pitche’. After the tracing was made it was pinned down on the ruled skin, the carbons were inserted and the outline was transferred to the skin by use of a steel bodkin. Tracing paper and carbon were then removed and the outline inked in. When dry, it was cleaned with breadcrumbs, and the names of ports, capes, and bays were added, those of ports in red ink, those of the rest in black. The chart was then garnished and beautified with cities, ships, banners, beasts, and compasses. The drawing in of the compases was particularly important. From the centre of the skin a large ‘hidden circle’, which could easily be rubbed out with breadcrumbs, was drawn in with a piece of lead. The quadrants were bisected with black lines. The eight principal winds had thus been drawn in. These were divided into half-winds, using azure or green lines, and quarter-winds, using red lines. The ‘mother compass’, as the central one was called, was completed by being filled in with a flower or rose, in colours and gold; lines of different colours were used to differentiate the rhumbs of the winds, which were marked, the north one with a fleur-de-lis, the east one with a cross, and the remainder with their letters. Where the winds of the mother compass crossed the hidden circle were drawn sixteen other compasses; larger charts had thirty-two. These compasses had their radiating winds drawn in also, after which the hidden circle was rubbed out, and the chart was almost complete. At first glance it appeared to be covered with a medley of criss-cross lines, but as soon as the hidden circle had been distinguished the fact that each line was a rhumb or wind leapt to the eye.¹ They were in fact indispensable, for by means of them and a pair of compasses, or as we should say today, of dividers, the pilot read off his course. Parallel rulers were not invented until 1584 when the Frenchman,

¹ See Pl. XXI.
Mordente, devised them, but the lack of reference to them in subsequent works on navigation, the continued directions to take off the course by means of compasses or protractors, and the continued, though slowly diminishing, inclusion of loxodromes or rhumbs of the winds in charts into the eighteenth century show that the parallel ruler came only slowly into use at sea. The time-honoured, centuries-old ‘rhumb and compass’ method died hard. It was supplanted first by the use of the protractor, also an invention of the 1580s but an English one. The charts, even the earliest ones, were completed with a distance scale, distances being measured off with a pair of compasses. When in the fifteenth century the Portuguese began sailing far south and west in the Atlantic, the pilot, in order to find his position, had to know ‘the true altitudes of the Pole, of certen principall capes, portes, and famous cities’ and correlate these with the pattern of his original bearing and distance chart. A latitude scale was therefore added, being drawn in ‘by the Islands of Azores’ or ‘wher the carde shall be lesse occupyyed’, and the graduation ‘begun from some one cape, whose altitude of the Pole is wel known’. Spanish pilots took Cape St. Vincent as their datum point, marking it correctly in 37° N; until the sixteenth century no longitude scale was drawn; even in the middle of the century Cortes’s latitude scale, which was necessarily drawn on a meridian, was not used as a prime meridian.

According to the opinion of the roundness of the earth it was reckoned that either 16½ leagues or 17½ leagues equalled one degree. Accordingly the scale or ‘Truncke’ was drawn in 100 leagues in length ‘and in the cardes that had XVII leagues and a halfe for a degree . . . ’ the roundness of the land and water were said to contain ‘six thousand and three hundred leagues’. This vagueness about the size of the length of a degree was caused by the inability of the cosmographers to measure it accurately. It can be measured only by observing accurately the latitude of two places on a meridian, measuring the distance accurately between them (making allowances for all detours, dips, and rises on the way), and then, knowing the angular distance apart of the two places, computing the length of a degree. Until the pilots began navigating astronomically the length of a degree did not bother them. In northern waters they worked in kennings for measuring the distance between places; in the Mediterranean in miles and in leagues. Pilots used neither degrees of latitude nor longitude. When at the close of the fifteenth century they began to have to relate linear distance to angular distance on the earth’s surface, the Portuguese and Spanish navigators generally counted 70 miles of 5,000 feet to the degree, or 17½ leagues, four miles going to the league. Many navigators and cosmographers, however, took shorter miles or counted less miles to the degree, 60 of 5,000 feet. It was the latter which the English eventually adopted when they came to navigate. Mediterranean pilots, however, did not trouble about latitude or longitude until the eighteenth century. They continued to cape their way around the coast. The result of the different values outlined above was that the length of the mile, and of the circumference of the earth, varied from
0.66 to 0.86 of what we know to be their true measurement. On the north-south route along the West African coast, where position could be frequently checked by observations of latitude, this shortening of the mile did not matter and errors arising from it were attributed to currents. The trouble started with east to west voyages in different latitudes, when at first the length of a degree of longitude was charted as being in all latitudes the same as the length of a degree of latitude. As the latitude of a place is the angular distance between the line joining it to the centre of the earth and the plane of the equator, the length of a degree of latitude never varies, but the length of a degree of longitude does. This is because, unlike parallels of latitude, meridians of longitude are not parallel. As Martin Cortes pointed out, they converge from the equator towards the poles, where they meet in a point. The consequence is that the length of a degree of longitude varies as the cosine of the latitude. As it happens the cosine of 35° is 0.8, and the east-west axis of the Mediterranean lies roughly along the parallel of 35° N. Thus in practice the Mediterranean hydrographers did correlate their distances east and west with their longitude fairly accurately. But as the Iberian cosmo-
graphers transferred the value of the length of a degree of longitude in 35° N to the length of a degree of latitude, and to the length of a degree of longitude, on the equator, their distances were always less than actuality

1 Nordenskiöld’s Periplus contains a valuable analysis of the value of the portu-
ian mile.

Taylor, E. G. R. (ed.), Brief Summary of Geographie, Hak. Soc., Series 2, Vol. 69, pp. xv and xvi and Appendix II, is valuable for the political and classical reasons underlying the different values of the length of a degree. At the beginning of the six-
teenth century seamen took the length of a degree to be 70 Roman (Italian) miles of 5000 feet or 17½ leagues of 4 Roman miles. The inspiration behind this was the ancient Greek astronomer Eratosthenes’ measurement of the circumference of the earth—252,000 stadia, 10 sea stadia being taken as equal to 1 Roman mile. This was included in Sacrobosco’s Sphaera, and thus made known to seamen through the Portuguese navigation manuals. By adopting the measurement of the earth’s circumference laid down by Ptolemy, 180,000 stadia, the Spaniards were able to try to claim the Moluccas in the East Indies, in the early part of the six-
teenth century, as being within their half-share of the world. 180,000 stadia gave 18,000 miles. Taking the league as 3 miles long, this gave the length of a degree as:

\[
\frac{18,000}{3} = 360 = 16\frac{2}{3} \text{ leagues}
\]

The important point was that by taking Ptolemy’s measurement the Portuguese half-sphere could be made to measure only 3000 leagues instead of 3150. The Spanish chances of successfully claiming the Moluccas were thus increased. Cosmo-
graphers got the value of 62½ miles to a degree by taking Ptolemy’s circum-
ference of the earth and 8 stadia to the mile, while if Strabo’s 8½ stadia to the mile was taken, the result was 60 miles to a degree—20 leagues of 3 miles. This, prob-
ably because of the ease with which it would be divided into minutes, was the value taken by English seamen as soon as the art of navigation was acclimatized in the second half of the sixteenth century. Seamen of other nations, with a longer tradi-
tion of navigation according to Portuguese methods, generally adhered to the Portuguese 17½ leagues (of 4 miles) to a degree.
by about one-eighth. The resultant north-south errors the navigator could correct by celestial observations, as already stated, but he had no means of checking his position east and west. He could only calculate it by keeping a careful reckoning. Therefore he preferred his miles, or leagues, to be short, for by this means he avoided the danger of being ahead of his reckoning and making a landfall unexpectedly. So, although the length of a degree was recognized by many navigators to be demonstrably false, all preferred to keep it so rather than correct it. As it was expressed, they preferred to have 'their reckoning before their ship', and so 'to sight land after they sought it'.

Most navigators blamed the winds and the currents, leeway, and compass errors for the gross differences that frequently occurred between landfall and the expected hour of landfall. Many continued to do so until the close of the eighteenth century.

Besides the confusion about scale there were other and grave errors in the charts. The meridians were drawn in or counted as being equidistant vertical lines, and the parallels of latitude as equidistant horizontal lines. The charts were 'plane' charts (often spelt 'plain'), and 'The Pilottes and Maryners neyther use nor have knowledge to use other cardes then only these that are playne', wrote Cortes, adding, 'The which, because they are not globous, sphericall or rounde are imperfecte, and fayle to shewe the true distances.' Thus, as Cortes explained, whereas two ships 100 leagues apart on the equator which sailed due north to latitude 60° N finished up only 50 leagues apart, on the plane chart they appeared to be still 100 leagues apart. 'Besides these considerations', he went on only too truly, 'one errour bryngeth in an other: and so an other . . . whereof to speak any more here . . . shall . . . be an endlesse confusion', adding somewhat bitterly that to do so was in any case but 'tocerten Pilottes . . . to paynt a house for blynd men.' As the Spanish and Portuguese pilots did almost all their navigating between the latitudes of 35° N and 35° S—the latitudes of Seville and Cape Hatteras and the Cape of Good Hope—they were not greatly affected by the inaccuracies of their plane charts induced by this defect in their compilation. It was in the higher latitudes that the error becomes pronounced. Scotland, for instance, in order to fit into the sea-charts, was drawn in twice as broad as it was, and the North American coast was stretched out in an east-west direction. This is clearly shown in the chart of the North Atlantic which Martin Cortes included in his *Arte de Navegar*. Here it will be found that whereas the coastline of North America between the coast of Florida and New England has a NE by N trend, in the chart the trend is ENE. Nevertheless as a result of this distortion it will be found that latitudes and courses, though not distances, are tolerably correct when compared with those on a modern chart. Martin Cortes's chart was up-to-date at that time because it was drawn with true bearing 'and not by the wyndes that the compass sheweth'. However, in

1 Mainwaring's *The Seaman's Dictionary*, amongst other works, explains this. See N.R.S., Vol. 56.
2 See Pl. XXII.
THE DOUBLE LATITUDE SCALE

'the Levant Sea (called Mare Mediterranean) and the Channel of Flanders (called the narrow seas) it was not inconvenient for the Navigation, that the portes were marked in the cardes by the wyndes, which the compass shewed; forasmuch as they sayled not by the altitude of the Pole'—a point already discussed. Elsewhere, however, failure to correct for variation before delineating the chart led to distortions that made position by compass bearing and distance and position by latitude irreconcilable.

It was about 1500, when transoceanic navigation became common for exploration and trade with the New World and India, that a latitude scale became essential on many charts. 'The cardes that lack this ought to be corrected and amended by wisse and experte men', observed Cortes; and well he might, for it was no easy task, as the charts of the Mediterranean and Atlantic and New World of the time show. For instance, the effect of the easterly variation prevalent in the Mediterranean at the time of the plotting by compass bearing of the original charts, from which all others of the region appear to have been copied, had been to raise their eastern end through an angle of about 11°. In navigating by compass, provided the needle was set under the north point of the fly like that of the compass used in the plotting, this did not matter. The north shown was then the compass north, and the directions shown were compass directions. These were what interested the pilot, and, as a matter of fact, since he caped his way about the seas in the Mediterranean the pilot was not too careful about accuracy, and the inaccuracies arising, for instance, from the as yet unsuspected secular change of variation. The fact that its southern—the North African—coast was shown as lying N and not N didn't interest or affect him. But add for his use as a navigator a latitude scale, and it did. The first known chart to show latitude—one of 1502 of the Mediterranean—has only one latitude scale, and that is on the eastern end, and as the chart is twisted this scale is inevitably incorrect for places at the western end. A solution of this problem was found in the addition of a second latitude scale at the western end. A beautiful example of this is contained in a manuscript Book of Hydrography, prepared in 1542 by a Dieppois navigator in the service of the English Crown, Jean Rotz, for King Henry VIII.1 Although in the Mediterranean chart Gibraltar and Alexandria are shown in the same horizontal line, the graduations on the latitude scale on the east start 5° above those of the west—at 19° N and 25° N respectively—so that the latitude of Alexandria reads correctly 30° N when read from the eastern scale, that of Gibraltar 36° N when read from the western, the east-west axis being swung through 11° to the north.

The double latitude scale was still not a very satisfactory arrangement for a navigator wishing to plot his latitude in the central Mediterranean. It was even less satisfactory on ocean charts where the distances and changes in variation were greater, and hence where distortions in plotting

1 Jean Rotz's Book of Hydrography (1542). 'This boke of Idrography Is made be me Johne Rotz servaunt to the kingis Mooste excellent Majeste. God saue his Majeste'. B.M. Royal 20. E.IX. See Pl. XXIII.
were greater too. In an attempt to counteract this, besides double latitude scales, double equators were often drawn in. In charts of the North Atlantic region recourse was also had to a twisted or 'oblique' meridian. This was because in the north-west Atlantic the great westerly variation experienced resulted in the coast of Labrador appearing by compass bearings to run due north and south instead of to the NNW, its true direction. As in the charts the coastline was drawn in by compass bearings, the main latitude scale, usually drawn in the charts in mid-ocean, and of course in a

![Map of Labrador and the North Atlantic](image)

**Fig. 8**

THE OBLIQUE MERIDIAN

(Alter chart of the Atlantic of c. 1502 by Pedro Reinel)

The problem that faced the hydrographer in the early part of the sixteenth century was to reconcile the observed latitude of places with their position as plotted by observed compass bearings. The methods of determining magnetic variation were rudimentary; indeed, the very existence of variation was open to question, the navigator sailed by compass course often uncorrected for variation; when he surveyed and plotted new coasts by a combination of latitude observations and compass bearings he often left them uncorrected for variation. One solution was the oblique meridian. The chart was drawn on bearings uncorrected for variation. Then, in addition to the meridian line drawn in as the general magnetic meridian, a sloping meridian line was drawn in through a region where there was marked difference of variation. It acted as the *geographical* meridian for that area. Thus the navigator who saw the coast trending north by compass knew that its true direction was NNW.

Fig. 8 after Gernet, D., *Importance de l’œuvre hydrographique et de l’œuvre cartographique des Portugais au 15ème et au 16ème siècles* (1949).

THE NORTH-WEST REGION OF THE ATLANTIC

Drawn according to the geographical and not the magnetic meridian and showing by isogonic lines—lines of equal variation—the great westerly variation experienced in the area (1937). In effect this chart is drawn by compass bearing corrected for variation. This became increasingly common from the middle of the sixteenth century as methods of finding variation were developed.

Fig. 9

THE OBlique MERIDIAN

Corresponding to points along the line A—B in Fig. 9 and indicating the amount of variation experienced on them

Fig. 10

THE MAGNETIC MERIDIAN IN THE NORTH-WEST REGION OF THE NORTH ATLANTIC

Fig. 11

Shown in Fig. 9 replotted on a magnetic meridian as in the chart of Pedro Reinel, and many another, that is, without applying the corrections for variation.

Fig. 12

Figs. 9, 10, 11 and 12 after Taylor, F. G. R., 'Hudson's Strait and the Oblique Meridian', *Imago Mundi*, Vol. 3.
north-south direction, was hopelessly misleading. The oblique meridian was an attempt to reconcile the conflicting claims of navigation by bearing and distance and of navigation by celestial observation. A short meridian was drawn on the chart off Labrador in a NNE and SSW direction (true) instead of in a north-south direction (true). This scale thus reconciled change of latitude in this region with coastal compass bearings and estimated distances. It was a solution no more satisfactory than the double latitude scale, of which, of course, it was an advanced type. Both were the source of much cartographical confusion, though perhaps the oblique meridian caused the most, because many navigators quite failed to appreciate its purpose. Nevertheless, since as late as the 1580s its use was condemned by an English navigator of great repute, William Borough, and in the early seventeenth century its use was still being condemned by English masters, it was clearly no short-lived device. Indeed some French navigators used it up to the close of the seventeenth century.

It was only when navigators really began to navigate by celestial observation that the conflicting hydrographical claims of bearing and distance and latitude and longitude were thrashed out. Gradually charts for navigation by latitude-finding carried the day. This meant that the land had to be drawn in with the bearings between places corrected for variation, so that they were true, and with distances which were, if possible, accurate. We have already seen that the leading navigators hoped to find a solution to the longitude problem by the use of compass variation. Nevertheless, many navigators steadily refused to believe in variation, holding that it was caused by the incorrect ‘feeding’ of the compass needle or by a fault in the making of the needle, or that it was an error arising from careless handling of the compass. They, therefore, preferred charts drawn by compass bearings, uncorrected for variation, and distances. This was partly because many a navigator in strange waters off rocky and inhospitable or verdant and seductive shores felt far safer relying for latitude determination on his compass, and a chart drawn from bearings taken from it, than on chancy sights and a chart drawn with compass bearings corrected for he knew not what uncertain and varying quantities of variation.

It was not until 1535 that a work (Spanish) appeared in print which described practical methods of finding variation, then called ‘the north-easting of the needles’, although Magellan appears to have taken a manuscript copy of it on his famous voyage of circumnavigation in 1519.1

In 1525 Felipe Guillen, an apothecary of Seville, devised an instrument for observing the shadows cast by the sun at equal altitudes before and after noon, and this was described in the 1535 work, which also gave three

1 This was the extremely rare Tractado del Esphera y del arte del marear: con el regimiento de las alturas: có algunas reglas nuevamente escritas muy necessarias of Francisco Falero or Faleiro (1535). The whole problem is dealt with in Chapter 8, ‘On the north-easting of the needles’. See the valuable papers by Harradon, H. D., ‘Some early contributions to the History of Geomagnetism’, Terrestrial Magnetism and Atmospheric Electricity, Vols. 48–50.
methods of variation finding: by the sun’s noon shadow; by the amplitude of the sun at sunrise and sunset; and by the equal altitude method. Pedro Nuñez (Nonius), 1502–57, the gifted young Portuguese cosmographer to the King of Portugal, improved on the instrument by enabling the altitude of the sun to be taken by it, and the brilliant João de Castro used it most successfully on a voyage to India in 1538 to plot the variation of the compass on the route.

By the middle of the century most skilled navigators had some form of ‘variation compass’. Jean Rotz presented one to King Henry VIII. Nevertheless, Pedro de Medina, who wrote an Arte de Navegar, published in 1545 at Valladolid, and much thought of on the Continent for many years, derided the existence of variation. Martin Cortes, on the other hand, firmly understood its existence, and was indeed the first writer to postulate that it was caused by terrestrial ‘attraction’, and to give the sum total of knowledge on the subject at the time; yet as regards its determination he merely said that ‘an instrument to shew the same by the sunne in the daye, and by the starres in the nyght’ could be easily made. However, we see that he had been able to reproduce a map of the North Atlantic area corrected for variation by 1545, when he wrote his treatise. A Mediterranean chart of 1546 exists similarly corrected, but a still older example is the magnificent portulan chart of the world, in two parts, by Diego Ribeiro, dated 1529. It is notable also for its exquisite delineation of a sea-astrolabe and quadrant of the time.¹

It was Pedro Nuñez who, in 1537, had first drawn attention to the cartographical faults of the plane chart in a work which also included observations on the art of navigation and on astronomy. One great contribution was the ‘double altitude’ observation of the sun. Provided the sights were taken over 40° apart it was possible by means of a terrestrial globe to fix latitude to within 1°. It would appear that ‘double altitude’ sights were not frequently taken, though they could be combined with variation finding by equal altitude and did free the navigator from being confined by day solely to a meridian altitude sight of the sun.

Pedro Nuñez, at the age of twenty-four, had first pointed out that the loxodromes or rhumb lines were not in reality straight lines but curved and, on a sphere, unless they were meridians or parallels of latitude, and thus one of the four principal rhumbs, were winding or spiral lines which twisted their way around the sphere towards the poles. He complained that globe-makers did not then know how to put them on their globes, but his representation was, in fact, incorrect.

A loxodrome is a line that makes the same angle with all successive meridians. When a ship sails along a loxodrome it crosses successive meridians at the same angle and maintains steadily the same ratio of northing or southing and casting or westing. Thus on a sphere a loxodrome, except when it lies along a parallel or meridian, because of the convergence

¹ The portulan world charts of Diego Ribeiro referred to are reproduced in Nordenskiöld’s Periplus. See also p. 56, n. 1.
of the meridians, traces out a spiral.\textsuperscript{1} To draw this on a sphere is no easy business, and Nuñez might well confess to being defeated by the task. Now on the plane chart, where the meridians were drawn as equal and parallel straight lines at right-angles to the equator, the latter was also drawn as a straight line. It was divided properly to scale. The remaining parallels were drawn equidistant from one another and also of the same length as the equator. This scale was true along the meridians and along the equator, but from the equator to the poles, since the convergence of the meridians was ignored, it was increasingly exaggerated along the parallels of latitude. This exaggeration was in the ratio of the secant of the latitude to unity. Thus, for instance, in latitude 60°, the secant of 60° being 2, the exaggeration will be found to be double.\textsuperscript{2} The result was that on a plane chart drawn up in terms of latitude and longitude a course N 30° W appeared to the navigator to be a straight line, but in fact was a curved line which tended farther and farther round to the west the farther along it he sailed, and which would never bring him 'unto the haven where he would be'.\textsuperscript{3} Moreover the farther north lay the latitude in which he started the voyage, the greater, over a given distance, was his error. It is no wonder therefore that, when they had to reconcile what appeared to be the true loxodrome on a globe with what also appeared to be the true loxodrome on the plane chart, the globe-makers were defeated.

To pursue the shortcomings of the plane chart no further, the result of these and the other various faults already reviewed was that as often as not the plane chart was 'an inextricable labyrinth of error'. The wise navi-

\textsuperscript{1} See Pl. XXIV.
\textsuperscript{2} See Fig. 13.
\textsuperscript{3} For example a navigator steering NW from a position given on his plane chart in, say, latitude 40° N, longitude 0°, would expect to arrive in latitude 70° N, longitude 31° W. Actually he would arrive in latitude 70° N, longitude 55° W.
The Art of Navigation.

Approach the Pole, and also goe round about it, but yet with unseen distance, so as he shalbe neither beyond it then on this side. By means whereof he cannot returne to the place from whence he came, as you may plainly perceive by this figure demonstrative here placed.

In which figure the letter A both signifies the North Pole, and the letters B C the Meridian passing through the Pole A, then suppose your ship to be in Q, whereas the Pole is elevated 30 degrees; and Q to be your Zenith, and the right line E, Q, D, to be your right line of East and West cutting the foresaid Meridian with right angles, and let D be the East point and E the West point.

Now you may saile from Q towards the North with a South-Wind, and from A you may sail against South-Ward.

XXIV. The Rhumb Line a Spiral Line, 1636.
XXV. The North Atlantic and Part of the Horizon Ring on Mercator's Terrestrial Globe of 1541.
XXVI. Chart of North-East Atlantic in Brouscon’s Tide-tables and Almanac of c. 1545.
XXVII and XXVIII. The Front and Back of Thomas Gemini’s Universal Planispheric Astrolabe of 1552.
gator used it with caution to supplement his far more reliable sailing directions. If he could afford it, by the middle of the sixteenth century he also took a globe to sea with him. On this he could plot his position with some certainty, and having his table showing the distance between meridians for every degree of latitude (Martin Cortes included an accurate one in his work) provided he had been sailing along a parallel of latitude, he could turn his departure—or distance run east or west—into degrees of longitude. Similarly he could measure on the globe the distances between places accurately (within the limits of the accuracy of their fixed position and the scale of the globe), and he could choose a series of courses along or close to a great circle, which demonstrably led him along the shortest track.\(^1\) Up to the discovery of America, globes had been almost exclusively celestial, showing the positions of the stars, the equinoctial, ecliptic, zenith, and meridians. The Portuguese explorations down the African coast and of the Atlantic islands had inspired the city council of Nuremberg in 1490 to commission Martin Behaim (1459–1507) to construct what appears to be the earliest surviving terrestrial globe. On it the world was hand-drawn—on strips of parchment affixed to a hard core of composition fashioned over a mould. John Cabot (1450–98), discoverer of Newfoundland, used a globe, probably of parchment-covered wood, to mark his discoveries. With the discovery of the New World, a popular demand for terrestrial globes arose on the Continent. At first it could be ill satisfied, as globes were either hand-drawn as well as hand-made, or were hand-wrought in metal and then engraved—again by hand. However, in the first decade of the sixteenth century the printing of paper goes mathematically constructed to cover spheres accurately was devised in Germany, and the reproduction of globes in quantity became possible. But these globes were generally small. Nevertheless their popularity is vouched for by the number that have survived, and typical examples are those depicted in Holbein’s famous painting of *The Ambassadors* (1536) in the National Gallery, London. While these globes were, of course, of value to navigators, what the latter really needed was a globe big enough to work out practical problems on, small enough to carry conveniently on board ship, cheap enough to buy, and last but by no means least showing rhumb lines correctly. A genius was to arise who was to satisfy their needs. Gerard Mercator (1512–94) was a native of east Flanders. He was born in a village close to the great port of Antwerp, whither the silks and spices of the east were brought in exchange for the fine cloths, fine printed books, exquisitely wrought instruments, and rich wines of Flanders and the Rhineland. Gemma Frisius, some of whose inventions we have already noticed, was a professor at Louvain University, at that time ‘the fountain-head of learning’. Thither the young Mercator went in the year 1530—the year that Nuñez, ten years senior in age, left

\(^1\) The shortest distance between two places on the earth’s surface lies on the arc of a great circle—the arc of a circle on the earth’s surface whose plane passes through the earth’s centre. See Fig. 42, p. 483.

9—A.O.N.
to take up the post of Portugal’s Cosmographer Royal. It was the year too in which Gemma Frisius produced his first terrestrial globe. Probably at his prompting, Mercator turned to the making of instruments, globes, and maps, and mastered the art of surveying. Seven years later appeared Gemma Frisius’s second terrestrial globe, and a companion celestial one. Part of the engraving of the gores was the handiwork of Mercator. The globes met with immediate popular approval. A feature of great interest was that they showed a strait to the north of Newfoundland connecting the Atlantic and the Pacific. It was in 1541 that Gerard Mercator produced his own terrestrial globe. It excelled technically, the twelve gores being designed with remarkable accuracy and terminated 20° from the poles, in the now general manner, separate circular sections being drawn for the polar regions. But what interested the navigator was that besides having drawn upon it the equator, a prime meridian, through the Canaries, meridians at 15° intervals, parallels of latitude at 10° intervals, the ecliptic, tropics, polar circles, and various scales, the Spanish one being 18 Spanish leagues to an equatorial degree, the sea surface was additionally laced with numerous wind roses and rhumbs. Moreover it was fitted with a flexible and adjustable quarter circle which enabled courses to be read off or laid off accurately on its curved surface. The size, too, of the globe (41 cm.—16 inches—in diameter) was ample enough for accuracy, yet handy enough for shipboard use. Furthermore, in various localities stars were represented, including the Pole Star and Ursa Major. Thus orientation and latitude finding at night were simplified. The globes gradually supplanted Frisius’s amongst the educated. Cheap as well as expensive models were sold, and many must quickly have found their way to sea. As we shall see, they held their popularity in England and amongst seamen till the close of the century. In 1551 Mercator produced a companion celestial globe. With this and an almanac, compass, and astrolabe the competent navigator could fix his position, tell the time and find the compass variation with considerable accuracy. With these two globes to supplement his rutter, plane charts, compasses, sea-compass, and azimuth compass, ring-dial, nocturnal, astrolabe, cross-staff, and quadrant, his shipman’s quadrant and his hour glass, traverse board, lodestone, journal, abacus and almanac, the navigator could be sure that he had provided himself with the best available equipment. If his voyage was one of exploration, he would also have ‘a Geographical plaine sphere’ (really ‘plane’ sphere) ‘to describe a country’. This was the precursor of the theodolite. It consisted of a horizontal compass dial with an alidade and, inset in the face of the dial, usually eccentric-

1 Taylor, E. G. R., Tudor Geography, 1485–1583 (1930), reviews the developments in geographical knowledge, theory and surveying in the sixteenth century. There is a valuable bibliography.

2 Blundeville, Exercises (1594). See Pl. XXV.

3 William Cunningham illustrates ‘The Geographical plaine sphere’ as ‘an Instrument serving the use to describe a country’ on fol. 136 of his Cosmographical Glasse (1559).
ally, a magnetic compass. By means of this instrument, and perhaps a plane table (now coming into use), he surveyed his discoveries, using the modern method, known as triangulation, devised by Gemma Frisius and first described by him in 1533. If, in addition, the navigator had a copy of Martin Cortes's *Arte de Navegar* of 1551, he had the very latest comprehensive navigation manual in existence, one which really did explain 'the way of a ship in the sea'. Much of its contents we have already drawn upon in describing the navigator's instruments.

The manual is divided into three parts. The first part describes the cosmos, and discusses its movements, rejecting absolutely the Pythagorean hypothesis that the earth itself revolved, 'for circular motion is proper to the heavens' (fol. ix.). The various divisions of the sphere—the horizon, meridian, zodiac, etc.—are defined, the size of the earth discussed, and its division into geographical climates explained.

The second part deals thoroughly with the course of the sun and of the moon, with the seasons, the use of sundials and nocturnals, and ends with the calculation of the tides and with weather lore.

The third part continues the practical note on which the preceding part closes. It deals exclusively with the ways and means available to the mariner to take his ship safely from port to port. The exact description of how to draw and use a sea-card is followed by shorter chapters on the characteristics and manufacture of the compass, and on the manufacture and use of both the astrolabe and the cross-staff, each process being described in detail, with clear drawings of the instrument under discussion, and finally on the manner of plotting or 'pricking' a position upon the chart. Wise admonitions on errors, omissions, and false estimates to be avoided conclude the work.

The navigator, explained Cortes, in the sixth chapter of the third part, must know two things which the sea-card would show him—his course, by 'the lynes of the sayling carde'—and distance 'by the scale or trunke of the leagues'. Taking 'with a compasse the distance of two places' he then 'directed his foreshyppe to the selfe same wynde' as his card showed to be the right one. As for 'the distance he ought to know how muche the shyppe goeth dayly'; well consyderyng . . . all suche thynge may be with hym or against hym'. According to his reckoning, 'he should knowe how muche he hath gone' and so the distance he had still to go. 'And because this estimation . . . cannot be . . . exacte', particularly on long voyages or over a long time, Martin Cortes advised that he should 'rectifie . . . it . . . by the altitude of the pole', either by a Pole Star sight or a meridian sun sight according to the rules given in his manual.

Plotting the ship's position was termed 'setting or making a pricke in the card', to do which, Cortes explained, the navigator had to 'knowe from what degree or how many degrees of the altitude of the Pole he had departed, and with what wynde he had sayled'. If on taking his sight he

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1 See Pl. XXVI. The quotations are from Eden's translation (1561) of Cortes.
found his latitude unchanged, he knew he had made good an east-west course, in which event 'what he hath gon the can not bee knowen but by the judgement of a wyse and expert man'. If, however, the navigator found himself in a higher or a lower latitude, he took two pairs of compasses, placing a point of one in the place where he reckoned his ship was, its other point on 'the lyne or wynde' along which he reckoned he had sailed. Similarly he put one point of the other compass on the graduation on the latitude scale of his observed latitude, the other point on the nearest east-west line where it met the latitude scale. 'And so he drew both the compasses, the one in one hande, the other in the other hande' together. Where the points of observed latitude and estimated course met, there was his position. From this position henceforward he kept his 'accounte'.

It was no doubt already common for navigators to practise latitude sailing. The favourite method—which Columbus had used—was to steer a course which would bring the ship on to the latitude, but either well eastward or well to the westward, of the intended landfall, and then to steer along the latitude until the expected landfall was made. By this means the inevitable errors in estimation were at least largely eliminated in a north-south direction. As for those in an east-west direction, there was nothing for mariners to do except to navigate with care by day, and at night to avoid standing in towards the shore, if it was reckoned to be very close. To facilitate latitude sailing, Martin Cortes included a diagram showing the distance in leagues (of 17½ to a degree) and in degrees and minutes that had to be run on a wind to raise or lower latitude by 1°, and the distance run east or west in so doing. It was a more accurate version of the type of traverse table already referred to. It was essentially one designed for 'latitude sailing'.

In keeping his daily reckoning at sea the navigator when out of sight of land used the astronomer's 'natural day'. In other words he kept his reckoning 'from the myddaye or noone, and ended it the next noone folowyng'. By this calendar the tenth day of a month ended 'the same daye at noone. And the houres that roen from that noonetyde forwarde, were of the eleventh daye'.

Although Cortes also included in his manual, as already remarked, an accurate table showing the value in minutes (angular) of a degree of longitude in every degree of latitude, nowhere did he touch upon the method by which departure should be turned into difference of longitude. In truth there was little point in doing so while the plane chart was the navigator's guide. Also, although 'the Navigation or course from one place to another [according to the cosmographers] ought to be by the arcke of the greater circle: for that . . . shall be the shortest course', great circle sailing was a method of navigation far too ambitious to be explained. Indeed it could only be done with the aid of a terrestrial globe, since a great circle course could not be found from a plane chart; and until globes big enough for

1 See Pl. XI.
navigational use were manufactured, great circle sailing was no more than a cosmographer’s theory. Mercator’s terrestrial globe of 1541 appears to have been the first globe offered for sale that could have been used by navigators for great circle sailing, for, in addition to the rhumb lines for ordinary sailing, it had the *quarta altitudo*, or adjustable flexible quarter-circle, which enabled great circle courses between places to be determined. The small size, however, of the globe must have rendered its navigational value low. The first brief, and by no means explicit description in English of great circle sailing by the aid of a globe is found in William Bourne’s *Rules of Navigation* of 1567. The lack of reference to the *quarta altitudo*, and of rhumb lines, implies that he had not Mercator’s globe in mind. It was not until over twenty years later that great circle sailing was clearly explained in print, or its practice recorded in an English journal, and it is significant that this was shortly after the appearance of an English globe much larger than Mercator’s.¹

Chapter Three

THE AWAKENING OF THE ENGLISH TO THE NEED FOR NAVIGATION

'Master John Cabot has his mind set upon even greater things, because he expects to keep more and more towards the east... where he believes that all the spices of the world have their origin, as well as the jewels... by means of this they hope to make London a more important mart for spices than Alexandria.'

Raimondo de Raimondi de Soncino, reporting the Cabots' discovery of Newfoundland to the Duke of Milan, 18 December 1497.

...the marchamites of London... also divers noble men and gentlemen as well as the [Privy] council as other... have furnysshed and sent furth certeyne shyppe for the discovering of... landes and regions... unknown, [and] have herein deserved immortall fame, for... they have shewed no small liberalitie upon certeyne hope of gavius... and... the two chiefe capitanyes of the same... Sir Hugh Wyllohy and the excellent pilotte Rycharde Chaunceler who have therein adventured theyre lyves for the commoditie of theyr countrey: are men doubtless worshippe for theyr noble attempts to bee made Knights of the Ocean or otherwyse preferred if ever God sende them home ageyne... For as suche have obtayned absolute glory that have brought great thynes to passe so have they deserved immortall fame which have only attempted the same...'


Sir Hugh Willoughby perished on this voyage, Richard Chancellor on the succeeding one.

When King Henry VIII died in January 1547 not more than a few score Englishmen were interested in the practice of oceanic navigation. Probably fewer could practise it. In company with the more numerous Bretons and Normans, a few hardy fishermen made the annual trip to the cod-banks and to the inhospitable shores of Newfoundland, there to cure their catch for the return. But they were not navigators.

Roger Barlow, whose three brothers were in the Church, and who was himself a Bristol merchant, trading in Seville, had voyaged to Morocco. In 1526, with Henry Latimer, he had participated in Sebastian Cabot's intended voyage to the Moluccas by way of the Magellan Strait that, after
the loss of the flagship, had finished up by exploring the River Plate in the hope that it would lead to the still fabulous treasures of Peru. Both Englishmen had become competent navigators during the two years of the expedition. But Henry Latimer, if not dead, must now, like Roger Barlow, have been close on sixty. Though one account has it that Henry VIII's death put an end to an intended voyage of 'discovery of the northern passage to the East Indies, with three of His Majesty's ships from Milford Haven' by Roger Barlow, the voyaging days of both must have been over. In the 1530s old William Hawkins of Plymouth and a few others had voyaged to Brazil and brought back dye-wood, but it seems certain that they all engaged foreign pilots to take them there and that the French wars put an end to their activities. We can say then that at the time of Henry VIII's death few Englishmen could navigate a merchant or a royal ship across the great ocean to a known landfall.¹ None could navigate to the East—to India, the Moluccas, Cathay. Nor had any Englishman penetrated the vast spaces of the Pacific Ocean—of the Great South Sea.

Most Englishmen, if not entirely ignorant of the New World, discovered almost a lifetime before by Columbus, were not in the least interested in it. Some might recall that Sebastian Cabot, now Pilot-Major of Spain, said he had sailed west in Bristol-manned ships with his father, John, some fifty years since and that it was they who had at last discovered the New Found Land and its cod-banks. Since then there had been a few voyages of discovery to the north-west planned and even attempted, but they had come to nought.

Although the study of geography was being advised in England by a few scholars from the 1530s, there was no popular work in print in English that described the wonders and possibilities of the New World or of the Orient now being discovered and exploited by the Spaniards and the Portuguese; indeed there was only one English book—little better than a pamphlet—that even mentioned America, and that had been printed in Antwerp and dated from 1511.² There was no popular demand for one. Except

¹ (a) See A Brief Summe of Geographic, Hak. Soc., Ser. 2, Vol. 69. See also Levillier, R., 'A Roger Barlow Map in Florence?*, Imago Mundi, Vol. 8, where an English chart of Guinea and Brazil of c. 1536, signed 'R.B.' is reproduced.

² (b) An action in the High Court of Admiralty in 1533 concerning the loss of John a Borough's sea chests (Public Record Office, High Court of Admiralty File 5, large bundle, John a Borough contra John Andreevs) shows that Borough had a cross-staff, quadrant, lodestone, running glass, a Portuguese Ephemerides, a Spanish rutter, an English rutter compiled by himself, two Spanish compasses, two other compasses, two charts, one being of the Mediterranean.

See Arber, E., The First Three English Books on America (1885). A new interlude and a mery of the nature of the iiij elementes etc. A play of 1519 described the New World in a dialogue between Experience and Studious desire. Arber reproduces the relevant dialogue.
for one brief manuscript with charts by a Dieppois pilot in English service, in the Royal Library, possibly two or three more elsewhere, like Roger Barlow’s Brief Summe of Geography (though only one comparable to Jean Rotz’s has survived, in Italy), not a single work existed in English on the art of navigation. The purely practical art of transoceanic navigation was of no interest to the English while they still got their oriental and tropical wares from the marts of Flanders, Portugal, and Spain.

The ignorance and indifference of the English of the middle of the sixteenth century to the geographical discoveries that were changing the whole conception and economy of the world were largely the result of force of circumstances, just as it was to be circumstances which were to oblige them ere long to take a practical interest in the discoveries. It was no ‘spirit of romance’ that inspired the Elizabethans. It was, in its crudest form, lust for gold; in its direst, lack of bread; in its noblest, love of country; in its sublimest, love of God—not a few died at sea ‘in defence of the realm’ and of ‘established religion’; in its most honest form, love of commerce. What is remarkable is not that the English took no part in and no interest in the great discoveries of the fifteenth and early sixteenth centuries but that, awakening in the latter half of the sixteenth century to the reality of the discoveries, they mastered the art of oceanic navigation that made them possible so rapidly and so effectually that within thirty years they had defeated the leading maritime state in battle at sea, and within half a century had planted colonies of their own overseas, and were trading regularly round the Cape to India and the Far East, and making original contributions of fundamental importance to the art of navigation. It was not through love of fame but by force of circumstances that when Elizabeth ascended the throne the English also grasped that ‘To be master of the sea is an abridgement of a monarchy’, and ‘that he that commands the sea is at great liberty, and may take as much and as little of the war as he will’.

It was not long before they concluded, again in Bacon’s words, that ‘the wealth of both Indies seems in great part but an accessory to the command of the seas’. The English were at once practical and imaginative. They went to the root of the problem of oceanic navigation, they built ships ‘sufficient’ for the ocean seas, and they trained men ‘sufficient’ for the task of navigating and, if necessary, fighting them.

It was King Henry VII who had made the naval interests of the English for the first time part of a deliberate, settled policy. If he had been unresponsive to Columbus, he had at least rectified his error by his reception of the Cabots. That their discoveries had not been further exploited was because they had found neither a way to Cathay nor to an inhabited land offering prospects of trade. Henry VII could not afford to seek elsewhere. He had had to fight to get his throne. He had now to retain it by diplomacy and wise economic policies. Men did not think of the north-east as a

possible route to Cathay. To seek 'elsewhere' meant trespassing upon the territories of either Spain or Portugal, for the Bull of 1493 had divided the New World between these powers; and by the Treaty of Tordesillas, a year later, they had agreed upon a line 370 leagues west of Cape Verde in Africa as the dividing line. It seems certain, although the wording is ambiguous, that the divisions applied only 'towards the South and West' of the latitudes of Lisbon and Madrid, since the English explorations north were never called in question. As these appeared to be impractical, Henry VII had to be content to build up the traditional home trade between Portugal, Spain, France, and the Netherlands and to seek to establish new European markets in the Baltic and the Levant. He cut his coat according to his cloth. He built up a modest 'narrow seas' navy of ships able to guard his shores and convoy his merchants' ships in troubulous times safely along the routes between the North Sea and Biscay ports. In quiet times they were available at attractive rates to enterprising merchants for voyages into the Mediterranean. Their armament was an important feature in their favour. Henry VII could not foresee that the diplomatically brilliant match of his son with a Spanish princess would later embitter relations with Spain to the point of war, and in so doing bring the English out on to the high seas of the world.

Henry VIII succeeded his father in 1509. He was ambitious, brilliant, forceful, and deeply interested in the sea. Because of his continental ambitions he built up a powerful 'narrow seas' royal navy and allied himself with the Empire and with the Spaniards, in three wars against the French (1511–14, 1522–5, 1540–6). In short, he continued the policy of not trespassing upon the new realms of Spain. In return English merchants long settled in Seville were allowed to continue their trading with the Atlantic islands of Spain, and even to have factors in the New World, like the Thornes, who were contemporaries and friends of Roger Barlow. One of the effects of the divorce of Catherine of Aragon in 1530 seems, however, to have been to lead to the suppression of such factors. Unlike the Portuguese, the Spaniards did not keep their achievements in the New World secret, though they did prohibit trade between their colonies and any other port than Seville, and did insist that it should be confined to Spain. To enforce this they licensed, with few exceptions, only Spanish pilots to undertake the voyage. Consequently, the English could learn of the New

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1 The wording of the Bull reads: '... by the fulnesse of Apostolycall power, doo gyue, graunt, and assigne to yowe, youre heyres and successours, al the firme landes and Ilandes found or to be found, discovered or to be discovered toward the West and South, drawynge a line from the pole Artike to the pole Antartike from the North to the South: Conteynygne in the donation, what so euer firme landes or Ilandes are founde or to bee founde towarde India, or towards any other parte what so euer it bee, beinge distant from, or without the fore sayd lyne drawn a hundreth leagues towards the Weste and South from any of the Ilandes which are commonly caule Dc los Azores and Cabo Verde ...' Reproduced in Richard Eden's The Decades of the newe worlde, London (1555), and in Arber, E. op. cit.

World only from the merchants in Seville and its port of San Lucar. Detailed knowledge was lacking and navigational experience, though it could be acquired openly up to the 1530s, was discouraged by the English Government from wider motives. The Portuguese on the other hand ruthlessly kept secret all their discoveries along the route to the East Indies. Sufficient information was released for the maps of the world to be kept corrected, but the runters and charts were rigorously protected by law from falling into foreign hands. Pilots experienced on the routes were closely watched. Henry VIII had none of the scruples over Portuguese possessions that he had with the Spanish ones; there were, too, pilots who had fled from Portuguese service for fear of persecution on the grounds that they had betrayed their knowledge, or for gain, and Henry had no qualms about employing them. Such pilots had probably guided old William Hawkins on his three voyages to Guinea and Brazil—there to get ivory and Brazil wood for cloth dyes.

Since 1528 the French in their wars with the Empire had had no scruples in preying upon the Spanish possessions and trade in the Caribbean and Gulf of Mexico. Soon religious passions were to add stimulus to their raids. The French had quickly mastered the art of navigation as practised by the Portuguese and Spaniards. As is evident from the early runters, they had always been the link between the mariner of the Mediterranean and the North. They were soon called upon to aid the English.¹

In building up his royal navy Henry gave it of the best—Italian shipwrights, French pilots, and German gunfounders.² He gave it also, as already mentioned, permanent administrative organizations—the Navy Board and Trinity House—to see to the maintenance of the ships and docks and of navigational aids, and to the provision of seamen. And he gave it officers drawn from the nobility and gentry. During his reign English shipwrights and gunfounders became second to none. The gunfounders cast fine cannon designed, and for the first time mounted, for shipboard use. The shipwrights built ships specially designed for the cannon’s efficient use.

¹ Nicolas de Nicolai, at one time in the service of Henry VIII as hydrographer and pilot, later Premier Cosmographer of France, who stole various English charts for the French in 1546–7, translated Medina’s Arte de Navegar of 1545, as early as 1549 or 1550. It was printed as Pierre de Medina, L’Art de Naviguer, at Paris in 1554. The Dieppois hydrographers of the early sixteenth century learnt their art from the Portuguese. This is unmistakably reflected in their surviving charts. Moreover, some illustrious Portuguese cartographers such as André Homem and Bartolome Velho stayed in France. The traditional link between France and Portugal was the wine trade between Rouen, the port of Paris, Nantes, Bordeaux, and the Portuguese ports. (Information provided by the late D. Gernez). For the dependence of Englishmen upon French pilots for the Brazil trade of the 1530s and 1540s, see Appendix 2. As late as 1577 the Spanish President of the Council of the Indies reported ‘All the pilots who go on these English and French Armadas [i.e. to raid Spanish shipping] are Portuguese,’ quoted in Taylor, E. G. R. ‘Instructions to a Colonial Surveyor in 1582’, M.M., Vol. 37.

² See Taylor, E. G. R. Tudor Geography, 1485–1583 (1930), for the contribution of French pilots to the navy of Henry VIII.
Under the tutelage of French pilots and the supervision of the Brethren of Trinity House the English finally became independent of foreign pilots in European waters, so that in the closing years of Henry's reign they were able successfully to conduct their fleet unaided against that of the French. But the Reformation, combined with the new wealth pouring into Europe from the Portuguese and Spanish empires, sadly upset the economic web of English trade, while the dissolution of the monasteries, the breaking up of the church lands, and the creation of new estates dislocated the domestic economy. By the time of Henry's death in 1547 English 'merchants perceived the commodities and wares of England were in small request... and that those merchandises, which strangers in the times and memory of our ancestors had earnestly sought and desired, were now neglected and the price thereof abated, although they were carried to their own parts'.

New 'vents' had to be found for English farms and looms. If England could find new markets in northern latitudes as well as a northern route to Cathay, she could both sell her staple products and corner the world's spice market. In an age when vegetables were few, and meat poor, when most men's beer was thin, and wine sour, spices were less of a luxury than a necessity in most households. The spice market was better than a gold-mine. But the discovery and exploitation of such a route involved two matters quite strange to the English—the economics of an exploratory commercial expedition and the art of navigation.

While indifference to the great discoveries was characteristic of the English as a whole, it was not so of a few individual Englishmen. They were a varied lot—some merchants, like Roger Barlow; a few of the nobility like John Dudley, Lord Lisle, the Lord High Admiral; some officials in London; one or two scholars, such as Richard Eden—young men chiefly. They were few but their influence was now increasingly effective. Henry VIII's successor, Edward VI, was a child of nine, so that it was the Privy Council that was to rule the realm in the king's name. To do this successfully they were dependent, if not upon popular support, at least upon the support of the commercial classes. This could be assured only by a sound economic policy. Such was the state of the traditional overseas markets that this meant successful overseas enterprise. Their first business therefore was to arrange for Englishmen to learn the techniques of navigation, of exploration, and of the financial and commercial organization necessary to exploit them. The Privy Council acted swiftly. Sebastian Cabot, as Pilot-Major of Spain, was familiar with all the navigational secrets of Spain and of her empire. He not only knew all the latest navigational charts, instruments and practices, and all the leading navigators of the day—he

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2 On the ignorance of the English about the geographical discoveries of the fifteenth and first half of the sixteenth century there is ample evidence. Taylor's Tudor Geography, 1485-1583 (1930), deals with it in detail, and a valuable review is contained in the opening chapters of Parks, G. B., Richard Hakluyt and the English Voyages (1928). It has a valuable bibliography.
was himself one of the most illustrious. He was experienced in exploration, and thoroughly conversant with the economic structure of the colonial empire of Spain, and with the methods used in financing expeditions. Moreover he claimed to be English. His loyalty to the Emperor was known to be not above question. Indeed there were some in England who knew of earlier negotiations with Cabot. He was approached and the bribe was accepted. Early in 1548 Sebastian Cabot on leave of absence from Spain reached England, never to leave again. There he remained till his death some ten years later, a royal pensioner, teaching the English all they sought to learn.¹

It seems clear that Lord Lisle, the Lord High Admiral, was the power behind Cabot. In February 1547, one month after King Henry's death, Sir Thomas Seymour, brother of Edward, Duke of Somerset, the Protector, had been created Lord Seymour of Sudeley, and had supplanted Lord Lisle as Lord High Admiral. In January 1549 Seymour's intrigues had led to his deprivation of office and two months later to his death by beheading. In October Lord Lisle, who had been created Earl of Warwick, had been reappointed Lord High Admiral and Cabot, who had retired to Bristol during Seymour's tenure of office, had at once been summoned to London. It is perhaps significant that Roger Barlow had been appointed

¹ See Appendix 4. 'Sebastian Cabot filled in Spain the office first of Crown pilot, from 15 August 1515, and then of Pilot-Major from 5 February 1518, until 25 October 1525 (when he went on the voyage of discovery of 1526), and from 1533 until at least October 1547. Nor should we omit to state that not only was Sebastian by virtue of his office supervisor of the Chair of Cosmography in the Casa de Contratación, and filled the professorship of nautical and cosmographic science in the institution, but he was a member of the commission of pilots and geographers who in 1515 were required by King Ferdinand to make a general revision of all maps and charts.' Harrisse, H., *John & Sebastian Cabot* (1896) p. 73. This is the standard authority on the Cabots, but Williamson, J. A., *The Voyages of the Cabots*, (1929) is the most recent authority. This is a scholarly work reviewing also earlier ideas on, and attempts to explore, the Atlantic, particularly by the West-Countrymen of England. The Portuguese hydrographer Diogo Homem, who had been banished to Africa for a year in 1545 for murder, was in England in 1547. In July he was given permission to return to Portugal to employ 'his knowledge of cosmography and his art of navigation'. It is not known when he left England. It seems clear he did not go to Portugal, but eventually to Italy. In April 1547 he had a law-suit over 'a certain great new chart or map' containing, as he asserted, 'a description of the land and provinces of the entire world and all the discovered navigations of sea, constructed and painted, as it appeared, in eight great rolls or sheets of parchment ...'. To confirm its value, which was very great in England because of 'the wante and lack of expert learned men in that faculte of makynge cartes or mappes, and the scareyte ... of such cartes withinne this realm of England ...', he called as witnesses 'Peter Poll, Italyen, beyng experte in shipmen's occupacion, born in the isle of Corsica, of the age of xxxye or thereabowte ...' experienced 'in conductyng of shyppes by the seas and cuntreys specified in the sai cart ...', also Ferdynamde Gonzalaez, ship master, beyng lernd in cosmographe or descreycyon of the world, borne in Lushborne in the realme of Portuguale, of the age of xl yerys ...'. Blake, J. W., 'New Light on Diogo Homem, Portuguese Cartographer.' *M.M.*, Vol. 28.
Vice-Admiral of the Coast of Pembrokeshire. Cabot had doubtless been discussing plans in the West Country, and Barlow had probably been influential in obtaining his services. Was it in recompense for his part in obtaining the services of Cabot that he was appointed Vice-Admiral? It could be a lucrative post.

The first navigators were soon trained. Within a year Sebastian Cabot seems to have organized a training ship—the bark *Auchier*—and a training cruise to Chios. The voyage was made under the command of one Roger Bodenham, who, it is not surprising to learn, was a Bristol captain. Its success may be gauged by the statement Roger Bodenham made years later to Richard Hakluyt: ‘All those Mariners that were in my sayde shippes which were, besides boyes, three score and tenne, for the most part were within five or six years after, able to take charge, and did.’ One of these ‘Mariners’ was Richard Chancellor—‘the incomparable Richard Chancellor’ as in later years, and long after his death, Dr. John Dee was to call him—a brilliant mathematician and astronomer, and soon to prove himself gifted as a sea-captain and skilful as a navigator.

While Sebastian Cabot was training navigators he was also organizing in London the preparation of charts, ephemerides and instruments and the economic backing essential to provide the ships, men, and wares for a trading venture into unknown seas and lands. By 1553 ‘The Merchant Adventurers of England for the discovery of lands, territories, isles, dominions and signories unknown’ had the first expedition ready. It sailed that year under the command of an Englishman, Sir Hugh Willoughby, in the ship *Bona Esperanza*, 120 tons, with, as chief pilot, Richard Chancellor in the *Edward Bonaventure*, 160 tons, of which ship Stephen Borough was the master. A third ship, the *Bona Confidencia*, 90 tons, completed this, the first all-English expedition of discovery. The destination was Cathay, the aim, old John Cabot’s. He, in 1497, discovering new land to the west, had supposed it to be a part of Asia and, it was reported, ‘had his mind set upon even greater things, because he proposed to keep ... more and more towards

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1 Roger Bodenham was the captain of the bark *Auchier*. The master was one William Sherwood. Bodenham ‘provided a skilful pilot to carry over Land’s End’, and recounts, ‘I had in my ship a Spanish pilot, called Nobiezia, which I took in at Cadiz at my coming forth. He went with me all this voyage into the Levant without wages, of good will that he bare me and the ship. He stood me in good stead until I came back again to Cadiz; and then I needed no pilot. And so from thence I came to London with the ship and goods in safety: God be praised!

‘And all those mariners that were in my said ship—which were, besides boys, three score and ten—for the most part were within five or six years after, able to take charge of ships, and did.

‘Richard Chancellor, who first discovered Russia was with me in that voyage; and Matthew Baker, who afterwards became the Queen’s Majesty’s Chief Shipwright.’ Hakluyt’s *Principal Navigations*, Hak. Soc. Extra Ser., Vol. 5, p. 76. It will be noted that even for the Mediterranean voyage a Spanish pilot was essential.

2 See Pls. XXVII and XXVIII.
the cast... where he believed that all the spices of the world had their origin, as well as the jewels... By means of this they hoped to make London a more important mart for spices than Alexandria.1

It was this that inspired the Merchant Adventurers who financed the voyage of discovery towards Cathay in 1553, as it had inspired Robert Thorne in 1526, and Roger Barlow in 1547. The preparation for the voyage brought out (in June 1553) the first book in English to treat at any length of the newly found lands, and the second to mention America, Richard Eden's translation from the Latin of Sebastian Munster's *A treatise of the newe India, with other newe founde landes... as well eastwarde as westwarde... of 1536.*

Born in about 1521, Richard Eden had received a good education, and had gone up to Cambridge. There he had studied for ten years, from 1535 to 1544. Then had followed years in official service, either in the Treasury or in the service of Sir William Cecil, later Lord Burghley, and already one of the Secretaries of State and a Privy Counsellor. Eden dedicated his work to the Duke of Northumberland, fated to be beheaded in the August after Mary's accession, but still the virtual ruler of the country, and a driving force behind the voyage of discovery.

The aim of the voyage was not realized. The expedition was scattered by a storm, and Sir Hugh Willoughby and his men were frozen to death.3 Richard Chancellor, however, survived. At Vardo he met Scotsmen who had heard of the rigours of the Arctic winter, and would have had him turn back, but he pressed on, 'persuading himself that a man of valour could not commit a more dishonourable part than, for fear of danger, to avoid and shun great attempts'. He, too, was ultimately held by the ice, but he made his way by the White Sea to Moscow, and out of his negotiations developed the Russian trade. He returned in 1554, and in 1555 a trading company, the Muscovy Company, was chartered by the new queen, Mary, and her consort Philip II of Spain.

At the time the fruits of the 1553 expedition—the Russian trade—must have seemed small, such richer ones had been hoped for; particularly as in 1555 had appeared *The Decades of the newe worlde or west India... Wrytten in the Latine touuge by Peter Martyr of Angleria and translated into Englyssh by Rycharde Eden*. It was the first collection of voyages printed in English, and the first work to contain narratives of English voyages. To encourage the furthering of other enterprises Eden contri-

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2 A treatise of the newe India, with other new founde landes and Ilandes, as well eastwarde as westwarde, as they are known and found in these oure dayes, after the desciption of Sebastian Munster in his boke of universall Cosmographic: wherein the diligent reader may see the good successe and rewarde of noble and honest enterpryses, by the which not only worldly ryches are obtayned, but also God is glorified, & the Christian fayth enlarged. Translated out of Latin into English. By Rycharde Eden. [London, 1553].

3 See Pl. XXIX and Appendix 5.
buted a lengthy preface on the noble nature of honourable exploration and enterprise by sea.1

By the time the book was published it was, of course, known that Sir Hugh Willoughby was dead. But the book must have been a revelation of the New World he was attempting to reach, an inspiration second only to that of his example. Moreover, for over a quarter of a century it proved to be the English source-book of geographical and navigational knowledge. As such it was to be of the utmost value to men like Hawkins and Drake. Here were Peter Martyr’s descriptions of 1511 of ‘the Ocean’; of 1516 of ‘the supposed continent’, America; ‘the discovery of the Pacific’; and ‘Cabots’ voyages’; his description of 1521 of the discovery of Yucatan and Mexico; Oviedo’s *Natural History of the West Indies*, first printed in 1526; Pigafetta’s *The First Circumnavigation of the Globe*, also first printed in 1526; a treatise *Of the Pole Antarctic, and the stars about the same* from Amerigo Vespucci’s narrative of his voyage to Brazil in 1501; and Andreas de Corsali’s *Voyage to the East Indies*.

Richard Eden was a shrewd editor. He not only adorned his tale with these descriptive works of hitherto unimagined isles and peoples, voyages, and adventures to excite the English imagination but he pointed the moral. Of Vespucci’s narrative he carefully included the portion containing the description and illustration of the Southern Cross, and of the world in relation to the zenith of travellers 90° apart in latitude, and Vespucci’s explanation that he could observe such things ‘hauynge knowledge of geometric’, and could successfully undertake such a voyage ‘in suche daungorous places wanderynge in vnknowne coastes’ only because he had ‘byn skylfull in the science of Cosmographie’.

Further descriptions—of Muscovy, Cathay, and the North Regions, and of the Indies—followed, and then the first printed English treatise on the compass, the first description of ‘What degrees are’, and ‘A demonstration of the roundnesse of the Earth’, with an account, too, of Gemma Frisius’s methods of finding the longitude. At the end of the book Eden added a section on metals, the first work of its kind printed in English, for the benefit of explorers and prospectors; and at the very last came accounts of the first two voyages out of England into Guinea.

Richard Chancellor, who had returned to England in 1554 to establish the Muscovy Company, had sailed again in 1555 with factors who were

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1 The Decades of the newe worlde or west India, Conteynyng the navigations and conquestes of the Spanyardes, with the particular description of the most ryche and large landes and Ilandes latelye founde in the west Ocean perteynyng to the inheritance of the kinges of Spayne. In the which the diligent reader may not only consider what commoditie may hereby chaunce to the hole christian world in tyme to come, but also learn many secreates touchyng the lande, the sea, and the starres, very necessarie to be knowe to al such as shal attempte any navigations, or otherwise haue delite to beholde the strange and woonderfull workes of God and nature. Wrytten in the Latine tongue by Peter Martyr of Angleria, and translated into Englysshe by Rycharde Eden. Londini. In aedibus Guylhelmi Powell. Anno. 1555.
to live in Russia and collect the Russian goods for transport to England. Returning in 1556 with the two ships of Sir Hugh Willoughby's lost squadron which the Russians had found frozen in the ice, Chancellor had met with a series of great storms. Of his four ships all save one foundered or were cast away. He himself perished on the Scottish coast, while attempting to save the life of the first Russian ambassador to the Court of St. James's. However, in that year three of the Muscovy Company's ships sailed for Russia. One of them, the pinnace Searchthrift (her commander, Stephen Borough), pushed eastwards along the Siberian coast in search of the route to Cathay, but at the island of Vaigats turned back in the face of approaching winter; and thereafter for over twenty years exploration in this direction ceased. The company, though vested with the rights of exploration, was content to exploit the Russian trade.

Modest as the success of the Cathay venture was, it was yet of prime importance in the development of English maritime enterprise and navigational skill. The immediate gains were important. The principal Russian products were naval stores—pitch, hemp, and timber. Hitherto these had come from the Baltic through the medium of the Hansa League, who could thus control the English navy and merchant marine. The Russian trade broke this monopoly, and placed a lever in the hands of the English with which they could prise open a way into the Baltic trade. This they soon did, as the ships of the realm had been made free of dependence upon the Hansa for their moorings, rigging, and spars. Moreover, the commercial organization, the joint-stock company, created to finance the trade that arose from the discoveries, proved so sound that it was adopted with equal success as a means of financing later trading, colonizing, and raiding ventures otherwise quite beyond the means of individual merchants or captains or even of the Government. Chancellor and Willoughby had not given their lives in vain.

While the English, under the expert guidance of Sebastian Cabot, were opening new markets in the north-east, an old one was closing up in the south-east. Since 1458, when Robert Sturmy of Bristol had first ventured into the Levant in search of wines and spices, English merchants had occasionally traded to the Levant for the wines of Chios and the currants of Greece. Henry VII and Henry VIII had fostered the trade, and individual merchants, despite the hazards of the voyage, which took a year, made fortunes. But in the face of the advancing Turks the risks mounted. The voyages, never very frequent, declined and, despite the bark Aucher's voyage of 1550, the last recorded voyage for a quarter of a century was made in 1553. But another and perhaps more lucrative source of trade was now being tapped. Cabot had with him John Alday, who described himself as his servant and 'a man of knowledge in the Arte of Navigation and Cosmographie', whom Cabot had prevented at the last from sailing as master of the bark Aucher in 1550. The reason is not clear, but it may have been that, as the voyage was likely to take a year, and he had a venture in a different region of the world on hand, he needed a man of Alday's abilities
to conduct it. John Alday claimed that it was on his suggestion that 'the first voyage of traffique into the Kingdom of Morocco in Barbarie, [was] begun in the yeare 1551, with a tall ship called the Lion of London, of 150 tons'. It is more probable that it came from discussion between Cabot and leading English merchants in the Spanish and Levantine trade. He may well have talked over with Roger Barlow the latter's voyages to Madeira and the Azores, made in the course of his trading at Seville, and the business journey, probably in search of sugar and dates, he had made to Santa Cruz in Morocco, the modern Agadir. Moreover, Cabot was related by marriage to William Ostrich, eventually Governor of the English merchants resident in Spain and deeply engaged in the Levant trade. It was in Cabot's interests to further those of Ostrich, and he must have known the Levant trade was becoming too risky. However that may be, John Alday should have sailed as master of the first English voyage to Morocco but was prevented by 'the sweating sickness', which broke out in London and which several of the promoters also caught. Nevertheless the Lion sailed. She left Portsmouth under the command of Thomas Wyndham, before, as the luckless John Alday put it, 'I was able to stand upon my feet'. Two Moors accompanied Thomas Wyndham 'whereof one was of the King's blood'; perhaps the other knew the coasts. Thomas Wyndham had served in the navy against the French, rising to the command of vice-admiral in the campaign of 1547. The settlement with France in 1550, which had followed the wrestling of Boulogne from the English, had left him conveniently free. He was clearly a competent, and probably French-trained, pilot, and he would have had the observations of Roger Barlow on the route. Wyndham returned from Barbary before the year was out, with sugar, dates, almonds, and molasses—luxuries the English longed for. Already they were beginning to benefit from Sebastian Cabot's guidance. A second equally successful voyage, but with three ships, followed in 1552, and included a call, apparently for the first time by an English ship, at the Canary Islands. The Portuguese viewed these voyages with anger and 'gave out in England by their merchants, that if they tooke us in these partes, they would use us as their mortall enemies'. But as they had withdrawn their garrisons from Safi and Santa Cruz in 1541, they were powerless to prevent the trade. Indeed, for them worse was to follow. A Portuguese, Anthony Pintado, falling into company with Wyndham, agreed with another Portuguese pilot, Francisco Rodrigues, to pilot Wyndham to the Guinea coast for ivory and gold. On 12 August 1553, three months after the first expedition for the discovery of Cathay by the north-east route sailed from London, the Primrose and the Lion, with the pinnace Moon, sailed from Portsmouth for the Guinea coast. After avoiding a Portuguese warship at Madeira, Wyndham came out in his true colours. He quarrelled with Pintado, usurping his command and thrusting him amongst the sailors with opprobrious words. Nevertheless

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10—A.O.N.
he saw to it that Pintado piloted them to the Guinea coast. There they
loaded 150 lb. of gold. Success assured thereby and the season growing
late, Pintado advised that the return voyage be started. But Wyndham
would have none of it. By threats and insults he forced Pintado and
Rodrigues to pilot him eastward along the coast of Benin to the delta of
the Niger, there to load pepper. It was his undoing. The crews, unaccus-
tomed to the tropical fruits and climate, fell ill and died. Wyndham him-
self died. The men remaining fell upon Pintado with bitter reproaches
for leading them to such a place and forced him to sail for home leaving
merchants on shore. Then Pintado too died. Of all that company 'of
seven score men came home to Plymouth scarce fortye, and of them
many dyed'. It was a sorry tale for all its golden ending, ignorance and
covetousness competing against knowledge and prudence.\textsuperscript{1}

The absence of such contentions over the Russian trade speaks much
for the wisdom of Sebastian Cabot's guidance when it could be exercised
personally. He had carefully drawn up 'Ordinances, Instructions, and
Advertisements' for the proper regulation of the voyage of discovery
to the north-east and for any subsequent trade.\textsuperscript{2} For us, following
the development of the art of navigation, the seventh instruction is of particular
interest. It reads as follows:

7. Item, that the merchants, and other skilful persons in writing
shall daily write, describe, and put in memorie the navigation of each
day and night, with the points, the observations of the lands, tides, ele-
ments, altitude of the sunne, course of the moon and starres, and the
same so noted by the Master and Pilot of every ship to be put in writing,
the Captain-Generall assembling the masters together once every
weeke . . . to put the same into a common leger, to remain a record for
the company: the like order to be kept in proportioning of the Cardes,
Astrolabes, and other instruments prepared for the voyage.

Here were the essentials for subsequent successful voyages over the
same route. So sound were they that they became an integral part of every
subsequent English voyage of repute.

Despite the mortality of the first Guinea voyage, despite the protestations
of Portugal, sustained by Philip, other voyages followed. The Portuguese
Pintado (whose defection, after failing to get him extradited, the King
of Portugal had tried to prevent by a belated pardon) had taught too well
the secrets of the wind system and the currents off the Guinea coast.
Besides, Rodrigues survived to impart to others the knowledge, lack of
which made voyaging there a desperate venture of dead calms or head-

\textsuperscript{1} Arber, E., \textit{The First Three English Books on America} (1885); and \textit{Europeans in
West Africa} 1450–1560, Vol. II, Hak. Soc., Ser. 2, Vol. 87. This has a good map of
the West African and Guinea Coasts showing the prevailing currents and typical
courses sailed on outward and homeward voyages. Ignorance of the currents often
prolonged the homeward voyages as much as the fickle winds.

\textsuperscript{2} See Appendix 4 for other of Cabot's ordinances.
winds and unaccountable drifting. The bitter lessons, too, of Wyndham’s shipboard quarrelling instilled a better sense of discipline and hygiene into the English seamen. John Lok commanded the second venture, of 1554 to 1555, and Richard Eden, by including in his *Decades of the newe worlde* a journal of the voyage, printed, in effect, the first English rutter for Atlantic, but not, of course, transatlantic, voyaging. It should be remarked that by including Oviedo’s *Of the ordinary nauyagation from Spayne to the West Indyes* he gave a good idea of the transatlantic routes used. The three ships Lok took on the second Guinea venture were again very small—the *Trinity* of 140 tons, the *Bartholomew* of 90 tons, and the *John Evangelist* of 140 tons. Sailing from the Thames they called at Dover, Rye, and Dartmouth. ‘The fyrst day of November at IX of the clocke at nyght departynge from the coast of Englunde, we sette of the stert [Start Point] barynge southwest all that nyght in the sea, and the neste day all day, and the next nyght after untill the thyrde daye of the sayde moneth about noone, makyng our way good, dyd runne 60 leagues. Item from xii of the clocke the thyrde daye tyll xii of the clocke the iii day of the sayde mooneth, makyng our way good southeast, dyd runne every three houres twoo leagues, which amounughteth to xvi leagues the hole [for the day’s run].’

It will be seen that the point and time of departure were carefully noted, and that the way or course ‘made good’, that is to say, the courses steered and the estimated speed, corrected by means of the traverse board and checking of the leeway, were recorded from noon to noon. Each day the journal or rutter recorded the daily run. Then on ‘the xix day at XII of the clocke, we had syght of the Ile of Palmes and Teneriffa and the Canaries’, the rutter went on. The means of recognizing these by the landfall followed: ‘The Isle of Palme ryseth rounde and lyeth southaste and northwaste, and the northwaste parte is lowest. In the south, is a rounde hyll over the hedde lande, and another rounde hyll above that in the lande. . . . This Ile of Palme lyeth in the XXIX degrees [in latitude 29° N] . . . Teneriffa is a hygh lande and a greate hyghe picke lyke a sugar lofe. And upon the sayde picke is snowe throughout all the hole year . . . it maye be knowne above all other Ilandes, . . .’ It was to become a familiar sight to Englishmen. In careful detail, giving land-marks, latitudes, soundings and the nature of the sea-bed in safe anchorages, the appearance of headlands, the lie of the land and the distances covered, the rutter carried on to the Guinea coast. It told what and where the ships traded. It was rich in casually thrown out hints and wonders. The pilot who wrote it was a friend of Richard Eden. He, though a scholar, could yet record ‘sum of oure men . . . affirme ernestly that in the nyght season they felt a sensible heate to coomme from the beames of the moone’ as credulously as the fact ‘that in certeyne places of the sea, they sawe certeyne stremes of water which they carle spoutes saulynge owt of the ayer into the sea. And that sum of these are as bygge as the great pyllers of churches’. The English now found for themselves and for the first time recorded that ‘the keles of theyr shyppes were marvelously overgrowen with certen shells of ii
ynches length and more, as thycke as they could stande', which greatly hindered their sailing, and that 'Theyr shyppes were also in many places eaten with . . . woormes . . .', to prevent which one of the ships of the 1553 expedition to the north-east had been sheathed with lead after the Spanish fashion—thanks to Cabot.  

'Amonge other thynge that chaunted . . . it is worthy to be noted', the account ran, 'that whereas they sayled thether in sevene weeks, they coulde returne in no lesse space than xx wecke.' This was explained by the prevailing easterlly winds off Cape Verde 'by reason whereof they were inforced to sayle farre oute of theyr course into the mayne Ocean to fynde the wynde at the west to bring them home. . . . It was also worthy to be noted that . . . they overtooke [for the first recorded time in English voyaging] the course of the Soone, that they had it north from them at noone the xiii day of Marche'.

It was Cape Verde, 'the green cape', he explained, 'to the whiche the Portugales fyrrst directe theyr course when they sayle to America or the lande of Brasile . . . departynge from thence, they turne to the ryght hande to warde the quarter of the wynde . . . betweene the west and south . . .'. But that was forbidden territory, and these English ships made their sweep out into the ocean for home. They checked their latitude frequently, but guessed their bearing and distance, to begin with from the Cape Verde Islands, later as they progressed north 'from the Azores untill we came in xlii degrees, where we set our course east northeast, judginge the Ile of Corvo south and by west of us and xxxvi leagues distant from us'. And so they came home bringing 'fourte hundreth pounde weyght and odde of golde . . . and about two hundreth and fiftie elephantes teeth . . .'. Also they brought 'certeyne black slaves . . .'.

An incident occurred during a voyage to Guinea undertaken by William Towerson in 1558 which fortunately has been recorded by the faithful Hakluyt. 2 It affords a good insight into voyages made in time of war, in the middle of the sixteenth century, into the superior sailing qualities of English ships, and into the arms and instruments of navigation carried by a ship—in this instance, a Danzig 'hulk'—trading to Bordeaux. The Marian government had declared war on France on 7 June 1557, in accor-

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1 The Spanish had tried sheathing their ships with thin sheets of lead as a protection against the worms which could rapidly reduce a ship's bottom to a honeycomb condition. This proved too expensive for normal use; also its weight made it fall away from the bottom. It also set up an electrolytic action with the iron bottom fastenings. In addition to the worms rendering the bottom unsafe, weeds and barnacles grew upon it and could take knots off a ship's speed. Frequent beaching and breaming (burning off the weeds with brushwood fires) and careening (stranding the ship or hauling it over in sheltered waters for scraping, recalking and coating the bottom with preservatives) were essential to seaworthiness. It was an Englishman, John Hawkins, probably in the 1560s, who first devised a practical form of wooden sheathing that combined cheapness with fair efficiency. It remained in use until copper sheathing was adopted in the 1780s.

ance with the wishes of Spain. On 8 January 1558 French forces occupied Calais. At the end of that month Towerson’s expedition left Plymouth Sound. On the day of their departure ‘they met with two hulks of Dantzick, the one called the *Rose*, a ship of foare hundred tunnes, and the other called the *Unicorne*, of an hundred and fifty tunnes . . . both laden at Bordeaux, and for the most part with wines’. On examination it was found that their ‘charter-parties’ were false, and it was suspected that they were laden with French goods. These suspicions were quickly found to be correct, for on opening the ‘bils of lading’, which were directed in Dutch to Hamburg, it was found that their contents were entered in French. As French goods were lawful prize, a conference was held to decide what was to be done, whether to carry the ships into Spain or whether to take what they could then and there, and proceed on their way. After much altercation from the crews of the English ships, and some quiet authoritative arguments by Towerson, it was decided not ‘to carry them into Spaine, seeing they sailed so ill that, having all their sailes abroad, we kept them company onely with our foresailes and without any toppe sailes abroad, so that in every two dayes sailing they would have hindered us more than one’.

The trouble was that Towerson dared not delay if he was to make a successful trading voyage to Guinea. He would miss the season, suffer calms, head-winds, sickness, scurvy, death.

‘All these things considered’, they all paused in their disputes while the Danzigers looked on with troubled eyes, fearful of what the heated words might mean. At the last it was determined ‘that every man should take out of the hulks so much as he could well bestow for necessaries’, and that they should then proceed. So they took for the ships a small hawser for ties for the yards and six double bases with their chambers—twin-barrelled breech-loading guns for rapid, close-range firing during boarding. Meanwhile the men helped themselves. They ‘broke up the hulks’ chests, and took out their compasses and running glasses, the sounding lead and line, and candles’; indeed they despoiled the crews of the *Rose* and the *Unicorne* of so much that Towerson and others of his type gave them, out of pity, ‘a compasse, a running glasse, a lead and a line, certain bread and candles, and what apparell of theirs we coulde finde in their ship . . .’. The French pilot, whom the Danzigers had been unable to set ashore after the passage down ‘the river of Bordeaux’, they ransomed; ‘. . . in fine we agreed to let them depart, and gave them the rest of the wine belonging to the Frenchmen for the fraught of that which we had taken . . .’. They then went on their way to make, as it proved, a very profitable third voyage to Guinea. It will be remarked that neither quadrant, astrolabe, cross-staff, nor chart was mentioned as being amongst the navigational instruments seized, perhaps because if carried they would have been the personal property of the pilot.

While English seamen were becoming more adventurous and obtaining their first experiences of navigation, the way to surer and swifter progress was being made by Englishmen in other walks of life.
When in 1558 Elizabeth came to the throne, not only was Chancellor 'the incomparable' dead, but the venerable and sagacious Sebastian Cabot, too. Chancellor had trained Stephen Borough to succeed him, and he in his turn had brought his young brother, William, to sea. By now the latter was a skilled hydrographer, and the elder Borough was privy to the instructional system of the navigation school at Seville, first described to Englishmen by Richard Eden. Moreover, a brilliant young Welshman, John Dee, had already established a reputation as a mathematician. With Chancellor he had made and used instruments for observing data and making calculations for the astronomical tables for the voyages to the north-east. He was in touch with, and the respected friend of, Gemma Frisius, now Cosmographer to the Emperor, of Pedro Nuñez, now Cosmographer Royal of Portugal and professor of mathematics at Coimbra, and of Gerard Mercator, now settled at Duisburg, cosmographer, globe-maker, instrument maker, and the leading cartographer in the world. John Dee took the place of Cabot as the technical adviser on navigational problems to the Muscovy Company, and tutor to their sea-captains.

Although there were as yet no chairs of mathematics at either of the English universities, and mathematics was not part of the ordinary schooling, there was a small but slowly growing number of students and teachers of that subject in England. Throughout the sixteenth and early seventeenth centuries the very language of mathematics—the symbols and abbreviations used—was still being evolved by individual scholars, so that original work in mathematics called for high intellectual powers. We have seen in the extracts from the Guinea voyage that pilots still used roman numerals. In these calculation is possible only with the aid of an abacus. The first printed work on arithmetic in English had appeared only in 1542. If we appreciate that 'arts' included what we should now term 'science', the title of the work, *The Ground of Artes*, was singularly appropriate.¹ In 1551 the same teacher, Dr. Robert Recorde, published a similar popular textbook on geometry and the use of the quadrant. Again it was the first of its kind in English. This book he called *The Pathway to Knowledge*—also a felicitous title.² As a knowledge of geometry was essential to the practice of navigation, we can be fairly sure that these later works were

¹ [Recorde, R.], *The groound of artes* teaynyng the worke and praactise of Arithmetike, moch necessary for all states of men. After a more easyer & exacter sorte, then any lyke hath hyhthero ben set forth: with dyuers newe additions, as by the table doth partly appeare. [1543. B.M. copy].

² The pathway to KNOWLEDG, CONTAINING THE FIRST PRINciples of Geometrie, as they may moste aptly be applied vnto praactise, bothe for use of instrumentes Geometricall, and astronomicall and also for prociection of plattes in euerye kinde, and therefore much necessary for all sortes of men.

Geometries Verdicte
All freshe fine wittes by me are filed,
All grosse dull wittes wishe me exiled,
Though me no manners witte reiect will I,
Yet as they be, I wyll them trye. [1551]
intended to aid navigation in England, for *The Castle of Knowledge*, a
treatise on the sphere, was written and specifically printed in 1556 for the
use of the Muscovy Company’s navigators; while *The Whetstone of Witte*,
another elementary mathematical text-book, was dedicated in 1557 to
the Governors of the Muscovy Company. Robert Recorde’s work may
have been popular, elementary, instructional, but it was invaluable for
just that reason. It brought mathematics out of the scholar’s closet into the
merchant’s counting-house and into the sea-captain’s cabin. ‘He made
Arithmetic plainer than it had ever been before. He taught Astrology and
expounded Cosmography, he illuminated Geometry...’ it was later
said. No doubt he would have done the same to navigation as a whole, but
he died before his promised work on that art could be completed.

When the gifted young John Dee, who had gone to Louvain University
to complete his studies, had returned in 1547, he had brought with him,
besides ‘sea-compasses of divers sortes’, what were comparative novelties
in England, ‘rare and exquisitely made instruments Mathematical’,
two great globes of Gerardus Mercator’s making’, and astronomical
instruments. These he had given to Trinity College, Cambridge, for ‘the
use of the Fellows and Scholars’. Two years later, by the time Cabot was
in England, the study of the classical geographers—Mela, Pliny, Strabo,
and the great Ptolemy—had been instituted as a branch of mathematics.

While Dee was essentially a mathematician with a bent for astrology,

1 [Recorde, R.], *The Castle of Knowledge*. [1556]
2 *The Whetstone of Witte*, which is the second parte of Arithmetike: con-
taining the extraction of Rootes: The *Cossike* practise, with the rule of *Equation*:
and the woorkes of Sturde Nombers.

    Though many stones doe beare greate price,
The whetstone is for exersice
As needesful, and in woorke as strange:
Dulle things and harde it will so change,
And make them sharpe, to right good use:
All artesmen knowe, thei can not chose,
But use his helpe: yet as men see,
Noe sharpenesse semeth in it to bee.

    The grounde of artes did brede this stone;
His use is great and moare then one.
Here if you list your wittes to whette,
Moche sharpenesse thorow shal you gette
Dull wittes hereby doe greatly mende,
Sharp wittes are fined to their fulle ende.
Now prove, and praise, as you doe finde,
And to your self be not vnkinde.

These Bookes are to bee solde, at the Weste doore of Poules, by Ihon Kyngstone.
[1557]

of his work.
astronomy, and navigation, the practitioners of other arts flourishing in England were now to make their contribution to the growth of the art of navigation. These were the astronomer, the astrologer, the almanac-writer, and the surveyor. The instruments and techniques of the latter, so necessary to the good charting of new lands, were developed on the Continent in the early sixteenth century, largely as a result of the demands of siege warfare with cast cannon. The discovery of the art of casting cannon, made at the end of the fifteenth century, had made bombardment at unprecedented ranges possible, and thus called for the means of siting cannon correctly, and of aiming and of elevating them accurately. In England a professional army, such as was to be found in every continental country, did not exist. The Crown strictly controlled the armed forces, and prohibited private ones. Under Henry VIII the Royal Navy attracted many of the nobility desirous of a martial career; moreover, England was still not fully conscious of having changed from being on the periphery of the world to being nearer to its hub. Siege warfare did not loom large in the military curriculum. Technical advice, when needed, was given by foreign experts. Indeed, the first English book on the art of gunnery was not printed before 1578, and then it was taken, lock, stock, and barrel, from a continental text-book of many years’ standing. What chiefly stimulated surveying in England was the break-up of the Church lands, and the creation of new properties, at the end of Henry’s reign. The arts of the land-meter and the steward took on a new importance. So it was in the 1550s that the first up-to-date English text-book on surveying appeared. It was based, of course, on the mathematical methods developed on the Continent; nevertheless it marked an important addition to English intellectual life and professional practice, as the author, Leonard Digges, claimed. A Book named Tectonicon came out in 1556. Leonard Digges was a landed gentleman of Kent with a passion for practical knowledge, who spent some time on the Continent where, like the studious John Dee, he mastered the latest scientific ideas and practices. So it was that Digges’s book placed before the English the latest astronomical and geometrical surveying methods developed on the Continent. Like John Dee, Leonard Digges was also an almanac-writer, and an astrologer. Dee’s Astronomicall and Logisticall Rules, designed for use on the voyage of 1553, were matched by an almanac, no longer extant, by Leonard Digges.1 It is possible that it, too, was intended to aid the first English navigators. A printed edition appeared in 1555, and was dedicated to Sir Edward Fiennes, Lord Clinton and Saye, and later Lord High Admiral of England until his death in 1585. This was probably the first English almanac covering a period of years to include tide-tables. Leonard Digges, and from 1570 his son Thomas, regularly produced new editions of the Prognostication, the last appearing as late as 1635. The fulsome title of the 1555 edition gives a good

indication of their contents when written by Leonard Digges. To many, the first part of the Prognostication, with its propitious days for various activities, was of little less importance than the succeeding astronomical and tide-tables or the instructions on how to make a sun-dial and use it for finding the time at night by the aid of the moon or the two stars Aldebaran and Abramech.2

That the practical and superstitious should be blended in one book was typical of men's minds at that time. But though they might be ignorant of the causes of natural events and even credulous, they were yet, for practical purposes, observing and reducing to order certain common phenomena; astrologers of the better sort were reputable physicians, mathematicians, or astronomers, and were among the first to respond to the ever-growing demand for more accurate astronomical tables for navigation based upon accurate observations of the celestial bodies.

Astrologers, astronomers, and, soon, seamen, needed instruments, wrought in metal, accurately balanced, graduated, mounted. Thanks to Henry VIII's introduction of skilled gunfounders and gunsmiths, and to the developments made by them in the art of gunnery, the skilled metal-workers were already in England. They were already making surveyors', astronomers', and gun-layers' instruments that, under the tutelage of religious refugees from Flanders, were soon to reach a high degree of perfection. The craftsmanship of Thomas Gemini (fl. 1550–60), and of Humphrey Cole (fl. 1560–80), for instance, is quite remarkable for its beauty, balance, and accuracy. Nor must the printers and publishers of books be forgotten. It is significant that it was from this time, in the reign of Philip and Mary, that the Company of Stationers received its first charter. Many of its members, too, were foreigners who brought with them, and demanded of the English, the advanced standards of the Continent in book production. They called for finely engraved illustrations, and so fostered the training of such men as Augustine Ryther, who towards the end of the century engraved amongst others the lovely charts illustrating Lord Howard's Armada dispatch. The handiwork of these men, many of them of humble origin, was, we must recall, to be indispensable to the seaman who aspired to be a navigator.

While these craftsmen played their part, no less important were the theorists, like John Dee and Leonard and Thomas Digges. William Borough

1 *A PROGNOSTICATION OF RIGHT GOOD effect, fruitfully augmented, containyng playne, breife, pleasant, chosen rules, to iudge the wether for euer, by the Sunne, Moore, Sterres, Cometes, Raynbowe, Thunder, Cloudes, with other Extraordinarie tokens, not omitting the Aspects of Planetes, with a breife Judgemente for euer, of Plente, Lacke, Sickenes, Death, Warres &c. Openinge also many naturall causes, woorthy to be knowë. To these and others, now at the last are adjoyned, divers generall pleasaunte Tables: for euer manyfolde wayes profitable, to al maner men of vnderstanding: therfore agayne publisshèd by Leonard Dygges Gentylman, in the yeare of oure Lorde. 1555.*

2 *Imprinted at London, within the blacle Fryars, by Thomas Gemini. 1555.*
complained to the Queen in 1578 of their lack of practical experience, but, although there was some justification for his complaint, the theorists kept the problems of navigation before the intellectual strata of society. Keen wits amongst them were to take Borough’s doctrine of ‘practice at sea’ to heart. Thomas Digges, for instance, spent three months at sea in order to demonstrate to seamen the truth of his mathematical proofs. He was only the first of many mathematicians to go to sea. Thereafter it did not take long for the value of mathematics in navigation to be grasped by the English. The contributions of scholars then became welcome along with those of the craftsmen. For instance it was William Barlow, an arch-deacon of the Church—who loathed the sea—who was to improve the mariner’s compass. On the other hand it was Edward Wright, a university scholar, who combined practical experience at sea with mathematical ability of the first order, who was to solve the greatest cartographical problem of the age. This was the representation of the earth’s curved surface upon a plane surface in such a manner that courses and distances could be accurately plotted by the navigator.

As yet, however, it is unlikely that any English seaman had crossed the ocean unaided. But the English had this much at hand: the elements of the necessary knowledge, the men to teach it, and, thanks largely to Richard Eden, the beginnings of the desire to learn.

In the very first year of Elizabeth’s reign, at Norwich on 18 July 1559, William Cuningham, doctor in physic, and since 1553 editor of an annual almanac, set out for readers ‘the dignitie and ample use of Cosmographie’ in the preface of his _The Cosmographical Glasse_, the first treatise exclusively on cosmography printed in English.¹

By cosmography, Cuningham pointed out, America, the fourth part of the world ‘(unknowne in all ages before our time)’ had been discovered, likewise the Indies in the East. And he advocated its study both on grounds of its practical value to seamen and its educative value to the man of affairs who was unable to travel abroad.

_The Cosmographical Glasse_ has been criticized as being of no originality, not up to date, and soon superseded; and by another as being beyond the mental powers of anyone who had not had a university education. The book may have had these faults, but it must be remembered the author laid no claim to originality. If by being not up to date is meant that there was no mention of the Copernican theory of the cosmos, this applies equally to


_In this glasse if you will behold_
_The Sterry Skie, and Earth so wide,_
The _Seas also, with winters so colde,_
_Then and thy selfe all these to guide:_
_What this Tyde meane first leare a right,_
_so shall the gayne thy travaull quight._
standard books on the subject written a century later; while as to its being quickly superseded, it is to be remarked that it was one of very few books forming the library of Martin Frobisher's expedition to find a North-West passage to Cathay in 1576. But just as it was a supreme mental achievement to develop mathematics in this era, so was it hardly less of an achievement to compose in English a book on a novel technical subject in language which can still be appreciated for its lucidity and nobility.

Whatever its faults, William Cuningham's book did for cosmography, and to some extent for navigation, what Robert Recorde's books had done for mathematics; it brought the subject from the recesses of the scholar's closet to the shelves of the gentry and the desks of the merchants. Within ten years of its publication, many Englishmen guided by it had learnt to 'like, love, get and use Maps, Charts, and geographical globes'. The seed sown by John Dee's gift of astronomical instruments to Cambridge University, and cultivated by a physician, sprang up and brought forth good fruit in many Englishmen's minds—a desire for geographical knowledge. This in its turn was a stimulant for nautical enterprise, which generated in Englishmen an interest in navigational problems and their solution that still survives.

1 Dee, J., Preface to Billingsley's *Euclid* (1570).
Chapter Four

THE INITIATION OF THE ENGLISH INTO THE ART OF NAVIGATION

'... how indigent and destitute this Realm is of excellent and expert Pilottes. ... But as touching Stephen A. Brough, the chief Pylote of your voyages of discovery ... he is neither malicious nor envious of his arte and science ... he desireth ye same for the comon profeite to be comen to al mi: And for the same intent was the fyrst that moved certen worshipful of your company ... to have this worke translated into the Englyshe tongue ... knowe therefore this worke of the art of Navigation, being publisshed in our vulgar tongue, you may be assured to have more store of skylful Pilotes ... such as by their honest behaviour and conditions joyned with arte and experience, may doe you honest and true service ...'


When Elizabeth I came to the throne English trade, which had been bad for twenty years, was getting steadily worse. The sale of woollen goods was becoming ever more difficult in the face of increasing competition from countries whose products, if not of superior finish—as they often were—could be bought more cheaply. An end had been put to the Mediterranean trade five years since by the ruthless advance of the Turks; and on the Guinea coast trading ventures had become increasingly hazardous by reason of increased Portuguese armed intervention. In only one direction had new markets been established, in the north-east, but here the market for woollen goods was limited, and the rigours of the north Russian climate seemed to place a bar upon further expansion in that direction. England was still smarting from the loss of Calais, her continental possession, lost in 1558 by Mary, in the interests of whose Spanish husband, Philip II of Spain, the country had rashly gone to war. Rashly, because the navy had been unready to go to the succour of the beleaguered garrison of Calais, which had been forced to capitulate. Englishmen looked back upon the Spanish interlude of Mary's unhappy, persecution-ridden reign with loathing and resentment. There had been no material gains, only losses and frustrations. Besides the culminating insult of the loss of Calais, they had been refused a share in the lucrative trade with the colonial empire of Spain. This had continued to be the absolute monopoly of the merchants and officials of the Casa de Contratación at Seville. Furthermore, the English merchants now long established in Spain, in Seville, Cadiz, and San Lucar, and in the Atlantic islands, the Madeiras and Canaries, had been looked upon with increasing
suspicion as heretics, and as legitimate subjects for the Inquisition. Philip, as Mary's consort, had done his best to suppress the Guinea trade, and had granted the charter to the Muscovy Company only because he was farsighted enough to allow an outlet to English energies by legitimizing a trade that clearly lay beyond the confines of Spain's sphere of interest.

In losing Calais the English had lost their chief export market or 'staple' for wool—an important though dwindling export—and experience was soon to prove this loss irreparable. Staples set up in the Low Countries never flourished. The loss of Calais did more than cause resentment and damage trade; unperceived it had this merit: it tended to divert the flow of Englishmen's ambitions at the very moment that the precariousness of England's European markets demanded it. Its most immediate effect, however, had been to make clear the fate likely to befall an island country lacking an adequate navy. England was only part of an island; Wales formed a part of the realm, but Scotland was an independent kingdom under French influence, and France was hostile and had a Scottish queen. Philip, Spain, the Spanish Empire, were Catholic; Elizabeth, and hence England, heretic and Protestant. Common prudence exacted the creation of an efficient navy and the prosecution of a policy designed both to restore the economy of the country, and to guide its feet into the way of peace.

It is impossible to dissociate the name of Sir William Cecil, later Lord Burghley, from the history of English maritime achievements. It is not too much to say that he was the presiding and directing genius behind them from the first day of Elizabeth's reign until his death in its closing years. Without his guidance, without his directing and controlling will behind the technical advisers of the Crown on maritime affairs, the rapid rise of Englishmen to fame on the high seas could never have occurred. Just how rapid that rise was can be gauged by the fact that in 1558 probably not one, as late as 1568 probably only one, English seaman was capable of navigating to the West Indies without the aid of Portuguese, French, or Spanish pilots. Yet, by the time of the Armada, a mere score of years later, Englishmen had gained 'the reputation of being, above all Western nations, expert and active in all naval operations, and great sea dogs'.

Right from the start of Elizabeth's reign the policy of England was to keep a navy 'ever in readiness against all evil haps', and to ground this healthily upon a mercantile navy of well-manned, well-found ships—well armed too, if need be—conned by experienced pilots. In this the people,

2 See Waters, D. W., 'The Elizabethan Navy and the Armada Campaign' in M.M., Vol. 35. A source-book of great value is E. M. Tenison's Elizabethan England, a magnificent production, profusely illustrated and covering every aspect of Elizabethan activity. Anglo-Spanish relations and culture are particularly well illustrated. The work is still being issued. The first eight volumes (issued between 1933 and 1947) cover the period 1553 to 1589. Naturally, however, no one can afford to neglect Conyers Read's Bibliography of Tudor History, which is the standard work, though much subsequent research on maritime matters has been published since its issue.
the merchants, Parliament, and, as important as any, the patrons of science and art, the nobility, were at one. While Burghley may thus be credited with being the able interpreter and executor of their policy, his minutes leave no doubt that he was the initiator as well as the planner and contriver of ways and means of a mercantile policy designed to support a strong, self-sufficient fleet by means of wide-flung seaborne trade and native fisheries. Nor is this surprising in view of his mental calibre, for it will not be forgotten that he must have been nurtured on Richard Eden’s translations of the maritime achievements of Spain.

In numerous Acts passed during the reign, in the charters of new companies, will be found wording such as ‘for the maintenance of the Navy’ or ‘for the maintenance and increase of the Navy and mariners’. An idea of the tenacity with which the English pursued their aim can be got by a brief citation of some of the most important early enactments. The sale of ships to foreigners was forbidden in the first year of the reign; besides subsidies to encourage the building of larger vessels, the small coastwise vessels were forbidden to partake in the foreign trade, so that the building of larger ships for this was obligatory; in 1562, by an ‘Act touching certain Politic Constitutions made for the Maintenance of the Navy’, the English coasting trade was confined to English ships and the wine trade, which for the last eighty years had been confined to English ships ‘the greater part of the crew of which were English’, was confined exclusively to English ships with English masters: it was further enacted that fishermen and ‘Mariners haunting the Sea as Fishermen or Mariners’, should not be compelled to serve as soldiers upon land or at sea, except as mariners, and shipwrights and shipowners were empowered to take apprentices; and in an attempt to encourage the fisheries, fish-eating days were instituted, and the landing of English-caught fish was made duty-free. It was three years later, in 1565, that, it will be recalled, the Trinity House of Deptford had its powers increased to include the setting up of beacons and sea-marks anywhere necessary on the coasts of England and to prevent the removal of land-marks, such as well-known buildings, towers, steeples, or trees, and to ensure their maintenance in good order. In 1571, in an endeavour to encourage the building of larger vessels, the carriage of fish was confined to ‘cross-sail’ vessels. These are only some of the earliest measures

1 Cunningham, W., The Growth of English Commerce and Industry in Modern Times (1903) is the standard work on the subject, and a fascinating source-book.

2 5 Elizabeth cap. 5 (1562). An Act touching certain Politic Constitutions made for the Maintenance of the Navy.

3 This was one of the measures advocated by John Montgomery in a treatise he wrote in 1570 ‘On the Maintenance of the navy’, which he dedicated to the Earl of Leicester (B.M. Add. MS. 18,035). John Montgomery was one of the young men trained in navigation during the voyage to Chios in the bark Aucher, in 1551. His treatise came to the notice of Stephen Borough and was used by him to strengthen his arguments in support of measures designed to increase the mercantile marine and the standard of navigation. After the Armada, 1588, Montgomery added to his treatise, embodying various naval ‘lessons learnt’. His MSS.
of the reign, but they suffice to give the tenor of its economic legislation and to illustrate the argument that the English, once forced to take to the sea, became competent seamen as a result of a deliberate national policy. As early as 1540 Henry VIII had framed a Navigation Act 'For the Maintenance of the navy of England . . . ' whose preamble admirably sets forth the case for the advancement of navigation.1

Now, united as never before in the last quarter of a century by the firm handling of the religious issue by Elizabeth, and by antipathy to Spain and Catholicism, and guided by the unobtrusive genius of Sir William Cecil, the English were at last taking whole-hearted measures to maintain and increase their navy, navigation, and seamen. The necessary supplies of timber and naval stores were being safeguarded, and the shipyards and shipwrights for ship-building encouraged; a sufficiency of seamen and masters to man the ships, and of pilots to conduct them in and out of port and overseas, was being assured; better sea-marks, surer land-marks, safer ports for lading and discharging cargoes—all were being legislated for, and, as we shall see, the legislation was being made effective through the medium of the Trinity Houses.

The man behind the initiation of this important legislation and the increased activities of the Trinity Houses was Stephen Borough. One inestimable gain the English had won from the Spanish marriage was this: in 1558 Stephen Borough, who had succeeded Richard Chancellor as Chief Pilot of the Muscovy Company, had been admitted to the Casa de Contratación at Seville as an honoured guest. There he had been shown the system of training which for the last half-century had been turning out pilots and navigators qualified to conduct ships on the various routes laid down to and from and in the Spanish Indies. He had been shown the instruments and manuals used and the process of examination. He had returned filled with admiration for an establishment where knowledge was so well organized and so well taught, and with a shrewd insight into the power that competence in navigation conferred on a nation.

Borough had returned impressed also with the depth of knowledge and the high degree of skill required for successful navigation. He appreciated that knowledge and skill could only be acquired by a combination of good teaching and practice. This he was determined English seamen should have. He brought back with him the best means for teaching his fellow-seamen the art of navigation that was possible—a standard manual of navigation used by the Spaniards themselves—Martin Cortes's Arte de Navegar. It did not take a great deal of persuasion to convince the Muscovy Company that it would be an action no less profitable than public-spirited to have it translated into English and published for the general public on these matters in the B.M. are Add. MS. 18,035 (1570) cited above, Add. MS. 20,042; Arundel MS. 22; Lansdowne MS. 1225 (1588). Large portions of the treatise of 1570 and 1588 are reproduced in Brydges, Sir S. E., Consular Literaria (1807) Vol. V.

as well as for the use of its own servants. An able translator was at hand, and indeed already in the company’s service. Richard Eden was concerned in the compilation of its records. He readily undertook the task of translation, and in 1561 the resultant work, The Arte of Navigation, appeared. It is probably not too much to say that this was one of the most decisive books ever printed in the English language. It held the key to the mastery of the sea.

It is true that William Cuningham’s Cosmographical Glasse had preceded Richard Eden’s The Arte of Navigation by two years, but it was altogether a different work. Cuningham claimed no more for it than that it was ‘a compilation’, designed (though it had a section on navigation and included examples of his own methods of longitude-finding and of determining the length of a degree) for the study. Eden’s book on the other hand was a manual of navigation designed from the start and written throughout for the instruction and use of practical seamen. The handy size of the English edition made it particularly suitable for use at sea, while its detailed directions on the making of charts and instruments, as well as on the solution of navigational problems, provided just the sort of information needed by a seaman mastering the art, and hitherto denied it either by the ignorance of his instructors or the jealousy of the initiated. Stephen Borough was far from being satisfied with this production of an English version of a standard Spanish manual of navigation. To ensure a supply of competent navigators something more was needed, and Borough was convinced that, as in Spain and other countries famous for the navigational skill of their seamen, only positive action by the Crown could bring this to pass. Accordingly, in 1562, the year following the publication of The Arte of Navigation, Borough petitioned the Crown to appoint and authorize ‘a learned and a skilfull man in the arte of navigacion to teache and instructe’ English seamen in that art. The office of pilot-major in Spain and elsewhere, averred Borough in the preamble to his petition, turned ignorant seamen into competent navigators, who thereby benefited the country by the wealth and honour that their skill brought and by the avoidance of losses through bad seamanship and shipwreck. The rest of his petition was an expansion of this theme. In Spain no young seaman, he pointed out, was permitted to take charge of any warship or large merchant ship or of any ship engaged upon a rich voyage who had not first been examined and approved as competent by the pilot-major. Nor could he call himself a pilot or master until he had a certificate stamped by the pilot-major entitling him to do so. Furthermore, whereas the English recognized only men and boys, in Spain and elsewhere there were established grades of seamen, as pilot, master, mariner, grommet, page, and boy, each having his scale of pay, and a man or boy had to be certified as being in one or other grade. In English ships, on the other hand, as soon as a youngster grew to ‘any reasonable stature, he will loke for his Age and not for his knowledge to have the name of a man and also of a mariner’, Borough complained.¹

¹ See Appendix 6A.
The superiority of the Spanish system was daily manifested, he pointed out, both by the wealth of overseas commodities brought in, by the number of 'skilfull men in those regions', and by the ability of Spain to undertake voyages of discovery, unlike the English, without the help of expert navigators from other countries. He claimed, too, that losses and wrecks caused by ignorance were avoided under the Spanish system. Borough then pointed out that only very few English mariners practised or tried to learn the new methods, the greatest number contenting themselves with the old and erroneous rules. Nevertheless, some, he added, would gladly learn if they had a teacher. The trouble was that those who knew more than the common sort of pilot or master 'wold not gladly teach other, for hinderinge of their oune lyvinge', while those who would learn if they could were either ashamed to admit it because for appearance's sake they already took navigational instruments to sea with them, though ignorant of their use, and so had already acquired 'the name of and preferment of a master or pilott', or else had learnt a little about navigation and thought they knew everything about it. These he complained were the chief causes of the many recent losses amongst English ships trading to Spain. Some had perished upon the Andalusian coast, others upon Cape Finisterre, and others upon Ushant and the Brittany coast; and, Borough concluded, most of these losses had been due to ignorance. It seems clear that the important Act of 1562 'touching the Maintenance of the Navy' was the immediate official response to Borough's petition. But there were further reactions. In January 1564 Elizabeth proposed to appoint, as recommended by Borough, a 'Cheyffe Piloc of this owr realme of Englande', and drew up a commission to appoint Stephen Borough himself to hold the office during his natural life. On the commission being granted he, or his deputy, or deputies, was to have the examination and appointing of all such mariners as from that time forward took the charge of any ship of 40 tons burden and upwards either as pilot or master. Furthermore, from henceforth no man was to be signed on as a mariner before being 'examyned, allowed, and authorysed' as a competent mariner by the Chief Pilot or his deputies (upon pain of forfeit of twenty shillings, half to be paid to the Chief Pilot and half to the Lord Admiral). As evidence of his competence every mariner satisfactorily examined was to have the signed testimony of the Chief Pilot or his deputy. Nor was any man without a mariner's certificate to be allowed to take on the office of boatswain, quartermaster, or master's mate nor to test another's ability to fill those offices nor those of 'boye, page or grommett', upon pain of forfeit of forty shillings, half to be paid to the Lord Admiral and half to the Chief Pilot. Moreover, in contradistinction to previous English practice, no mariner was to be admitted to the offices of boatswain, quartermaster, and master's mate except by the Chief Pilot or his deputy.

1 See Appendix 6B. Both Taylor and Parks, Richard Hakluyt and the English Voyages (1928), ascribe it to 1563; Oppenheim, M. The Administration of the Royal Navy, 1509-1660 (1896), a very meticulous authority, ascribes it to January 1564.

11—A.O.N.
Lastly, the Chief Pilot, both at the admission and approbation of the mariner, and also of the pilot or master, was 'to geve rules and Instructions towching the poyntes of navigacion and at all other tymes to be redye to enforme them that seke knowleg at his handes'. So much for the intention. It was never fulfilled. Borough's commission as Chief Pilot was never completed. He was, however, appointed 'one of the fowre masters' of the Queen's ships in the Medway.

In failing to confirm Borough's appointment as Chief Pilot and in confirming his appointment to one of the four new posts of 'masters of the Queen's ships in the Medway', the Crown knew exactly what it was doing, what it wanted done, and how it was to be done. Briefly, it decided to foster the art of navigation amongst its seafaring men and to ensure the material efficiency of the ships of the Royal Navy with the administrative machinery already at hand.

As one of the four masters of the Queen's ships Stephen Borough had the responsible task of 'the kepyng and over syght of owr shipps'. But he had, as well as to 'direct and oversee the Boatswains and Shipkeepers who were allowed in harbour, to perform the ordinary maintenance service of the ships . . . also to carry in and out of the River such ships as happened to be prepared for the seas, and to see them rigged and fitted completely'. Whom more competent could the Crown have appointed to discharge these responsible tasks—and the Medway and the Thames estuary are notoriously tricky waters of pilotage—than Stephen Borough? The post might be unadventurous, but it was fundamental to the fighting efficiency and activity of the navy. As a master of the Queen's ships he personally examined and recommended pilots and masters for the royal ships besides overseeing the ships themselves and piloting them up or down the Medway and Thames. Monson, who fought against the Armada and whose writings have already been noticed, specifically states that 'A master' of a royal ship 'is to be chosen by the election of the Trinity House . . . upon commendations from them to the four principal Officers of the Navy', upon

1 There is ample evidence to prove this. The annual sum to be paid to the Chief Pilot is left blank in the commission, and there are no references subsequently, or on Borough's epitaph in Chatham Church, to his having been Chief Pilot of the Realm.

2 Boteler's Dialogues, N.R.S., Vol. 65, contains a dissertation upon the duties of the pilot and the master of a ship; and in the course of it a footnote, based on a contemporary MS., defines the duties of the four Masters of England. Nathaniel Boteler (?1577–?1643), the author, was a member of the Council for Virginia (1619), Governor of Bermuda (1619–1622) and a commissioner of the Crown Colony of Virginia (?1624), and commanded a hired merchantman on the Cadiz (1625) and Ile de Ré (1627) expeditions and a royal ship at La Rochelle (1628). From 1638–1640 he was Governor of Providence Island. His Dialogues—discussions between an Admiral and a Captain—were probably written between 1634 and 1639. They contain little original material of his own, but are of great value as they conveniently collect together a variety of authorities who wrote on nautical matters of the time, such as Mainwaring and Raleigh. Like Raleigh, Boteler was no practical seaman.
which he was ‘to receive warrant for taking charge of the ships of the Crown’, and this, it may be remarked, was still the practice in the eighteenth century.\(^1\) The Trinity House (of Deptford Strand), it will be noticed, was thus directly concerned with the navigational competence of the masters and pilots of the Royal Navy. So Borough, who was a member of that corporation, and its master ten years later, when it was granted its coat of arms, was doubly implicated in ensuring the navigational proficiency of the pilots and masters of the royal ships.\(^2\) Certain it is that he discharged his duties well. The navy got competent pilots and masters without having to go to Spain or France, as heretofore. In Elizabeth’s reign no royal ships were cast away or lost by stress of weather, faulty handling, or careless pilotage. It is equally certain that, although the Crown created no office of Chief Pilot to supervise and enforce the training of the masters, pilots, and mariners of the merchant ships in the latest navigational practices, in the late 1560s and early 1570s Englishmen in rapidly increasing numbers did master them and did reap the benefits that Borough said would accrue therefrom; and it was through the agency of the Trinity Houses of the Realm and of the Trinity House of Deptford Strand in particular that this was achieved. There can be little doubt that the opposition to the appointment of Stephen Borough to the post of Chief Pilot of the Realm—and there must have been opposition for his prepared commission to have remained incomplete—came primarily from the master, wardens, and assistants of the Trinity House of Deptford Strand. No doubt they quoted their original charter of 1514 and pointed out that upon her accession Elizabeth had confirmed this charter; that their powers had been consistently upheld by the Admiralty Court; that to create a Chief Pilot of the Realm could only result in the usurpation of their authority and privileges; in short, that the Crown had already the

\(^1\) Monson’s Tracts, Vol. 4., N.R.S., Vol. 45, p. 22. 8 Elizabeth cap. 12 (1565) concerning sea-marks and Mariners is reprinted in part by Hunter, How England got its Merchant Marine (1935), and in full in Cotton, J., Memoir on Trinity House (1818).

(Anon.), The Laws, Ordinances, and Institutions of the Admiralty of Great Britain, Civil and Military, (1746) contains in Vol. 2, p. 449, ‘An Account of the Trinity-Corporation’ and states: ‘The Ends and Intents of this Foundation were for the Encrase and Encouragement of Navigation, for the good Government of the Seamen, and the better Security of Merchant Ships. And a Power is granted them in their Charter, to make By-Laws for the said good and useful Purposes.

‘They examine and report to the Navy Board, if desir’d, the fitness of Masters for the King’s Ships; and Certify what Rate the Ships are that they take Charge of; and give Certificates and Testimonials to the said Masters, under the Masters and Wardens Hands.

‘They examine, authorize and appoint all Pilots under the Seal of the Corporation, as well for taking Charge of the Royal Navy, as other Merchant Ships . . .

‘They bind and enrol Apprentices to the Sea; though many, or most are bound elsewhere nowadays.’

\(^2\) This grant, with comments on the earlier seal of the corporation, is reproduced in Cotton, J., op. cit.
necessary machinery for implementing those recommendations for improving the navigational knowledge and skill of English seamen made by Borough.

The creation and functions of the Trinity Houses of the Realm has already been briefly mentioned in the opening chapter. It was on 19 March 1513, during the middle of Henry VIII's first war with France, that the Thames ship-masters petitioned the king to empower them to reform the management of shipping in the River Thames and other places.¹ They complained that whereas in times past only experienced English ship-masters and pilots, well acquainted with the dangers of the Thames and other places, had been allowed to handle shipping—and had done so with marked success—now young and inexperienced men, foreigners among them, were meddling in the business. Not only were many ships damaged or lost but the 'ancient mariners' who could no longer work at sea, because of 'bruises and maimings' incurred in the king's service, were being forced out of employment. More serious, too, and dangerous, was the knowledge of the estuary which was being picked up by potential enemies of the realm. From his petition it is clear that Borough, when he petitioned for the creation of the office of Chief Pilot forty years later, had read the original petition of the Trinity House to which he belonged and had framed his petition for improved navigational skill—as distinct from skill in piloting—along its lines. On 20 May 1514, when Henry VIII had returned with the army from France and peace negotiations were under way, the Trinity House of Deptford Strand had received its first charter. This re-established the guild as the fraternity of 'the shipmen or mariners of this our realme of England', and empowered it, while maintaining almshouses for aged and maimed sailors, also to hold lands and tenements and to perform acts of piety, to meet regularly in order to secure the sound government of the guild, the conservation and good state of 'the science or art of mariners', and to make 'laws and ordinances, and statutes amongst themselves, for the relief, increase and augmentation of the shipping of this our realm of England'.²

One master, four wardens, and eight assistants might be elected annually, who might 'admit and accept whatsoever persons our natural subjects only to be born within this our Realm of England, and other places under our allegiance, and not others . . . as brethren'.

Thus was established the machinery for controlling the shipmen, pilots, and mariners not only of the Thames but, it should be noted, of the whole realm.

The first master, Thomas Spert, lately successively master of the Mary

¹ The Trinity House petition of 1513 is given in full in Ruddock, A. A., 'The Trinity House at Deptford in the Sixteenth Century', E.H.R., Vol. 65. The original is given as 'Chancery warrants for the Great Seal, file 388, No. 36'. This otherwise valuable study underestimates the authority of the Trinity Houses in naval navigational affairs and national navigational affairs.

² The Latin original is reproduced in Ruddock, A. A., op. cit., and an English translation in Cotton, J., Memoir on Trinity House (1818), Appendix 1.
Rose and Henry Grace à Dieu, two of the king's finest ships, wasted no time in promulgating by-laws to bring pilotage in the Thames under the control of Trinity House. Indeed he drew them up before the charter was granted, for, on 10 May, it was ordained 'that no maner persone shall take uppon hym to be a lodesman within the said River of Thamys withowte he be a Brother of the said Fraternitie'. The only exceptions were the brethren of the Trinity House of Dover, an unchartered 'Court of Lodesmanage' of the Cinque ports, and pilots of the estuarine ports such as Harwich and Orwell, bringing ships from their own ports to the Thames. For this privilege the pilots paid a fee to the Deptford Trinity House, which in fact claimed the monopoly of the pilotage of all ships passing between London and the sea.¹

By 1529 Thomas Spert had been knighted for his services to the Crown, was controller of the king's ships, and a wealthy Thames shipowner. Enforcement of the authority of Trinity House over all pilots and shipmasters had proved impossible with the powers granted by the charter of 1514; accordingly, in 1536, probably through Sir Thomas's personal intervention with the Lord High Admiral, who had granted him the 'ballastage' of Thames shipping, a warrant was issued in the Admiralty Court for the arrest of pilots and ship-masters refusing to pay the Trinity House dues, and ordering them to be brought to the Admiralty Court at Orton Keys to explain their conduct. Henceforward by payment of an annual fee on Trinity Sunday to the Judge of the Admiralty Court a general warrant was obtained upholding the Trinity House's rights for the ensuing twelve months. By this means its authority over all shipmen of the realm became undisputed.²

This action of the Trinity House of Deptford evidently inspired the Guild of Masters, Pilots, and Mariners of Newcastle upon Tyne to apply for a similar charter for the port of Tynemouth. Accordingly on 5 October 1536 it too received a charter empowering it to create a Fraternity of the Holy and Undivided Trinity of Newcastle upon Tyne. This Trinity House could set up a master and four wardens to govern the fraternity and admit brethren (and sisters). Property could be owned and meetings held to further the objects of the guild, which was also empowered to levy a due to set up and maintain two towers, one on either side of the port entrance 'with a perpetual light, to be nightly maintained'—the first lighthouses of England.³ By 1538 this Trinity House, too, was applying for and receiving an annual Admiralty Court warrant to enforce its powers.³ Early in their reigns Edward VI, Mary, and Elizabeth I confirmed the original Newcastle upon Tyne, as they confirmed the original Deptford, charter.

¹ Ruddock, A. A., *op. cit.*
² Ruddock, A. A., *op. cit.* reproduces the Latin original of the High Court of Admiralty warrant of 1536.
³ Whormby, J., *An Account of Trinity House and of Sea Marks (1746)*, (ed. of 1861), reproduces in translation much of this first charter.
The Hull Guild of Trinity House originated from a religious guild founded in 1369, and changed in 1456 into a guild exclusively of shipmasters supporting a chantry in Holy Trinity Church and an almshouse for the maintenance of maimed or aged seamen. The necessary funds were raised by the payment of 'lowage and stowage' (later known as 'primage'), the payment for loading and unloading cargo customarily made in certain trades and ports in addition to the voyage wages. In 1505 this agreement—which had received royal sanction in 1457—was renewed, and seven years later the mayor and aldermen of Hull agreed that only members of the guild should have the right to bring ships up and down the Humber. It was not until 1541 that this guild received a royal charter, and it is significant that this should have been the year in which Henry VIII visited the port and by tradition was piloted up the Humber by a Scot until he ordered his replacement by an Englishman. Within a short time of becoming by charter 'The Wardens or Masters, Mariners and Brethren and Sisters of the Fraternity or Guild of the Holy Trinity of Kingston upon Hull', this corporation also was petitioning for a warrant under Admiralty seal similar to that granted to Deptford and Newcastle upon Tyne.

This charter, too, was renewed by Edward VI, Mary, and Elizabeth I, upon their accession to the throne.

Thus, although the three incorporated Trinity Houses of Deptford, Newcastle upon Tyne, and Hull, and the unincorporated one of Dover, were distinct and independent one from another within what may be termed their parochial bounds, that of Deptford Strand was by far the most considerable, and exercised authoritative influence over the others by virtue of its being a fraternity of 'the shipmen or Mariners' of the whole realm empowered to treat of 'all and singular articles' concerning the ships of the realm and the craft of the seamen of the realm. It is clear too that by 1563 Trinity House was failing in its responsibilities to ensure that English seamen should have an up-to-date knowledge of 'the science or art of mariners' and did not grasp that it was thereby failing to ensure 'the relief, increase, and augmentation of the shipping' of the realm. What is quite certain is that Borough's petition and the provisional commission appointing him Chief Pilot aroused the Trinity House to a full sense of its current navigational responsibilities. In Henry VIII's time its main tasks had been to ensure a supply of English pilots competent to act as port pilots and of English masters competent to conduct ships safely on the then almost exclusively coastal voyages undertaken, also to deny to foreigners the opportunity to become acquainted with the secrets of our port channels by acting as local pilots and so to expose the realm to the risk of invasion in time of war. As we have seen, the merchants' trade and the naval operations of the time had demanded no more. Now times had changed. Mere pilotage no longer sufficed. Trinity House must now ensure the competence of masters and pilots to undertake protracted overseas, indeed oceanic, voyages, and, if the Act of 1562 'in the Favour of Fishermen and Mariners
haunting the Sea' which freed such men from military service was not to be abused and was really to assure to the Crown a supply of mariners, would have to certify mariners as such. There was, in fact, no denying the soundness of Borough's contentions. Trinity House took action. We can see reflected in the Act of 1565 'Concerning sea-marks and Mariners,' already referred to in the opening chapter, something of the struggle for power, some of the heart-searchings that must have gone on, and some of the results. This Act it will be recalled, in order to reduce shipping losses, authorized the Trinity House of Deptford Strand 'being a company of the chiefest and most expert masters and governors of ships', to set up and maintain beacons and sea-marks anywhere on the coasts of England, and to prevent the destruction of existing natural aids such as conspicuous trees, towers, and steeples.

This Act is important as marking the first practical action by the Crown —no doubt on Borough's prompting—to reduce on a national scale by means of navigational aids the risk of shipwreck round the coasts. But it is important from yet another aspect. Besides being concerned with 'sea-marks', it was also concerned, it will be recalled from its title, with 'mariners'. In effect it confirmed that, as recommended by Borough, stipulated in his provisional commission as Chief Pilot, and rendered necessary by the act of 1562, seafaring men who were mariners were to receive a certificate of competence from the Master, Wardens, and Assistants of Trinity House. They might then ply their own or hired boats upon the Thames for their own pleasure or for hire. The fact that the Act referred only to men dwelling beside the Thames is accounted for by the privilege of wherrying being granted only to Thames-side mariners. One result of this registering of seamen was that the Government from now on was better able to keep check of the numbers of masters (for we shall see that masters had also to be licensed as such), mariners, and fishermen in the realm, and periodically did so, together with the numbers and tonnages of the shipping of the realm. By this means it was enabled to check the effects of its maritime legislation and its readiness for war. Thus a muster of ships and mariners throughout England taken in 1582 showed that there were some 1,600 merchant vessels—of which only 250 were above 80 tons—and about 16,500 mariners of all sorts, some 6,500 being fishermen.1

The Trinity House of Deptford Strand never received a new charter from Elizabeth, but the charter granted to it by James I, in 1604, after his accession to the throne, was a redrafted one and not a replica of the original. For the first time a distinction was made between Elder and Younger Brethren, there being thirty-one of the former, from whom were elected the Master, Wardens, and Assistants, 'all the rest of the seamen and mariners' of the guild being Younger Brethren. This charter clearly stated

1 Monson's Tracts, Vol. 3, N.R.S., Vol. 43. The masters, mariners, and fishermen are not always specified separately under the county headings in which they are arranged. The masters probably numbered between 1,600 and 2,000.
that the corporation was to consult 'of and upon the Conservation, good Estate and wholesome Government, maintenance and increase of the Navigation of this Realm, and of all mariners and seafaring men within the same', and of 'the cunning, knowledge, or science of seamen and pilots'. It empowered the corporation to make and enforce the necessary by-laws.\textsuperscript{1} The Trinity Houses of Newcastle upon Tyne and of Hull, however, did receive new charters from Elizabeth I. Hull's original charter had been renewed by each successive sovereign, including Elizabeth, upon accession; and in 1580 Elizabeth granted it a modernized and amplified one, distinguishing between Elder and Younger Brethren and embodying amongst other powers—and from a purely navigational point of view this is most significant—the certification of masters, pilots, and mariners.\textsuperscript{2} For instance, concerning the masters and pilots, the Master and Wardens of the Trinity House of Hull were authorized to forbid any mariner to sail from the port of Hull whom they had not certified as competent. They could limit his licence according to the degree of his competence, noting the ports to which he was entitled to sail. In the early eighteenth century a tablet was hanging in the Hull Trinity House with Elizabethan by-laws reputed to date from 1570 painted upon it. Amongst these was one to the effect that outward bound masters were to give to the Trinity House an account of the number of their mariners, and, on their return, of their behaviour on the voyage, and that straggling seamen from other ports were not to be employed without certificates.\textsuperscript{3} The mid-seventeenth-century oath book of the corporation shows that mariners applying to become masters or pilots were examined, that incompetent candidates were failed and that successful ones were admitted, the ports to which they were authorized to sail being entered against their names.\textsuperscript{4}

In 1582 the Newcastle upon Tyne Trinity House also obtained a similar new charter creating Elder and Younger Brethren, but it lasted for only seven years, when the town of Newcastle upon Tyne asserted its prior rights of judicature. The Trinity House therefore reverted to its original charter, and the Deptford Trinity House intervened when special maritime powers were needed.\textsuperscript{5}

Unhappily a series of disastrous fires has resulted in the destruction of many of the records of the Trinity House of Deptford Strand, but,

\textsuperscript{1} Whormby, J., \textit{op. cit.}, gives these essential features of the charter.


Whormby, J., \textit{op. cit.}, reproduces in translation most of the charter of 1541, and a précis of that of 1580.

\textsuperscript{3} Whormby, J., \textit{op. cit.}, where the charter is reproduced in some detail and the by-laws are summarized.

\textsuperscript{4} Brooks, F. W., \textit{The First Order Book of the Hull Trinity House} (1942).

\textsuperscript{5} Whormby, J., \textit{op. cit.}, reproduces much of the 1582 charter, and illustrates its revocation and the intervention of the Deptford Trinity House.
from the evidence already quoted, to say nothing of the books on navigation in due course dedicated to or published by its Brethren, it is clear that henceforth, in Elizabeth I's day and in early Stuart times, it discharged its navigational duties towards the seamen of the realm as conscientiously as the Houses of Newcastle upon 'Tyne and Hull.

The decentralized method of navigational training outlined above, without any established school of navigation, sufficed the English in the 1560s, '70s, and early '80s, because it suited their still limited needs. The only chartered overseas trade was that of the Muscovy Company, of whom Stephen Borough was the distinguished Chief Pilot. As this company had a monopoly of the trade, the only pilots and masters engaged in it would be those in the service of the company. It could be only in the interests of the company to attend to the advice of their Chief Pilot in matters concerning the navigational skill of their servants, whom, despite his naval appointment, he could still easily supervise, since London was their port of departure and return. The only other overseas trade was that to Guinea, which was not the monopoly of a chartered company. Portugal, as we have seen, claimed exclusive trading rights here by virtue of first discovery, and so far as it was able took measures to prevent the activities of interlopers. If English Guinea activities had been known to have been legalized by charter by the English Crown, open hostilities must have ensued. What actually happened was that the Government, from the queen downwards, recognizing only the right of 'effective occupation', invested in the Guinea trading ventures of syndicates of merchants and even allowed them to hire royal vessels. Borough was one of the officials responsible for ensuring that these royal ships were furnished with pilots and masters who were as adequately trained as the ships were adequately armed. The success of the voyages speaks for the success of the system.

That no school of navigation of the continental pattern was established can also be attributed to the economic structure of the English overseas trade. Unlike that of Spain, it was not a monopoly from whose profits an actual school of navigation could be financed, nor was it extensive. To set up an institution to train masters for oceanic navigation when there was little of such navigation to be done, and small prospects of any without incurring conflict, would have been a measure as extravagant as it would have been provocative. As it was, the requisite standard of navigation, when the demand for many more oceanic navigators arose in the 1570s, was achieved by the English masters qualified by the Trinity Houses, employing, as the Spanish records show, French and Portuguese pilots to assist them. For a text-book on navigation Englishmen had Eden's translation of Cortes, and by the middle of the '70s their activities had called forth an English manual to supplement this. When internationally legitimate explorations to the north-west began to be undertaken from 1576, and navigational skill of the highest order was called for, the deficiency of public instruction in higher mathematics and navigational theory was made good by consultation with the navigational adviser to the
Muscovy Company, Dr. John Dee, whose preface to the first English *Euclid*, published in 1570, had stimulated intelligent interest in navigational problems to an unprecedented degree.

Such flexible arrangements also suited the independent spirit of the Elizabethan seamen, who were first and foremost individualists, conscious of nationhood, but impatient of governmental control and intolerant of officialdom. The secret of the success of the Tudors as rulers was that they could judge both the needs and the temper of their virile, restless, people with extraordinary insight. They had the ability of knowing how to satisfy their needs by the means most in harmony with their temper. Thus Elizabeth’s Government, by listening to the best informed nautical advisers, by applying the apprentice system to seamen under the surveillance of revitalized Brotherhods of Trinity House, assured itself early in the reign of an adequate ‘store of skylful Pilotes’. After seeing to the provision of ships and seamen, this was its chief concern. By itself participating in overseas ventures, and by encouraging individual adventurers of outstanding merit, such as Hawkins, Drake, and Frobisher, to take well educated young gentlemen to sea with them to learn the art of navigation, the Crown began at the same time to ensure that there should also be a sufficiency of men qualified by navigational skill and experience as well as by birth and education to command its ships in the event of war.
Chapter Five

THE SPUR TO MASTERY

'...Cecil simply said the Pope had no authority to divide up the world...'

'Secretary Cecil sent to ask me to furnish them with a memorandum of the places where it is forbidden to trade without your Majesty's license. I sent it to him saying that the places were all the West Indies Continent and Islands. He sent to say the Council do not agree....'
Guzman da Silva, Spanish Ambassador to the Crown, London, October 1566.¹

Some ten years of Elizabeth's reign elapsed before the Government felt that the economic and political situation of the country justified the prosecution of a more aggressive mercantile policy than hitherto. After 1568 the whole emphasis changed. Partly it was in response to the growing awareness of Englishmen of the possibilities latent in oceanic exploration and trade. Partly it was because Englishmen were growing increasingly conscious of the religious and political issues at stake and that, despite the risks, these demanded action if vassalage to Spain was to be avoided. Partly it was because for the first time conditions both at home and abroad had become favourable for action. In 1568 Mary of Scotland had become a prisoner in England—the threat from over the border had ended—and a year later the crushing of the Rising of the North put an end to the Catholic threat in the north of England itself. In 1569 the third and most formidable of the wars of religion that since 1562 had been sapping the strength of France had broken out; La Rochelle had been established as the Huguenot headquarters, and Huguenot privateers had recommenced harrying all Catholic commerce in the Narrow Seas; in 1568, too, the embers of rebellion that since 1565 had been glowing in the Netherlands burst into flames. Though they were quickly stifled by Alva's army of Spain, 1569 saw the struggle transferred to the sea by the issuing of letters of marque by William, Prince of Orange, to seamen who were soon to become famous as the Beggars of the Sea. The same year saw an English expedition under John Hawkins sail to the succour of the garrison of La Rochelle. In short, the time had come to start curbing by all overt and indirect means 'the exorbitant power of Spain'. The spark which had fired the train of events that, in a few brief years, was to establish the fame of

¹ From *English voyages to the Caribbean*, Hak. Soc, Ser. 2, Vol. 62, p. 10. The first quotation is from a discussion upon English traffic to Guinea, the second is on Hawkins's voyages to the West Indies.
English seamen upon the seven seas had been struck late in 1568 by the Spaniards themselves in the little Mexican port of San Juan de Ulloa.

In the 1560s the Muscovy, North Sea, and Baltic trades were still primarily the concern of the merchants of the East Coast ports. London, though already the chief port of the realm, was still only on the way to its rapid rise as the undisputed economic centre of the country. The merchants of Southampton, Plymouth, and Bristol, whose ports faced south and west, had for long been the principal traders with the Biscayan and Peninsular ports and Atlantic Islands. It has already been mentioned that in the 1530s, aided by foreign pilots, they had started going farther afield. Hakluyt expresses it this way:

Olde M. William Hawkins of Plimouth, a man for his wisedom valure, experience and skill in sea causes much esteemed, and beloved of K. Henry the 8, and being one of the principall sea-captaines in the west parts of England in his time, not contented with the short voyages commonly then made onely to the knowne coaste of Europe, armed out a tall and goodly shippe of his owne of the burthen of 250 tunnes, called the Paul of Plimouth, wherewith he made three long and famous voyages unto the coast of Brasil, a thing in those days very rare, especially for our nation. In the course of which voyages he touched upon the river of Sestos upon the coast of Guinea, where he traffiqued with the negroes, and tooke of them elephant's teeth. . . .

There is clear evidence in the Plymouth port books that as late as 1540 the Paul was still plying the trade started in 1530. Certain duty was paid by William Hawkins on 24 February 1540 on an outward cargo of the Paul of knives, combs, hatchets, bracelets, cloth, copper, lead, and '19 dozen nightcappes'. On 20 October 1540 duty was also paid on an inward cargo of the Paul's consisting of Brazil wood and '1 dozen elephant's teeth weighing 1 cwt'.

Old William Hawkins had been born at Tavistock in Devon at about the time of the Cabot voyages. He lived until 1553 or 1554, and thus long enough to see the English Guinea trade, of which he had been the pioneer, revived, probably at the instigation of Cabot. Old William Hawkins left two sons to carry on his West Country shipping business; both were born at Plymouth, William in 1519, and John in 1532, the year of his father's third successful Brazil voyage. For a few years after their father's death the brothers carried on the family business together. Then they divided; William kept Plymouth his headquarters, made a number of voyages as a merchant for the Crown, and died in 1589. John, the younger, while keeping closely in touch with Plymouth, made London, not without good purpose, his headquarters. He had inherited his father's discontent with short voyages.

The right to explore and trade to the north, north-east, and north-west had been vested in the London Muscovy Company, of which Hawkins was not a member. Pope Alexander VI in his bull *Inter Caetera*, 1493, had given to Spain the New World within which lie the Caribbean coast and islands, and had forbidden 'all persons of no matter what rank, estate, degree, order or condition' to dare, without Spain's permit, 'to go for the sake of trade or any other reason whatsoever to the said islands and countries after they have been discovered'. Spain claimed upon the strength of this grant a threefold monopoly of the New World—political, commercial, and religious. In West Africa, Portugal in the 1560s was making good her claim to the right of exclusive trade by sending more and better armed ships to guard the coasts. To make longer trading voyages legitimately would be no easy task for an Englishman, particularly as climatically the Spanish colonies did not promise to be particularly suitable marts for English cloth. Nevertheless, an enterprising trader might find a commodity that was in demand, and one so much in demand that the Spanish colonials might be prepared to juggle with the regulations about trade so that both trader and colonial buyer might make transactions to their mutual benefit. With suitable financial backing and suitable ships, and possibly with the connivance of the English Government, a breach might be made in the ramparts of Spanish colonial trade. The area was vast, Spanish defences were few and far between, and the needs of the colonists greater probably than their loyalty. So it was that in 1562, having considered carefully the fact that the first of the revived Guinea voyages had brought back 'certain tall slaves', that the Portuguese were the chief suppliers of slaves to the West Indies and that, in order to keep the prices high, they had the habit of keeping the supply short; considering moreover that, since the Spaniards had exterminated the docile, and failed to exploit the intractable natives of the New World, manpower was the greatest need of the Spanish colonists, John Hawkins determined to attempt the trade. Therefore, early in the 1560s he formed a syndicate in London of merchants and officials willing to finance him. In the West Indies, whither he sailed late in 1562, touching at the Canaries, to pick up a Spanish pilot, and the Guinea coast to collect slaves, he found the colonists eager to trade, provided adequate safeguards were taken to ensure that though illegally engaged in trade with him they could not be punished from home. He hoped to become a concessionaire in the trade, and so render it legitimate as well as profitable.

John Hawkins was not, as it happens, the first English sea-captain to break into the isolation of the West Indies. Thirty-six years before there arrived off Santo Domingo in 1527

'a large three-masted ship belonging to the King of England... this ship, together with another, cleared perhaps nine months ago from England on

order from their King, to make a certain exploration toward the north, between Labrador and Newfoundland, in the belief that in that region there was a strait through which to pass to Tartary. . . . They had sailed as far north as fifty and some degrees, where certain persons died of cold, the pilot had died; and one of the said vessels was lost. . . . For which reason they came to this land to take in water and subsistence and other things which they needed, and they asked for safe-conduct to enter this port which their honours extended to them in his Majesty’s name, sending with them to the ship . . . pilots to bring the said ship into the harbour . . . today. . . . They boarded that said ship, when the Master received them well, and gave them to eat and drink abundantly indeed, and showed them certain linens, woollens and other merchandise which he carried for barter.

‘And just when they had dropped anchor,’ [off Santo Domingo], ‘and the ship being anchored, all hands had begun to eat, with much pleasure and good humour, from the fortress of this city a lombard was fired, and the stone passed by the poop of the ship, very near to it.

‘Whereupon the ship’s Master turned colour, saying . . . it was a plot to betray them’;

and at once raised anchor and made sail ‘on a course for Castile.’¹ This ship (possibly the Mary Guildford, with Jean Rotz, the French pilot, as master) was the first English, the first interloper indeed of any nation, in the Indies. Though this visitation was brief, it had held a threat—expressed by some of the crew—and been an omen. The threat had been answered by the shot, and for thirty-six years that had sufficed the English. Not so the French, who had followed in ever-increasing numbers and boldness. Now, in the ’60s, if old memories were not revived by Hawkins’s voyages, at least the threat inherent in them was felt as keenly. The Spanish Government refused to legalize his ventures, either his first, or his second, made in 1564. In their eyes he was not only a law-breaker—for he was a foreigner and without a licence to pass to those parts, his goods had not been manifested at Seville, and he had traded without a trading licence—he was a threat to the very security of the Indies. Consequently they determined to nip his activities in the bud.

After his second voyage, and when Hawkins was known to be preparing a third, the Spanish Ambassador delivered an uncompromising ultimatum to Elizabeth. This was in October 1566. After the first voyage Spanish protestations had been met by assurances that Hawkins would ‘do King Philip’s subjects no harm’²; now Hawkins was forbidden by the queen ‘to go to any of Philip’s prohibited ports’.³ His ships were stayed. Nevertheless he sailed them secretly on 9 November 1566 under the command of a deputy, John Lovell, and a young man, Francis Drake by name. Thus

² Ibid. p. 16, note 1.
³ Ibid. p. 16.
Hawkins's ships reappeared in the West Indies with the Frenchman, Jean Bontemps, Juan Buentempo or John Goodweather, who seems to have acted as confederate and probably as navigator on these later voyages. Lovell's expedition returned in September before Hawkins sailed on his fourth voyage—the third which the English Government had now countenanced his making. Indeed, as on the second voyage, he sailed not only with royal ships under his command but under the orders of the queen. Hawkins in fact was sailing as an official seeking to extend England's overseas trade and, it would appear from negotiations with da Silva, the Spanish ambassador, in an attempt to persuade Spain to hire the English ships for the defence of the Caribbean, as she hired Genoese warships to serve her in the Mediterranean against the Barbary pirates. On the Guinea coast Hawkins fell in with a French captain, and forced him to join the expedition—probably to aid him in his pilotage. Another joined him voluntarily before the Atlantic was crossed. Once again Hawkins's skill as a trader, negotiator, and leader led to satisfactory trading with the colonists eager for manpower. But on Friday, 17 September 1568, John Hawkins's fortune changed. He was anchored in the port of San Juan de Ulloa, driven there by stress of weather and lack of victuals, at the tail of the hurricane season, when in the offing were seen the sails of Spanish ships. It was the fleet from Seville, on board it the new Viceroy of Mexico. Hawkins was in a most unenviable position. There was no other port on the whole coast of the Mexican Gulf whither either he or the Spaniards could go. To exclude them might mean their destruction by storm; to admit them his own destruction by treachery. He did the only thing he could do. He admitted them on terms. They did what they deemed most expedient. For them the situation was galling. Indeed it was undignified as well as dangerous. The Englishman's impertinence was matched only by his effrontery as an interloper in forbidden territory and trade. So, while openly they accepted Hawkins's terms, secretly they planned his destruction by treachery. A week later, on the morning of Thursday, 23 September, some time before noon, suddenly a trumpet sounded in the Spanish flagship. The fight was on. Hawkins had two royal ships, the Jesus of Lubeck and the Minion; a 50-ton ship of Drake's, the Judith; two smaller ships, the Angel and Swallow; and a French caravel. Though he had prepared his squadron against treachery, only the Judith and the Minion escaped, Drake in the former, Hawkins in the latter. The tale was told in January 1569. It was the end of an epoch. Far from driving the English from the New World, by that act of treachery the Spaniards attracted Englishmen's attention to their New World possessions, and this they did at the very moment that the Narrow Seas were absorbing the activities of the French corsairs who hitherto had harried the Spanish Main and islands in the Caribbean Sea. If they had not known of it before, it was not long before the English learnt of the comparative defencelessness of the Spanish possessions.

Hawkins's disaster had been caused by his being forced to fight a pitched
battle with the guard-ships of the Seville fleet, as a result of treachery. Nevertheless he had sunk the "capitana" and "almirante"—the flagship and second-in-command's flagship—and a third ship, and this was no mean feat. The Spaniards had had the fight by no means all their own way. Indeed, in the history of the Royal Navy that action at San Juan de Ulloa proved of singular importance. From the year in which it was fought the character of the Royal Navy changed. Hawkins's royal ships had been the customary high-charged ships designed for battle in the Narrow Seas by a combination of bombardment by cannon and cut-throat, hand-to-hand boarding. At San Juan de Ulloa he destroyed the three Spanish ships by cannon-fire, by relatively long-range cannon-fire, alone. The significance of this feat, and the unsuitability of the traditional type of warship for oceanic warfare, were immediately appreciated by the Navy Board. The new warships were designed, and the old ones reconstructed, on new lines and, before long, they were victualled, armed, and manned for long sea-voyages and battle far from home.\(^1\) Equally surely from that action can be traced the rise of the English oceanic merchant marine, the development of the English merchant ship capable of trading over the oceans, and, concurrently, the appearance of a growing band of sea-captains capable of navigating them without the aid of foreign pilots. By the 1580s English sea-captains no longer subordinated themselves to Frenchmen in order to learn the ropes of navigation, though they might still bribe or abduct the foreign pilot, Portuguese or Spanish, to conduct their ships to a desired landfall in unfamiliar seas—the technique of Hawkins and Drake to their dying day. On the contrary, by the 1580s it was the English who were teaching the seamen of the world new-found secrets of the art of navigation.

The immediate economic lesson of San Juan de Ulloa for Englishmen was that if they wanted to trade with the Indies, they would have to fight for the right under one guise or another, and that the wealth of the Indies could be won only by hard endeavour on the high seas. Into the mêlée of the religious wars, lapping along the Channel coasts, in the 1570s, they ventured as privateers, or, to use the current expression, 'letters of marque' men: the more heartily from 1570 in that their queen had been excommunicated.

Deprived by his personal relations with the Government from gaining redress by his own actions, Hawkins dispatched privateers and illicit traders to the Caribbean on his own behalf. Others joined them. Of these Drake was the most successful. His exploits culminated in his classic voyage of circumnavigation of 1577–80, the first by an Englishman, and his return with the richest cargo yet brought by an Englishman into an English port. But the venture, it is important to remark, was still made possible only by Drake's practice of seizing competent pilots to aid him on his voyage—a Portuguese, Nuña da Silva, for the voyage to Brazil.

\(^1\) For a full discussion of the naval results of San Juan de Ulloa, see Waters, D. W., 'The Elizabethan Navy and the Armada Campaign', \textit{M.M.}, Vol. 35.
XXIX. The Haven of Death, 1553.
XXX and XXXI. Tide-tables and Rules for their Use in Leonard Digges’s *A Prognostication everlasting*. . . . (1556).
and down the South American coast—two Spanish pilots, or at least, since they refused to accompany him, their charts and runters, for the passage across the Pacific. In the British Museum there lies today a manuscript manual of navigation of 1577 incorporating a runter covering the trade routes followed by the English at that time, those from England (Orfordness) to St. Nicholas in North Russia, to Barbary and the Guinea coast. Significantly, it includes two detailed Portuguese runters of the Brazilian coast, one of them continuing with the route down the South American coast to the Strait of Magellan, and up the coasts of Chile and Peru to Panama. The probability is that Drake made a copy of it for his voyage of circumnavigation.  

Drake’s venture had official backing. Two of its main objects were to exploit the Southern Continent—Terra Australis Incognita—shown on the new map of 1570 of Abraham Ortelius, the great Flemish cartographer, and to find the Strait of Anian. This strait was believed to run from the Pacific, in the latitude of California, whose coastline was still unexplored, to the Atlantic, either in the region of Chesapeake Bay or (shades of the 1527 voyage!) north of Newfoundland, neither region being as yet explored. Drake’s mere achievement in sailing round the world has pushed this aim of exploration into the background of history, but it is of importance because the discovery of the Strait of Anian continued into the seventeenth century to be a motive in English exploits in North America. It lay behind the Frobisher voyages of 1576–7–8 to the north-west, of the Davis voyages of 1585–6–7, and the voyages in the early seventeenth century of Hudson, Button, Baffin, James, and Foxe. It formed also an element (and a disruptive one) in the plans of the early colonists in Virginia. But for us its interest lies in the fact that it was the preoccupation of the English with northern navigation that made them tackle the hardest problems in navigation, because the hardest problems are met with in northern waters.

Once war was joined with Spain openly, in Europe as well as in the West Indies, as it was in 1585, further navigational problems had to be solved. The problems inherent in the successful interception of ships on the high seas brought home to the English sea-captain in command of a ship or squadron of the Royal Navy the vital need for accurate position-finding by celestial observation and accurately deduced reckoning and plotting. While the northern explorations by sea brought to the fore the problems associated with the magnetic compass and with chart projections in high latitudes, the voyages of reprisal and the naval operations in the latter part of the century, particularly around the Azores and in the approaches to Spain, underlined the universal nature of these problems. They led to what was probably the greatest advance ever made in marine cartography. This was the so-called Mercator’s projection. Charts on this projection are those most generally used by seamen today. It was evolved by the


12—A.O.N.
Cambridge mathematician Edward Wright probably as a result of a raiding voyage to the Azores and against Spanish treasure ships in which he took part in 1589. From this latter period, the 1590s, can be dated the introduction of the plotting board and protractor, and of trigonometrical tables, improvements in the mariner’s compass and of the means of finding and plotting its errors, the general introduction of the log and line for measuring the distance run, and assiduous attempts to measure longitude accurately.

By then the world had been encompassed for the second time by an Englishman, Cavendish (1586–88), and, though the Spanish war put an end for twenty years to attempts to reach Cathay by the northern route, his voyage whetted men’s appetites for eastern spices. John Davis, who had made his fame in the ’80s, by his voyages in search of a North-West Passage to Cathay, passed the Strait of Magellan in an attempt to find it from the other side of America.1 He was forced back through the Strait and had to abandon the attempt, but James Lancaster rounded the Cape of Good Hope in 1591, and reached the Indies that way—the first English navigator to do so. Though he was wrecked in the West Indies on his return voyage, he had blazed the trail which Davis was to follow. Enlisting as chief pilot in a Dutch expedition to the East Indies in 1598, Davis returned in mid-1600 in time to pilot the first voyage of the recently chartered East India Company which sailed from the Thames in 1601 under James Lancaster’s command.

Navigation in low latitudes, like navigation in high latitudes, had its special problems; in particular that of observing the sun’s altitude. It was doubtless his first voyage through equatorial waters which caused John Davis, who was an exceptional man in many ways, to develop his ‘Back-Staff’ for observing the sun’s altitude. It was the greatest advance made towards accurate observations at sea until the sciences of optics and mechanics enabled Hadley to produce the reflecting quadrant with Vernier’s scale adjustment a hundred and forty years later.

These voyages to the East Indies by the English, despite their mastery of the art of navigation, were possible only by reason of their possession of the necessary route books and charts. Those to the East, as we have seen, represented the work of two centuries of laborious exploration by the Portuguese and, on the final discovery of the route via the Cape of Good Hope, had been kept closely guarded secrets. But these secrets had passed into the possession of Spain when King Philip had seized the crown of Portugal in 1580. This act warned the English anew to prepare for the danger to come, for after the conquest of the Azores, in 1582, the Spanish captains had openly declared, ‘Now that we have all Portugal, England is ours.’ Not only had the English co-operated in the Portuguese defence of the Azores, in 1582, but they had given refuge to the displaced pretender, Dom Antonio, and his followers. In return they had gleaned invaluable information from them concerning the Indies. Above all, war with Spain once joined, the Portuguese carracks from the East Indies had become fair

1 1591–93.
game. The capture of one, the *San Felipe*, in 1587, and of another five years later had rendered up many secrets, including charts. Thus warfare and trade together played their part in making the English proficient at sea. By the end of the century ocean voyages were a part of the nation's daily life. The first decade of the new century found Englishmen trading regularly to the East Indies; and not only that, when the war ended in 1603 the English turned their energies to the realization of other schemes cherished for thirty years—the planting of colonies. Originally conceived as trading ports on the route to Cathay, or as advanced bases against Spain, as sites for gold prospectors or outlets for surplus population, colonies had come to be viewed as potential sources of natural products that, given time, would be valuable for trade, and provide another source of naval stores. A diversity of objectives, inexperience, and war had left of the first attempts, made in Virginia in the '80s, scarcely a trace. Now the object, even if experience in 'planting' was lacking or ignored, was at least not distracted from execution by war. It was the old object in new guise: to make England the richest storehouse and staple for merchandise in all Europe, old John Cabot's intention of 1497. But in earnest of this intention the Government, carrying on the Elizabethan practice, legislated to foster such shipping. The English colonies had by law to trade with the mother country, England, alone. Small ships were forbidden to make the ocean passage. Although by law transatlantic trade by Englishmen, in English ships navigated by English sea-captains, was assured, it was up to them to exploit it. The assumption implicit in such legislation, that Englishmen were competent to put it into effect, when tested, proved sound. By the time of Captain Smith's death in 1631 their trade routes laced the Atlantic and stretched between Murmansk and Madras.\footnote{An Elizabethan navigator pays tribute to Sir John Hawkins as a pioneer English navigator (Captain John Davis, *The Hydrographical Discourse* (1595)):

The first Englishman that gave any attempt upon the coasts of West India, being parte of America, was syr John Hawkins, knight: who then and in that attempt, as in many others sithins, did and have proved himselfe to be a man of excellent capacity, great governement, and perfect resolution. For before he attempted the same it was a matter doubtfull, and reported the extremist lymit of danger to sayle upon those coastes. So that it was generally in dread among us . . . howe then maye Syr John Hawkins bee esteemed . . .}
Part II

THE ENGLISH CONTRIBUTION TO THE ART OF NAVIGATION UNDER ELIZABETH AND THE EARLY STUARTS

'They neyther have true Rules too direct theymselves, the highest course, ne yet treadinge their beaten pathes can assuredlye decide of theyr certayne place. For reformation of these errours and imperfections, newe Chartes, newe instruments and newe Rules must bee prescribed.'


'There is great reason . . . to prefer Hydrographie or Navigation before any other arte or science . . . as . . . by the use and practice thereof . . . is the Navy Royal furnished, the Realme fortified, and the commonwealth enriched.'

Chapter One

FIRST CONTRIBUTIONS TO THE SCIENCE OF NAVIGATION

'The first rule is of a good Navigator.
'Of all sciences that is used with us in England, Navigation is one of the principall and most necessary for the benefite of our Realme and native countrey and also most defencible against our enemies, because we lie environed rounde aboute with the sea.'


'I have . . . set downe whatsoever I could finde by exact triall, and perfect experiments . . . foundyng my argumentes onely upon experience, reason, and demonstration, which are the groundes of Artes.'


The first man to meet the growing need of the English in the 1560s and '70s for general instruction in the art of navigation was himself an Englishman, William Bourne by name, a native of Gravesend. The town stands on the south bank of the Thames, some 20 miles below London Bridge, opposite what are now Tilbury Docks. By 1562 Bourne was a jurat; for a time he was an inn-keeper and for a time a gunner, perhaps at Tilbury. He became a skilled surveyor, and was port-reeve of Gravesend. Dying in 1583 and leaving a widow and four sons, he closed the short list of the recorded activities of his life. Yet Bourne was singular in that, of humble origin, 'a gunner . . . unlectured in Schooles or un-lettered in bookes', he yet mastered the arts of gunnery, surveying, and navigation and wrote the first English manual on the art of navigation. No copies of Bourne's first printed work, An Almanacke and Prognostication for iii yeres, with serten Rules of Navigation, 1567, are in existence. The almanac, on the stereotyped lines of which Leonard Digges's has been cited as an example, is known to have been ordinary enough; what made it exceptional were the 'serten Rules'. In some quarters Bourne was looked upon as presumptuous in publishing rules of navigation; nevertheless the popular demand for his production was such that a second edition was called for on the first becoming out of date. Accordingly in 1571, appeared An Almanacke and Prognostication for three yeares that is to saye for the yeare of our Lord. 1571. and 1572. & 1573. nowe newlye added unto my late Rulles of Navigation, yt was printed iii. yeres past.

Practised at Grauesend for the Meridian of London by William Bourne student of the Mathematicall science.1

Before examining Bourne's almanac with its rules, we must notice several important almanacs which had been published since Leonard Digges's of 1556. In 1556 an almanac in Latin by John Feild had appeared with a preface, also in Latin, by John Dee.2 While it is very doubtful whether the almanac was of any use to English navigators it was important because, like Recorde's Castle of Knowledge which appeared in the same year, it made the first English references to the Copernican theory of the universe. In 1564 and in 1567 new editions of Leonard Digges's Prognostication everlasting had appeared, and, probably in 1566, the forerunner of the modern pocket diary, A perpetuall Almanack, complete with note tablets, tide-tables, and rules for their use.3 Although its publication may have been delayed until 1569 it is probable that Philip Moore's A fourtie yeres Almanack, covering the years 1567 to 1606, first appeared in 1567.4 This contained 'A Verie plaine and perfecte table, called of some Mariners the Flyce', which was in fact a circular tide-table. Probably it was of Dutch origin. A simplified version of 1568 exists in a Danish translation of a Dutch rutter of 1566.5 Moore, who was a doctor living in Halesworth in Suffolk,

1 It was a reissue of the 1567 edition but with slips of paper for the years 1571-72-73 pasted over 1567-68-69 wherever these dates occurred, and a new title page. As no copy with the 1567 title page is known, the 1571 edition is discussed, but the observations are equally applicable to the 1567 edition, with suitable adjustments for the year in question. It was 'Imprinted at London in Paules Church-yrade, at the signe of the Lucrece, by Thomas Purfoote.'

2 EPHEMERIS ANNI. 1557. CURRENTIS IVXTA COPERNICI ET REINHALDI CANONES fideliter per Ioannem Feild Anglium, Supputata ac examinata ad meridianum LONDINENSEM qui occidentalior esse indicatur a Reinhaldo quam sit Regii Montis, per horam. 1. Scr. 50.

Adiecta est etiam brevis quaedam Epistola IOANNIS DIE, qua vulgares istos Ephemeridum factores merito reprehendit. TABELLA. per eundem Ioannem Feild confecta . . . IONDINI M.D.LVI. SEPTEMBRIS XII.

3 A blanke & perpetuall Almanack, serving as a memorialis, not only for al Marchantes and occupiers, to note what debtes they haue to paie or receiue, in any moneth or daie of the yeare: But also for any other that will make & keepe notes of any actes, deedes, or thinges that passeth from time to time (Worthy of memory, to be registred) Which may be written in this Almanack, or the like that may be made to serue for any yeere of our Lorde, that you would haue that Almanacke to serue for. Also in the ende hereof, ye shall finde a Table for Ebbing and Flowing, with certaine other Rules. Imprinted at London in Paules Church-yrade, at the signe of the Lucrece, by Thomas Purfoote. [c. 1566].

4 A fourtie yeres Almanacke, with a Prognostication continuing the same space of tyme (that is) from the yere of our Lorde God 1567 vntill the yere of our Lorde, 1606. Wherein is conteined and set forthe many, and very . . . perti [19th line] culerly declared. Gathered and sette forth by Philip Moore appractioner in Phisicke, and Chirurgerie. Imprinted at London, by Iphon Kyngston, for Henry Saunderson. [1567-1606].

and was no seaman, was not likely to have been the inventor; on the other hand, there were many refugees in the district from the Low Countries who might easily have given him the idea.

The fly was a crude wood-cut of a compass surrounded by seven concentric circles. In these, opposite the rhumbs of the compass, were (working from the outer circle inwards) the names of ports and of headlands in England and north-west France; cuts representative of the place-names for use by illiterate young seamen; lozenge-shaped cuts, whose significance is not clear; and the time in hours and minutes of high-water on the first, fourth, eighth, and fifteenth days of the moon's age. It was an elementary circular tide-table, the earliest known of many circular tide-tables printed in England up to the close of the eighteenth century.

An Almanack and Prognostication for 1569 had the prognostication written by Joachim Hubrigh, a doctor and astronomer of Middleburgh in Zeeland. It must have been particularly useful to the mariners engaged in the important and growing coal trade between Newcastle and London, for it contained a rutter of the route between Berwick-on-Tweed and the Thames. For the south coast carrying trade a tide-table for places 'from the byll of Portlande, to the riuere Thames, thorowe the narrow seas', was also helpful. The rutter is notable for giving the depths on 'the spetz' —a dangerous shoal between Harwich and the Nore in the Thames Estuary—at three states of the tide: ordinary, neaps, and springs. This appears to be the exception to the rule that the datum level was not specified in rutters when depths were recorded. The directions for entering the Tyne are of particular interest, for they include notification of the light established in one of the two leading-mark beacons—apparently the earliest of such notices to mariners concerning lights.

The year 1570 saw a new edition of Philip Moore's almanac, now called an Almanack and Prognostication, which still included the fly, and the next year there was a further edition. Besides Bourne's, which came out again that year, other almanacs of nautical interest that have survived include the first of a number by Richard Grafton, entitled A little treatise,

1 An Almanack and Prognostication, for the yere of our Lorde God. 1569. sernying for all Europe: Wherein is shewed the natures of the Planettes, and mutation of the ayer, verie necessarie for all Marchantes, Mariners, studentes and trauellers bothe by Sea and lande: calculated and gathered by Joachim Hubrigh Doctour of Phisicke and Astronomie. Whereunto is annexed a profitabile rule to know the Ebbes and Fluddes for Mariniers, also their courses, soundynges, landynges, markes, and daungers all along the coast of Englaunde and Normandie. Also all the principall Faires and Martes where, and when thei be holden, mete for all those that use the trade thereof. Imprinted at London by Ihon Kyngston, for Wilyam Pickrying. [1569].

2 A little treatise, conteyning many proper Tables and rules, very necessary for the use of al men, The contentes wherof appeare in the next page following. Collected and set forthe by Richardi Grafton, 1571. LONDINI. In aedibus Richardi Tottelli, Cum privilegio ad imprimendum solum.
and *A Newe Almanacke and Prognostication* by Gossenne.¹ These, besides containing tide-tables, also included the earliest lists of highways and of distances along them between towns.

So far the growing number of English almanacs containing information or devices designed to assist the mariner had been concerned with coastal work—pilotage. But Bourne's almanac of 1567—like that of 1571—was different. Both contained sixteen lengthy 'rules' for the mariner, and ten of them were for the mariner who aspired to take celestial observations and be a navigator. The first rule was 'of a good Navigator' and will be examined later; the second was on the compass—and an illustration of a compass-fly, the earliest English one apparently, if that in Eden's translation of Cortes's Spanish manual be excluded. In addition to giving the division of the fly into two 12-hour periods, Bourne numbers the 32 points, beginning with north as the first point. The third and fourth rules concerned the computation of tides. Then began the rules of interest to the navigator. These were the fifth and sixth, which dealt with the zodiac and the sun's declination in 1567, '8, and '9; the seventh and eighth, which explained how 'to take the altitude of the Sunne,' and of the Pole Star; the ninth, which was of the distance to raise or lay a degree; the eleventh and twelfth, which treated of 'the Longitude, although that it be very tedious', and the length of a degree of longitude; the thirteenth and fourteenth concerned the latitude and longitude of English towns, and of fixed stars; and the fifteenth explained 'How to sayle by the Globe.' The tenth rule and the sixteenth rule, like those relating to the tides, were useful to both pilots and navigators; the tenth because it dealt with soundings in the Soundings (the Channel Approaches), the sixteenth because it explained how to find the 'hour of the daye' by compass.

Here then was something quite new, the beginnings of a native literature on the art of navigation. It augured well that this first modest example should be written in simple language by a practical man for practical men. It included an excellent illustration—the earliest printed as well as the first original English one—of a sea-astrolabe of the cast ring pattern, and a device consisting of a compass-fly with sixteen points and two movable dials, which a quarter of a century later John Davis was to call 'An Horizonall Tide Table'. It was a tide computer of considerable ingenuity, but extreme simplicity. Given the establishment of a port and the age of the moon, then the time of high-water at that port on that day could be seen at a glance. It relieved the ship-master of the need to refer to long and rather complicated-looking tables listing the time of high-water at the different ports on each day of the moon's age, and reduced the essential information to a list of establishments of ports and a calendar of the moon's

¹ A newe Almanacke and Prognostication, seruing for the yere of our Lord God M.D.LXXI wherin is shewyd the varietie of the ayre through this present yecare, . . . [11th line]. Herevnto are annexed the principall Faires in England, . . . [14th line]. Calculated for the Meridian of the Citie of London, by G. Gossenne Doctour in Physicke. Imprinted at London by H. Byneman. [1571].
age. Curiously enough Bourne does not explain how to manipulate the computer. In the one he illustrated, the moon pointer was set to the establishment, and the sun pointer was used for reading off the hour—or rather rhumb, since hours were not marked on Bourne's computer—of high-water on the day corresponding to that of the age of the moon. The sun pointer was attached to a small dial engraved anti-clockwise with 30-day divisions. The day of the age of the moon was set against the moon pointer; consequently the sun pointer indicated the time of high-water—48 minutes later than the establishment for every day of the moon's age. Pocket horizontal tide-tables in brass, wood, or pasteboard appear to have come quickly on the market, and it seems fair to assume that they were frequently used in conjunction with the tide-tables in 'the Rutters of the Sea' and in many of the common almanacs. Bourne, it would also appear, was the publicizer, if not the inventor, of this useful instrument.

In the year before the reissue of Bourne's *Almanack* and *Rules* of 1567, appeared Sir Henry Billingsley's monumental edition of the first English translation of the works of Euclid, with Dr. John Dee's lengthy and masterly preface. Billingsley maintained that it was the absence of English translations of important works in other tongues that had kept the English as backward in the sciences as they were. Dee's preface was intended 'to aid and show the way to declare your discourse mathematically or to invent and practise things mechanically'. Both brilliantly achieved their aims. Indeed it may well have been Billingsley's *Euclid* which inspired Sir Thomas Gresham to establish the first public lectures on mathematics and navigation in English at an educational foundation. Probably no other work in the English tongue has been so influential in stimulating the growth in England of mathematics, navigation, and hydrography, and in leading to the general application of mathematics to the daily problems of life, as Billingsley's *Euclid*. The manner in which Dee, in his preface, handled his subject as a whole was masterly, while his detailed analyses of the arts of navigation and hydrography, to name but two, have never been surpassed. It was Dee who first defined the tasks of the hydrographer, and his wider view of the hydrographer's duty still holds good to this day. It was not long before Dee's preface had the desired effect of widening the Englishman's horizon in navigational and mathematical affairs, for it evidently inspired Bourne to expand his sixteen rules

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1 THE ELEMENTS OF GEOMETRIE of the most auncient Philosopher *EUCLIDE* of Megara.

Faithfully (now first) translated into the Englishis toung, by H. Billingsley, Citizen of London. Whereunto are annexed certaine Scholies, Annotations, and Inventions, of the best Mathematicians, both of tyme past, and in this our age, with a very fruitfull Praeface made by M. I. Dee, specifying the chiefe Mathematicall Seicces, what they are, and wherunto commodious: where, also, are disclosed certaine new Secrets Mathematicall and Mechanicall, untill these our daies, greatly missed.

Imprinted at London by John Daye. [1570].

2 For fuller extracts of Dee's definitions of navigation and related subjects, see Appendix 8.
into a manual of navigation—the first purely English navigation manual published. *A Regiment for the Sea* appeared in 1574, on the expiration of his almanac for 1571–2–3.¹

*A Regiment for the Sea* ('regiment' being used in the sense of 'rule') William Bourne dedicated to 'Edward, Earl of Lincoln, Lord High Admiral of England, Ireland and Wales, and of the Dominions and Iles thereof, etc., and Captain-General of the Queenes Majesty's Seas and Navie Royal'—the Edward Fiennes (Lord Clinton and Saye) of earlier days—and in his preface to the reader he explained that he had decided that his best contribution to his country would be a simple manual of navigation 'for the simplest sorte of seafaring man'. Although Bourne protested that this *Regiment for the Sea* was 'as it were a Nosegay, whose Floures are of myne owne gathering' and that it contained nothing already in Martin Cortes's *Arte of Navigation*, it derived substance as well as inspiration from that work. In so far, however, as it included matter not mentioned by Cortes, it was no paraphrase of the earlier work but an original contribution to the art of navigation.

Bourne drew the reader's special attention to the Ephemerides, the 'Table of Declination calculated for fewer yeares [1573–6] which the Seamen doo call a Regiment', and pointed out that it would serve for twenty-four years without much error, and, though calculated for noon-tide on the longitude of London, 'will serve all Europe and Africa, neare unto the coast of America, without much error', except in February, March, or September, when the sun's rapid change of declination made a correction for longitude necessary. It was simple, too. Whereas Cortes's and some other Ephemerides had given and continued to give the sun's declination in the form of the sun's successive positions in the signs of the zodiac, with a second table of declinations of these signs, a method which necessitated quite lengthy calculations to find declination in degrees or minutes, Bourne's table was the straightforward one of the sun's altitude, north or south of the equinoctial, in degrees and minutes, on each day of the first, second, third, and leap or 'bisxestilis' years from 1573 to 1592. It was, in fact, the first complete English nautical declination table printed since the similar tables in his *Almanach* and *Rules* of 1567 and 1571 were for three years only and not the complete four-year cycle.

*A Regiment for the Sea* opened with the calendar of saints' days; the position of the sun in the first point of the signs of the zodiac; and a correction of the erroneous belief, then common, that every fifteen days the day is an hour longer or shorter. As the rate of change of the sun's declination varies throughout the year, according to the position of the sun on the ecliptic, being greatest at the equinoxes and least at the solstices, the change in the length of the days varies in accordance with the seasons. The rule Bourne gave was that, as the length of the day is determined by the sun's declination, when 'the Sunne hath declined five de-

¹ See Pl. XXXIII (a).
degrees and twelve minutes in this our latitude [that is, when its noon altitude had changed by that amount], then is the day an hour longer or shorter'. The shortest day, one of 7½ hours, was, he explained, on 11 December. This was according to the Old Style or Julian, or unreformed calendar, as distinct from the New Style or Gregorian calendar. The latter was not adopted in England until 1752. Most Catholic countries on the Continent adopted it from 1582. As in many almanacs now, Bourne included a table of the reigns of kings. Brief definitions of the circles of the sphere were then succeeded by a lengthy and comprehensive definition of 'the Use of Navigation'—Bourne's original first rule, reinterpreted in practical form for the navigator. Bourne's grammar was not always too clear, but what he said amounted to a recapitulation of what the navigator had to take into consideration, such as the effects of winds, currents, and storms, in order 'to attain unto the port in shortest time'. Having dealt with the use of navigation, William Bourne then turned his attention to the user of it, the master. He 'ought to be . . . such a one as can wel governe himself, for else it is not possible for him to govern his company well . . .', he wisely observed, and further advised how the master should order the conduct of his crew, and when reward and when punish them. The technical qualifications of a master were that he should 'be a good coaster, that is to say, [to] knowe every place by sight thereof . . .', the dangers en route, 'how the tide gates', and how to calculate the tides from the moon's course; and that he should understand oceanic navigation. This last requisite was something new indeed for 'the simplest sort of English sea-fairing man'. And so on folio 8 'beginneth the Regiment for the Sea'.

The first rule was of the 32 winds and 24 hours of the compass and of its property 'always to stand due South and North'. The next dealt fully with the calculation of the tides and so of the Golden Number, or Prime, Epact and Age of Moon. Bourne explained that the time of full sea or high-water changes every 48 minutes, or 'one point' and 3 minutes. The calculation of tides, he added, seamen called 'shiftyng their Sunne and Moone'. As 'some seamen will take upon them to correct the Almanacks as touching the change and quarters of the Moone', holding all moons should be of equal days and hours and full moon half-way, Bourne explained that the moon has a cycle of 19 years which 'causeth sometime the full of the Moone to happen sooner and later'. This explanation was followed appropriately by 'a Table of Tides', or list of the establishments of the principal ports of England and Flanders, with a correcting note to the effect that spring tides in rivers 'will flow a poynpt of a compass more (¾ hour longer) . . . than . . . the neap tides'. Bourne gave the tides at Gravesend as an example.

The 'Regiment of the Sunne', which was preceded by the important rule for determining moonrise and moonset, consisted of the declination-tables in the simple form already outlined. Not content with this innovation, William Bourne went on to describe the use of the declination-tables
in determining latitude, giving simple rules for ensuring that declination was added when it should be added, and subtracted when it should be subtracted—the essence of the business being the bearing of the sun, whether northwards or southwards of the zenith when transiting. To make doubly sure of avoiding confusion he included three very clear diagrams. These make the rules foolproof. His treatment was a great improvement on Cortes’s, whose work not only lacked the diagrams but contained the rules for sun sights in one short chapter. Bourne next dealt with the novel problems met with in navigating south of the equator. Again he illustrated the text with diagrams such as are found in modern manuals. In Chapter 10, the fourth rule on ‘how to handle the declination of the Sunne’, Bourne explained with another diagram showing how to find the latitude ‘where the Sun doth not set under the horizon, and also to take the Sunne at the lowest being due North’.1 This was a most important and significant chapter. The explanation was an original English contribution to the art of navigation. Bourne first explained how it is possible in high latitudes to take a sight when the sun is at its lowest, ‘commeth nearest unto the Horizon’. This, of course, is at midnight. Such sights were ‘very necessarie for them that did occupy unto the Northwardes of Saint Nicholas in Rousey’, and ‘for them that would attempt any voyage of discovery unto the Northwards, as into the East by Nova Zemla, or to the west by Cape de Paramantia, on the back side of the North part of the taile of America . . .’, because, though Bourne gave no reason, in mid-summer the twenty-four-hour day makes star sights impossible. He then explained the ordinary sun sight taken ‘when the Sunne is upon the Meridian at the greatest heighth from the Horizon’.

Clearly these latter rules were evolved from the experience of the English in northern navigations, and Bourne took the opportunity to add arguments in favour of such navigations, as that in summer the farther north you went it was ‘the more temperate warme, by meanse of the long continuance of

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1 See Fig. 14.
the sunne and furthermore he that were in the Latitude of 80 degrees, should have but a short parallel: this is, a short cut to the East.

To these same northern navigations can be attributed a modification of the cross-staff, based, no doubt, on that devised by Gemma Frisius for taking the distance apart of stars. Bourne's modification was designed to make observations of the sun's altitude practicable when it transited low over the horizon. This modification, illustrated by Bourne, consisted of graduating the staff from 40° up to 90° near the eye end, and the transversary from 40° down to about 5°, and of fitting the latter with two sliding vanes (Gemma Frisius's transversary had been fitted with only one sliding vane on one arm of the transversary). By this means not only was the navigator able to shoot the sun when it was less than 20° above the horizon, which he could not do with the original mariner's cross-staff, but he was also able to have larger graduations and so to make more accurate readings of the result of his observation. Bourne advised restricting the use of the cross-staff to sights made when the sun's altitude was less than 50°. His reasons were that the degrees were large on the scale up to 50° and that the sun and the horizon could be seen in one wink when they were up to 50° apart. He also advised the use of a piece of smoked glass to protect the sight, or else the practice of covering the sun with the end of the transversary and deducting 15°—the sun's semi-diameter—from the observed altitude. This advice, if not original, was first given expression by Bourne. Unfortunately he concluded with the advice that, to correct for parallax caused by the eye-socket, the navigator should pare away the end of the cross-staff. As there was no handy means of checking an individual's parallax, the cure was in practice often worse than the disease, many a master shortening his cross-staff, 'just to make sure', when there was no need to do so. For sights above 50° Bourne advised the use of an astrolabe, the sight being taken by letting the sun shine through the holes in the vanes on the alidade. He also recommended taking two such sights in order to correct any observational errors. Referring to the determination of variation Bourne gave the usual three daytime methods: the sun's bearing at sunrise and sunset; equal-altitude bearings; and meridian-altitude bearing. He advised the use of the Pole Star at night, using the Pointers of Charles's Wain. Above all he implored mariners not to adjust the compass-fly for variation but to correct their courses by allowance for variation. As for the determination of longitude by variation, 'no maister or pilot of a shippe, doth keepe so simple account of the shippes way, but that he may know what distance he hath unto any place, better then he shal know by varying of the compas', he shrewdly observed. Then with judicious and scientific caution he added, 'whether . . . the compas doth keepe any such proportion in the variatio, I do refer that unto them that have tried the experience thereof: for I for my part can say nothing in that matter. But if it be true, that the compasse doth vary by that proportion, then'—and here he put into a nutshell the preoccupation of the English with the determination of variation—'it were very good for them too pratyse that matter.
that should make any discovery unto the Northwardes, for that the degrees be so short in those Parallels'.

For the Regiment of the Pole Star Bourne used the polar distance of 3° 30' and included a diagram of the rule on the lines of that in Fernandez de Enciso's *Suma de Geografia* of 1519.1 Explaining the rule for 'raising and laying a degree', he observed, 'in the most part of cardes they allow for every degree, but 17 leagues and a half. Your cardes', he added—and the comment throws an interesting light on English hydrography—'be most commonly made in Lisborne, in Portugal, in Spain, or else in France. But as I take it, we in England should allowe 60 myles to one degree', and

![Diagram of the North Star](image)

**Fig. 15**

A REGIMENT OF THE NORTH STAR

1. After the diagram (fol. 38) in Bourne's *A Regiment for the Sea, 1574.*

2. The Guards' are the Pointers (in practice only Kochab) in *Ursa Minor.*

60 miles to a degree Englishmen in future allowed, assisted no doubt by the diagram included in the Regiment.2 Though he explained that departure and difference of longitude are the same only 'under the Equinotiall. . . . For ever as you goe to any of the two poles, your degrees by styll shorter and shorter, tyll such tyme as your Meridian meete under the two poles . . .', he did not here explain how to convert departure into difference of longitude.

Bourne's experience both as a surveyor and a gunner came to the fore in Chapter 14, where he gave rules to know at sea 'the distance between

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1 See Fig. 15.
2 See Fig. 16.
A REGIMENT for the Sea:
Conteyning most profitable Rules,
Mathematical experiences, and perfect knowledge of Navigation, for all Coates and
men, who shall use the same book for all stuffed
men and Travellers, as Pilots, Mariners,
Parriu, or, Certifiiede and
made by VV. H. VV.

Imprinted at London for Thomas Hackett, and
are to be solde at his shop in the Royal Exchange,
at the Signe of the Greene Dragon. 1574.

XXXIII(a). A Regiment for the Sea (1574).
any two headlands and how far offshore the ship is by the use of the crossstaff'. In other words, he explained how to fix the ship's position, in modern terminology, by sextant angle, and how to avoid hidden rocks or reefs, or to chart their position, by measuring the danger angle or range. Once again this, if not a new technique, was the first description of it in English. It was followed by that of a new instrument 'to know the ships way'. This was 'a pece of wood, and a line to vere out ouer borde, with a small line of great length', and 'either a minute or [i.e. of] an houre glasse, or else a knowne part of an houre, by some number of woordes . . .'. His description, the earliest extant, leaves no doubt that the log and line had by then been developed almost into the form that it has to this day, but he gave a general rule for finding the distance sailed in terms which must have left the ordinary ship-master scratching his head in perplexity and no doubt finally condemning the infernal contraption to perdition. Sixty years later Boteler in his Dialogues described the log-line as 'a small [thin] line having a little piece of a board at the end thereof, with a little piece of lead fastened so into it as to make it swim edge-long in the water . . . this line and the board which is termed the log are heaved overboard out of the poop of the ship; the line being laid loose at length that it may freely run out . . .'. Although in Captain Smith's opinion its use was 'so uncertaine, it was not worth the labour to trie it'1 or as Mainwaring put it, 'this is a way of no certainty

1 Smith, Captain John, A Sea Grammar (1627).
13—A.O.N.
unless the wind and sea and the course continue all one, besides the error of turning the glass and stopping the line',¹ the fact that it did form part of the equipment of many navigators from Elizabethan to modern times merits an explanation of its use. Indeed in the revised, 1580, edition of the Regiment Bourne treated of the log and line at length, which in itself is evidence of its importance in contemporary seamen's eyes. The log-line was attached to the 'crow foote', as Bourne called it, so that the log when veered, 'should drive a stern as fast as the shippre doth go away from it, alwayes hauing the line so ready', he cautioned, 'that it goeth out as fast as the shippre goeth'. The log-line was divided into two parts marked 'according unto the shippre' so that when the log was 'let downe handsomely' into the water sufficient log-line was run out clear of 'the edie of the sternre', which might stop it, for the log to be in 'quicke water' before the timing of the line was begun. In later years this first portion of the line became known as the 'stray-line' and was from 10 to 20 fathoms in length. Its end, and thus the commencement of the log-line proper, was marked with a piece of bunting. Bourne recommended a length of only 'two or three fadame'. To heave or veer the log after the line had been 'laid loose at length that it might freely run out', the log was thrown clear of the ship, to windward, by the master, from the poop. When the log hit the water, the line was paid out freely by an assistant according to the speed of the vessel. As the bunting marking the end of the stray-line passed the taffrail a second assistant turned the glass, and as soon as the sand had run out he called 'stop', and the log-line was nipped by the first assistant. The nipping of the log-line snubbed the stray-line, jerked the pin out of its socket and thus pulled the log edge-on to the water. This made hauling it in easy. As it was hauled in, the length of log-line veered was measured 'in foote or fadames'. If a half-minute glass had been used, this was equal to '120. part of an houre'. Then, explained Bourne, 'suppose that you have verred fiue and twentie fadames', if you 'multiply a hundreth and twentie by fiue and twentie, . . . there commeth 3000 fadame'. As 'an English league is 2500 fadame . . . the Shippe hath gone one league and one fifth part of a league in an houre'. Provided you veered the log whenever the wind increased or decreased, he considered you could 'keepe a verie good reckoning of your ships way', and he proceeded to show how you should do so over a 12-hour period in which the wind strength changed three times. Provided the humidity had not greatly affected the flow of the sand in the glass, and the readings were taken regularly and frequently, say 2-hourly, a good measure of the speed could with experience be made. Yet until the second quarter of the seventeenth century the log and log-line were not, as the evidence quoted shows, popular instruments. The labour of computing the distance sailed had much to do with this. As the distance was computed in leagues on the basis of the number of fathoms sailed in the period—the only method known—it was a formidable and repellent mathematical prob-

lem to the ordinary navigator, involving both multiplication and long-
division. In part also the log was neglected because, as the number of fathoms
considered to be in a league was too few, the distance logged was always too
high. Navigators relying on it—if any did—thus always had ‘their reckoning
before their ship’. Although this did not perturb them (for, as we have seen,
they preferred to have it so), nevertheless it undoubtedly led to little faith
being placed in the log as a reliable aid to increased accuracy in navigation.
The earliest illustration of a log, log-line, half-minute glass, and log-reel is
in Champlain’s Les Voyages de la Nouvelle France, published in 1632. This
includes the illustration as part of the ‘Traité de la Marine’ which he
added in this edition. In the accompanying text he describes the log as a
means of estimating distance run which he has seen in use amongst a
number of skilled English navigators. This would have been during the pre-
ceding years of the seventeenth century. The log was a thin board of beech-
wood about 12 inches high and 6 inches wide, with a strip of lead on the
lower edge. A small wooden tube was attached by a bight of cord to the two
lower corners of the log, and a wooden pin, attached to the end of the stray-
line, fitted easily into the tube, the stray-line being roved through the top of
the log, a hole being drilled through it for this purpose. By this means the
log was kept vertical in the water and thus did not follow the vessel as the
log line was unreeled and paid out. On the log-line being snubbed the pin
was jerked out of the socket, the log was pulled on to its front face on the
sea-surface, and was then easily hauled in. The log-line is shown knotted,
with single knots. Champlain described the stray-line as of 8 to 10 fathoms
in length ‘before coming to the first knot’. The knots he assumed to be
spaced 7 fathoms apart, that is 42 feet, and to be single knots throughout
the length of the line; thus at a speed of one mile an hour one knot of line
ran out in half a minute. 1 It must be remembered that Champlain was
writing 50 or 60 years after Bourne, who makes no mention of knots.

Closely related to the log-line was the problem of longitude. Bourne’s
discussion of this was knowledgeable but concluded with the practical
advice, ‘I would not any Seaman should be of that opinion that they might
get any longitude with instruments, but (according to their accustomed
manner) let them keep a perfect account and reckoning of the way of their
shippe, whether the shippe goeth to leewardes, or maketh her way good,
considering alwayes what things be against them or with them: as tides,
currents, winds or such like’, what William Borough called, the ‘dead
reckoning’. 2 It may be remarked that today, owing to the almost universal

1 Champlain, Le Sieur de. Les Voyages de la Nouvelle France Occidentale,
dicte Canada . . . A Paris, Chez Claude Collet au Palais, en la Gallerie des Prison-
niers, à l’Estoille d’Or. M.DC.XXXII. Avec Priuilege du Roy [which contains
‘Traité de la Marine et du Devoir d’un Bon Marinier’].

2 ‘Instructions and notes very necessary and needfull to be observed in the pur-
posed voyage for discovery of Cathay Eastwards, by Arthur Pet, and Charles
Jackman: given by Mr. William Burrough, 1580’. Hakluyt’s Principal Navigations,
use of mechanical propulsion, the significance of the expressions, the way made good, and dead reckoning, has been transposed.1

Although Bourne did not explain the conversion of departure into d. long. (difference of longitude) he gave, in the sixteenth chapter, the rule and a diagram for ascertaining ‘how many miles there are in a degree of longitude in any given latitude’, the first printed in English. The rule had been given in tabular form by Cortes, who had quoted the length of a degree at 60° latitude as being half that of its length at the equator, but who had then dismissed the problem as a matter which if further expounded would ‘be an endless confusion’. Bourne gave many more examples of the length of a degree of longitude at different latitudes, and showed how the length of a degree in any latitude could be ascertained by the use of a piece of thread and the accompanying diagram. He followed this, logically, with an account of the difference of time between places on different longitudes, quoting the Canary Islands as being on the prime meridian. The account was short. It will be recalled the longitude correction to the declination-tables had been very cavalierly treated. As yet instrumental accuracy did not warrant more care in its calculation and application. Chapter 17, however, contained a list of the principal places in England with their latitudes, longitudes, and differences in time from London’s.

‘The most part of seamen’, said Bourne in the eighteenth chapter, ‘made their account as though the earth were a platforme. For they did not consider that the earth is a Globe ... for it is unpossible to draw the face of the earth and the sea true upon a platforme.’ It was thus that he introduced the rule: ‘How to sayle by the Globe’, a very necessary rule for those who ‘had any occasion to attempt any

voyage to the north parts... for so should they better see the distances and bignesse of the landes, and in like manner their lines and courses', a thing impossible on the plane chart, as it so grossly distorted the earth's surface in northern parts. As already remarked in an earlier chapter, his instructions for laying off a course on a globe mention neither the quarta altitudo nor engraved rhumb lines. The nearest he gets to describing great circle sailing is the advice to plot position and course 'euer and anone, for the oftener you do observe this custome, the better and perfecter shall your course be'. He followed this useful but by no means foolproof rule with 'the making of Plats or Cardes for the Sea', and while referring the student to Cortes for the method, had some valuable comments on the content and use of charts. He deplored the hydrographer's practice of filling vacant spaces on land 'with so many Flagges' (originally done to indicate the port's sovereignty) and colouring the compasses 'with so many colours', and suggested that, instead of wasting their time and confusing the mariner by such embellishments, they should instead include tidal information and the elevation of the shore from the sea. The tidal information should, he said, take the form of a compass with letters against the principal rhumbs, and each port should have the letter entered against it appropriate to its establishment. For example 'where it floweth an East Moon = A and where it runneth halfe tyde under other, to make some note upon the poynte of the compass'. Thus Bourne would have incorporated the chief tidal information contained in the rutters and have adapted Brouscon's tidal charts to conform with the ordinary one. He was twenty years ahead of his time. His other suggestion was based upon the Portuguese practice of already over half a century's standing, though by no means general, of drawing 'the shape or fashion of every headland or high land alongst every coast that is needful to be knowne'. He truly observed: 'There is nothing more needful and necessary for a Seaman, than thys: to knowe the land when he seeth it, and there is no better way, to make him remember it, than to have notes howe the land doth ryse upon every side...'. Nowadays Bourne's tidal information and coastal elevations are included on coastal charts. It was in the year of his death that the first charts delineated with coastal elevations came from the press.

Ever practical, it was in his nineteenth chapter that Bourne gave the clearest directions hitherto penned on how to take off course and distance on a chart with compasses, how to read off latitude, and how to correct the 'deade reckoning' by 'taking the height of the pole'.

After the table of declination of fixed stars Bourne included two supplementary tables, designed to help in the choice and identification of the stars. These listed in what quarters they rose and set, how long they shone, and the time of their transiting. As in northern navigations it might well happen that the sun was not visible at noon and above 50° N or 60° N the Pole Star was too high to be shot with the cross-staff, Bourne
amplified Cortes's chapter on star-sights, explaining how to find latitude by the use of other stars besides the Pole Star.

Although Cortes had devoted a whole chapter to the equinoctial dial, a sun-dial that could be adjusted so as to show the correct local time in any given latitude of observation, Bourne did the same, describing how to make one in wood (in his earliest rules he had described how to make it out of an old or discarded compass-fly), and recommended Cortes's manual for the explanation of how to make it in metal, because 'the Equinoctiall dial be not used amongst our Mariners heere in Englande, for that the charges is so much in the making of them'. Indeed, he continued, 'I have not known them used by any English Maister or Pylot, but only by one man', and he, he added slyly, had it only 'to bragge, that he had such an instrument. . . .' Why Bourne was anxious for it to come into common use was that, apart from its possibilities as a time-keeper on long voyages, its use on short voyages 'in these our chanelles' could obviate mistakes in the time of high-water based on the bearing of the moon, and ignorance of its declination. Such mistakes arose, Bourne pointed out, 'by cause in setting the Moone with their compas (the Moon having northerly declination) she seemeth to be East by the compasse, when she is neere East South east in her course . . . which is a very perillous matter unto them that should put into a . . . haven where he knoweth there is water enough for him, if that he do the come at a full sea . . . '. (He would put in, of course, one hour and a half after high-water, and run the risk of stranding on a falling tide.) Nevertheless, Bourne's reasons for the lack of users of equinoctial dials were not really correct. Owing to the difficulty of orientating the dial correctly and of keeping its base level on board ship it was impracticable to find the time accurately by it.

In the twenty-second chapter, 'for that it is a dangerous place to hit or fall with, or enter into cumming homewards out of Spayne or Portugall, or from Barbary, or any place from Southwarde' (the chief direction as yet for English seamen), Bourne gave the soundings in 'the Sleve' for channelers, directing them 'to seeke the Ile of Ushant, or the Lizard', landfalls the modern navigator still makes for. Curiously enough he gave the latitude 'midway between the Lizarde and Ushant' as 50° N, one degree too high; it is really 49° 49'. As a result, the channeller who had some pride in his navigational skill might well be excused if he got confused as to his position. However, a very valuable section gave directions for piloting amongst sands and shoals, on the choice of leading marks and thwart marks, and on knowledge of soundings and cross-tides in shoal-water—all subjects never before treated in print.

In the last chapter Bourne, with the old problem of longitude in his mind, returned to the question of variation. He concluded that if variation did change in proportion to longitude, it would be useful only close to the meridian where the compass was made, a good example of the prevalent ignorance on the nature and cause of variation. The lack of Englishmen's curiosity hitherto with regard to variation is shown by his lament that
despite the 'many times English men have been in the West Indies' none could tell him how a compass touched in America behaved.

Such then was Bourne's *A Regiment for the Sea*. Of course it appealed to Captain John Smith and was recommended by him fifty years after its first publication. He was a practical man. The *Regiment* was a practical manual, written by a man who, if not practised in his art at sea, had the sea-breeze in his nostrils, seamen at his elbow, and the rare faculties of quick comprehension and lucid exposition. Its essential feature was that it supplemented Cortes's *Arte of Navigation* in exactly the right way—where it was weakest. Cortes's manual was valuable to the navigator chiefly for its detailed descriptions of how to make the principal instruments of navigation; Bourne's manual, apart from its innovations and simplifications, was valuable chiefly for its detailed instructions on how to use the instruments.

The growing awareness of Englishmen of the need for navigational skill was soon evinced again. In 1576 Thomas Digges published a new edition of his father's *A Prognostication everlastinge*, but with a very important *Addition*. This *Addition* comprised the first detailed and illustrated description in English of the Copernican system, a discourse on the variation of the compass, and a short discourse on certain errors practised by Englishmen in navigation. Thomas Digges rededicated the *Prognostication* very appropriately to the Earl of Lincoln, and in the course of his dedication he explained that he had included the 'certain errours touching matters of Navigation transferred into our language', because English seamen 'have been and are (in allNavigations) so misled, that were they not by sight of the coast, & soundings better directed, then by any troth in their Arte, many moê vessells should daily perish'. In half a dozen paragraphs he summarized the main faults of the plane chart, the errors resulting from the impossibility of finding longitude accurately, the malpractice of paring away the end of the cross-staff in an attempt to correct eye parallax and, most notably, the fact that the Rule of the North Star required a correction for the effect of latitude.

The explanation of the Copernican system, with its diagram, while of no practical value to the navigator, contributed to his knowledge and understanding of the astronomical problems lying at the root of navigation, and

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1 *A Prognostication everlastinge of righte good effecte, fruitfully augmented by the auctour, containing plaine, briefe pleasaunt, chosen rules to judge the weather by the Sune, Moone, Starres, Comets, Rainebow, Thunder, Cloudes, with other extraordinary tokens, not omitting the Aspects of Planets, with a briefe judgement for euer, of Plenty, Lacke, Sickenes, Dearth, Warres &c. opening also many naturall causes worthy to be knownen. To these and other note at the last, are joyned divers Generall, pleasaunt Tables, with manye compendious Rules, easye to be had in memory, manifolde wayes profitable to al men of understanding. Published by Leonard Digges Gentleman. Lately corrected and augmented by Thomas Digges, his sonne. Imprinted at London by Thomas Marsh. Anno 1576.*

See Pl. XXXIV.

2 See Pl. XXXV. For Digges's *Errors*, see Appendix 11.
no doubt quickened the critical faculties of the more intelligent. By its inclusion in this popular almanac it must have contributed powerfully to the stimulation of interest in astronomy and so indirectly have assisted the development of navigation. The Short Discourse touchinge the Variation of the Compasse has the distinction of being the first original English discourse to be published on a subject in which the English were soon to take the lead in scientific observation, experiment, and speculation. Digges in his Discourse disagreed with the theory of eccentrically sited 'Attractive Points', which it was frequently considered should make it possible to find longitude by determining variation. He believed eclipses to be the only practicable way to do this, and promised to produce the necessary lunar tables.

When Bourne's Regiment had appeared preparations were on foot for a project long discussed in the highest, and geographically best informed, circles in England—the possibility of discovering the longed-for North-West Passage to Cathay. In 1576, and the two following years, expeditions under the command of Martin Frobisher sailed for the attempt. The later ones were also to exploit what was at first believed to be a gold-mine discovered on the first voyage, in what is now known as Frobisher Bay. Financially the outcome was disastrous, but the attempts aroused the greatest popular interest. Frobisher and Hall, the principal captains concerned, although experienced mariners, were specially coached by Dr. John Dee in 'Geometry and Cosmography' in order to improve their 'use of the Instruments for Navigation in their voyage'. But they confessed themselves, from the start of the first voyage, 'not able to be Scholers'. The books they did take were not well chosen for practical navigation. They were evidently the choice of a scholar inexperienced at sea, not of a practising navigator. Cuningham's Cosmographical Glasse, Recorde's Castle of Knowledge, 'a book of cosmographic in French of Andres Thevet', and a Regiment of Medina in Spanish, comprised their stock.1 The emphasis was on theory. Medina's work, the only navigation manual, was however (whichever work of his was taken) particularly good on the practical problems of sights, chart-work, time and tides. So was Bourne's. That this was evidently the contemporary view is indicated by the appearance, probably

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1 For the full list of Frobisher's library and instruments, see Appendix 10. Dee's preface to Billingsley's Euclid, 1570, enumerated most of these instruments as part of the master-pilot's equipment, but included proportional compasses (dividers) and paradoxal compasses (circumpolar charts), hour, half-hour, and three-hour sand glasses, and detailed, as might be expected of him, a universal astrolabe, instead of a mariner's, and included 'quadrants' and 'Clockes with spring', see Appendix 8A. In the inventory of Frobisher's instruments the 'Armillar Tolomei' or 'Hemispherium' was an armillary sphere, illustrated by Cortes and in most works on navigation and of which a fine example of 1582 by Humphrey Cole is preserved at St. Andrew's University. With an armillary sphere all the ordinary problems relating to the position of the sun at various seasons that could be solved by the globes could also be solved (Edw. Wright, Description and Use of the Sphere, 1613).
A Regiment for the Sea: Contayning most profitable Rules, As also mathematical experiences, and perfect knowledge of Navigation, for all Coautes and Countries usefull and necessary for all men, being men and Travellers, as well as others:

Etca. by William Bourne.

A Prognostication everlastinge of right.

To these and other now at the last, are joined divers General "pleasing Tables, most apt and necessary Rules, to decide and help in many, many cases, perhaps for further understanding. Published by Leonard Digges, Gentleman. Laste corrected and augmented by Thomas Digges, his sonne.

Imprinted at London by Thomas Marsh. Anno 1576.

XXXIV. Title-page of Digges's A Prognostication . . . (1576).
XXXV. Digges's Diagram of the Copernican System, 1576.
XXXVI. Signed and dated MS. chart of the N.W. Atlantic by W. Borough, 1576.
this very year, of an unauthorized second edition of his *Regiment*. On the title-page, in place of the astrolabe of the first edition, was the lively representation of a warship of the period formerly on the back of the title-page.

Apart from its list of navigational books in the captain’s chest the inventory of the first Frobisher voyage in search of the North-West Passage is of singular interest for its list of navigational instruments and charts provided. These were not Frobisher’s, but the Adventurers’ property. This arrangement followed the precedent of the first voyage in search of the North-East Passage, for which ‘Cardes, Astrolabes, and other instruments were prepared . . . at the charge of the companie’. In 1553 there were few navigational instruments in England. There were probably no native and few foreign instrument-makers in the country competent to make them. Perhaps the beautiful universal astrolabe wrought in the Blackfriars workshop of the Flemish craftsman, Thomas Gemini, in 1552, was provided for the expedition. However that may be, by 1576 Englishmen, such as Humphrey Cole, were themselves making instruments of exquisite accuracy and unsurpassed design. Flemish refugees, who had brought their skill in metal work with them, were repaying the sanctuary afforded them by enriching the native handicrafts. It is probable that the company’s navigational advisers recommended the use of instruments of only the finest workmanship, in place of the masters’ much homelier ones. Normally the master and the pilot provided their own navigational instruments.

William Borough must have seen to the provision of many of the navigational instruments, for ‘although he was not so well persuaded of this enterprise that he would venture his money therein’, yet for the ‘service of his country’ he went to much trouble to produce ‘a master and many mariners for the ships, and agreed to the route to be followed by the captains’. Besides doing this he drew a special chart, still extant, of the northern regions with spaces left blank which it was hoped the explorers would fill in. The instruments provided consisted of twenty compasses of different sorts, eighteen hour-glasses, a cross-staff, an astrolabe, a meridian compass for finding the variation, an equinoctial or universal dial, an astronomical ring-dial, an armillary sphere, and ‘a great globe of metal in blanke in a case’. The last item cost £7 13s. 4d., and was by far the most expensive, the cost being more than twice that of the astrolabe. For charting the coasts there were supplied ‘a little standing level of brass’ (which was filled with water to give a plane surface) and a *Holometrum geometricum* or plane table.

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1 See Appendix 4, giving some of Sebastian Cabot’s instructions for the 1553 voyage. See Pl. XXXVI for chart of 1576 voyage and Pl. XXXIII (b) for title-page of the 1576 edition of Bourne’s *Regiment*.


3 Facsimile reproductions are included in Penzer, N. M., *The Three Voyages of Martin Frobisher* (1938).

See Pls. XXXVI and XXXVII, and Appendices 10 and 13.
with sights. As we have seen, Frobisher and Hall had to be instructed in the finer points of the use of these aids to navigation. Nevertheless George Best, who described the three Frobisher voyages in *A True Discourse*, in 1578, was probably not greatly exaggerating when he claimed that: ‘The making and prickung of Cardes, the shifting of Sunne and Moone, the use of the compass, the houre glasse for observing time, instruments of Astronomic to take Longitudes and Latitudes of Countreys, and many other helps, are so commonly known to every Mariner nowadays, that he that hath bin twice at Sea, is ashamed to come home, if he be not able to render accompte of all these particularities’.\(^1\)

It was George Best who remarked ‘how the Latitudes were alaways take in this voyage rather wyth the Staffe than Astrolabe . . . bycause the long day taketh away the light not onlilly of the Polar, but also all other fixed starres’, and the graduations in the astrolabe were too small for accurate observations of the sun, while the Pole Star, if visible, was too high to be shot with the cross-staff. This experience indicates that failure to provide themselves with Bourne’s *Regiment* had resulted in futile attempts to take star sights. One shrewd remark Best made surely echoes the voice of William Borough: ‘Captaine Martine Frobisher’, he recorded, ‘diligently observed the variation of the Needle. And suche observations of skilful Pylots, is the onely waye to bring it in rule, for it passeth the reach of naturall Philosophy.’

Encouraged by the success of his *Regiment*, Bourne published three more books this year, 1578, *A Treasure for Travellers, Inventions or Devises*, and *The Arte of Shooting in great Orndaunce*. *The Arte of Shooting* marks Bourne as unmistakably as *The Regiment* as an exceptional man, for he could claim, ‘I am the first Englishman that put foorth any booke as touching the art of gunnery.’\(^2\) Hitherto English seamen had been backward in

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1 *A TRVE DISOCRSE* of the late voyages of discoverie, for the finding of a passage to Cathay, by the Northwest, under the conduct of *Martyn Frobisher* Generall: Devided into three Booke: In the first whereof is shewed, his first voyage. Wherein also by the way is sette out a Geographickall description of the Worlde, and what partes thereof have bin discovered by the Navigations of the Englishmen.

Also, there are annexed certayne reasons to proue all partes of the Worlde habitable, with a generall Mappe adjoynd.

In the second, is set out his second voyage, with the aduentures and accidents thereof. In the thirde, is declared the strange fortunes which hapned in the third voyage, with a severall description of the Countrey and the people there inhabiting. With a particular Card thervnto adjoynd of *Meta Incognita*, so farre forth as the secretes of the voyages may permit.

AT LONDON, Imprinted by Henry Bynynman, servant to the right Honourable Sir CHRISTOPHER HATTON Vizchamberlaine. *Anno Domini, 1578.*


[Woodcock’s ornamental device]. Imprinted at London for Thomas Woodcocke, 1587. No copy of the first, 1578, edition is known, but it was ‘extant in print’ in 1581, see Bourne’s *Almanacke and Prognostication for X. yeeres* (1581).
that art, as in navigation. Without proficiency in it they could sail in safety nowhere. The unrivalled reputation of English seamen as gunners dates from the years succeeding the printing of Bourne’s *Arte of Shooting. Inventions or Devises*, also published in 1578, Bourne dedicated to Charles, Lord Howard, who was destined to succeed Lord Lincoln as Lord High Admiral in 1585, and was a nobleman already noted for his knowledge and skill in seamanship. It dealt chiefly with ‘Martiall affayres by Sea’ and with ships.¹ The preface to the reader took the form of an able essay on the need to study tactics and the art of leadership at sea. It is, in effect, the first English book on the problems of naval tactics. Incidentally, the appropriateness of Bourne’s choice of patron was confirmed by Edward Hellows, who dedicated his translation of a Spanish history of *The Invention of the Art of Navigation*, also published in this year, to Lord Howard. In this he paid tribute to Howard’s nautical knowledge and skill.²

*A booke called the Treasure for Travellers* Bourne dedicated to the ‘Maister of the Queens Maisties Ordinance by Sea’, Sir William Winter, who was also ‘Scruaier of her highnesse marine causes’,³ and had been responsible for laying down in 1569 the scale of armament of the royal ships that were to defeat the Armada in 1588.

*The Treasure for Travellers* was important for many reasons: because it contained the first popular explanation of surveying by triangulation, illustrated with an example of a triangulation by Bourne; because it was the first English book to describe the volumes, capacities, and proportions of ships’ hulls, and the methods, based upon calculations of cubic content, of getting ships over bars or shoals; because it was the first to describe the sizes and weights of cordage, with rules for their computation; because it contained one of the first descriptions of the currents of the ocean, and explained in popular language the value of mathematics to the seaman. From a navigational point of view the last two were its most important features. Bourne distinguished three sorts of ocean currents: those that are now known as the North and South Atlantic Drift currents; currents caused by storms; and currents caused by the discharge of great rivers into the sea and by the melting ice and snow of the Arctic regions. From

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¹ Inventions or Devises. Very necessary for all Generalles and Captaines, or Leaders of men, as wel by Sea as by Land: Written by William Bourne. A. 1578. AT LONDON. Printed for Thomas Woodcock, dwelling in Paules Churchyarde, at the signe of the blacke Beare.

² A booke of the Invention of the Art of Nauigation, 1578. [Translated from the Spanish of A. de Guevara, *Aguja de Marear y de sus Inuentores* (1545) by Edward Helenwes]. B.M. copy temporarily mislaid. Hellows described Howard as an experienced seaman, apt in all weathers, and a skilled navigator and coastal pilot —adding that these accomplishments were ‘not usual to Noblemen’.

³ A booke called the Treasure for trauelers, deuided into ffeue Bookes or partes, contaynyng very necessary matters, for all sortes of Trauailers, eyther by Sea or by Lande, written by William Bourne.

*Imprinted at London for Thomas Woodcocke, dwelling in Paules Churchyarde, at the sygne of the blacke Beare, 1578.*
Bourne's explanation it is apparent that he was one of the first Englishmen to attribute the clockwise circulation of shipping in the North Atlantic to the currents. Nowadays it is attributed primarily to the wind system. But in Bourne's day the wind, which was considered as 'an exhalation of the earth', was not associated with drift currents, although the general pattern of the wind system in the Atlantic had long become evident to the Portuguese and Spanish navigators, and was becoming known to English ones. As we have seen, the controlling forces of the vertical movement of the tides were popularly considered to reside exclusively in the moon. It was therefore natural to associate the only recently experienced lateral movements of the waters of the ocean with the motions of the moon, and it is by these that Bourne explains, for example, the South Atlantic Drift current, of whose pattern he gives a remarkably accurate description.

In the absence of a printed rutter of the Atlantic Bourne's descriptions of the ocean currents were the only ones generally available in English, although only a year before a new edition, by Richard Willes, of Richard Eden's *The History of Travayle in the West and East Indies* had contained a learned discussion on cosmography, ocean currents, and shipping routes by Willes, who had been a professor at an Italian university. This had probably been a main source of Bourne's information.¹

Probably as an aid as well as a stimulus to English mariners, John Frampton, who had long associations with Spain and was to translate Medina's navigation manual of 1545 and publish it in 1581, translated and published at this time, *A briefe description of the portes ... of the Weast India*, the section of Enciso's *Suma de Geographia* of 1519, devoted to the ports and havens of the West Indies. In his dedication to the king, Enciso had made it clear that he had written this part especially for the help of mariners and pilots, so that it must be considered as the first printed rutter of the West Indies. Frampton's translation was thus certainly the first printed English one. However, the fact that it was never reprinted seems to indicate that the original data must have been either inadequate or too out of date for pilotage purposes in the '80s and '90s.²

In explaining in popular language and in a book of easy price the value

¹ The *History of Travayle* in the West and East Indies, and other countrieys lying eyther way, towards the fruitfull and ryche Moluccaes. As *Mosconia, Persia, Arabia, Syria, Africa, Ethiopia, Guinea, China in Cathayo*, and *Giapan*: With a discourse of the Northwest passage.

of mathematics in navigation, Bourne frankly admitted his indebtedness to John Dee’s *Preface* of 1570. But this, with its accompanying *Euchid*, besides being a work of great cost and bulk, was cast in a mould better suited to the needs of the scholar than of the seaman. Bourne in effect edited, for popular consumption, Dee’s *Preface*, or that part of it concerning mathematics and the sea. Mathematics, which to most seamen was still a cabalistic art, was, he explained, indispensable.

Of the branches of mathematics he concluded that ‘two are pryncipal, *Arithmeticke* and *Geometricie*’. He also summarized some of Dee’s able definitions of various arts and sciences; the following are examples of his summaries:

*Geographie* is the description of Countries or Kingdoms. *Hydrographie* is the description of the Seas, with the Ilandes and rockes, and dangers and lynes, and Courses. . . . *Astronomie* is the moving of the lightes and Planets. . . . *Cosmographie* is the descripþio of the whole earth, and the Parallel of the heavens answering thereunto. . . . *Navigation* is saying on the Sea. . . .

Such a book attuned the English seaman to the intellectual problems of oceanic navigation, and showed him the way to their solution. Whether he liked it or not, the discipline of science, with its precisions, was already beginning to impose itself upon his rough and ready empiricism. Further proof of this was forthcoming a year later when Thomas Digges completed and published *An Arithmetical Militare Treatise named Stratieticos*, begun by his father, Leconard.¹

In order to disillusion Englishmen of their fond belief that they could be competent soldiers and sailors without any mathematical training, this work taught them the application of ‘the science of nübers . . . and equations Algebraical’ to military problems, particularly those of gunnery. The bombardment of a moving target such as a ship was particularly dealt with. From the strictly navigational point of view the chief interest of this book today lies in the ‘Preface to the Reader’, for it reveals the difficulties and obstructions encountered by a mathematician with a practical bent, such as Thomas Digges, in his endeavours to impress on English seamen of the 1560s and early ’70s some of the advantages of the application

¹ An Arithmetical Militare Treatise, named *STRATIOTICOS*: Compendiously teaching the Science of Nübers, as well in Fractions as Integers, and so much of the Rules and AEquations Algebraical and Arte of Numbers Cossical, as are requisite for the Profession of a Soldiour.

Together with the Moderne Militare Discipline, Offices, Lawes and Dueties in euer wel governed Campe and Armie to be obserued: Long since attepted by LEONARD DIGGES Gentleman, Augmented, digested, and lately finished, by THOMAS DIGGES, his Sonne.

*Whereeto he hath also adioyned certaine Questions of great Ordainance, resolved in his other Treatize of Pyrotechny and great Artillerie, hereafter to bee published. VIVET POST FUNERA VIRTVS. AT LONDON: Printed by Henrie Bynneman. Anno Domini, 1579.*
of mathematics to navigation. At the same time it describes the attitude of the English mariner to mathematics up to that time, his distrust of the mathematicians' 'pretty devices', and his reliance on his own empirical rules. Digges was determined to prove that his rules were of practical application, and to this end spent fifteen weeks at sea. At the end of this time he had convinced a number of hitherto scornful masters and pilots of the errors of their navigational practices and the superiority of his. Though he published little on navigation, his example in thus taking mathematics to sea was worth more than a library of books. The finest tribute to his influence—and Bourne's—was Best's description of the sea-men of the later '70s.

The year 1579 saw a third edition of Eden's translation of Cortes's *Arte of Navigation* on the market—the second edition had appeared in 1572. Apart from an advertisement of a supplementary book on navigation, intended as an addendum to this new edition, there was no change in its contents. The book advertised was Richard Eden's translation, delayed in publication by the deaths in succession of Eden, the publisher and his son, of John Taisnier's tract, originally published at Cologne in 1562 as *De natura magnetis et ejus effectibus*, on magnetism and other subjects. Eden called the book *A Booke concerning Navigation . . . named a treatise of continual Motions*.1 Much of the work was of but indirect interest to navigators, but it contained the first summary published in English of knowledge about magnetism. It also sketched out a perpetual motion machine making use of magnetism as the motive force, and had a section on the relation of hull shape to speed in ship design. Its most valuable contribution was a long dissertation upon the causes and sequence of tides. This, explained Taisnier, was derived largely from 'Fredericus Delphinus, Doctor of Artes and phisicke, and publique professor of Mathematicall Sciences in the famous universitie of Padua'. This treatise was important, for it was the first detailed attempt to explain the cause of tides and their cyclical nature, and it is particularly interesting as it correctly associates tides with the sun as well as with the moon. 'Firstly and lastly, is to be known that the Sunne and Moone, both togetheuer every naturall day . . . are the causes of flowyng and refloowyng or increase and decrease of the water of the sea twyce . . . ', Taisnier wrote, explaining that the sun and moon in opposition as well as in conjunction caused strong flowing tides, that is, spring tides, and that when they were in quadrature neap tides occurred, when the Venetian pilots said, 'l'qua è stiana'. While this was quite correct and in

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1 A very necessarie and profitable Booke concerning Navigation, compiled in Latin by Ioannes Taisniers, a publike professor in Rome, Ferraria, & other Universities in Italie of the Mathematicales, named a treatise of continual Motions.

Translated into Englishe, by Richarde Eden.

*The contentes of this booke you shall finde on the next page folowyng.*

Imprinted at London by Richarde Iugge. Cum priviliegio. [1578]. The treatise on magnetism was derived from Peter Peregrinus' M.S. of 1269 *Epistola de Magnete.*
accordance with Cortes’s teaching, he erroneously attributed the sun’s and the moon’s influence to the amount of light that they gave out. Other planets he reasonably enough thought ‘might cause disorder in ebyng and flowyng’, but was certain that strong winds could also affect the velocity of tidal streams as well as the times of high- and low-water. As this was coupled with the observations that ‘the straytenesse or narrownesse of places’ also affected the tidal flow, Taisnier was getting very close to associating the surface currents of the ocean with the prevailing wind systems. This work marked a definite step forward in tidal theory, but the manner of treatment was so repetitive and unnecessarily involved that it is doubtful whether any but the most studious seamen would care to work out the full import of the arguments.

The advertisement in the companion edition of the *Arte of Navigation* is interesting as being the earliest one known of navigational works.

Although Frobisher and Hall had not taken Bourne’s manual with them, it was because of the current interest in northern navigation and the appearance of the unauthorized and fault-filled second edition of *A Regiment for the Sea* that in 1580 Bourne produced his ‘Corrected and amended’ edition ‘Wher-vnto is added a Hydrographical discourse to goe vnto Catay, fiue severall waies’.¹ This discourse gave the five ways as via the Cape of Good Hope; the Strait of Magellan; the north-west, as attempted by Frobisher and Hall; the north-east, as attempted by Stephen and William Borough; and the North Pole; and discussed their practicability. It was in effect a rutter for the first, second, and fourth routes, though the directions for the second, the Strait route, were extremely vague. Bourne admitted that he did not know the watering places that would make this route via Magellan Strait possible: interesting proof of the dependence of Drake, who had sailed in 1577 on his voyage of circumnavigation and to seek the North-West Passage from the west, upon Portuguese and Spanish pilots, charts and rutters. Again Bourne’s main source was probably Willes’s work of 1577.

The unauthorized edition of the *Regiment* had shown that there was a popular demand for it on its own merits. Nevertheless the inclusion of the *Hydrographical Discourse* in the new edition at a time when interest in northern voyages was aroused showed that Bourne was thoroughly alive to the problems of the day. Probably taking a hint from the *Cosmographical Glasse*, he also completely revised his chapter on longitude. He now included directions on how to find it by eclipses of the moon and by alteration in time; also how to find it by the Prime when the moon, owing to the eccentricity of her orbit, was in her ‘slow’ or ‘swift’ motions; and how to

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¹ A REGIMENT FOR THE SEA, CONTEINING VERY NECESSARY MATters, for all sorts of Sea-men and Trauailers, as Masters of ships, Pilots, Mariners & Marchauntes, NEWLY CORRECTED AND AMENDED by the Author. Where-vnto is added a Hidrographical discourse to goe vnto Cattay, fiue severall waies. Written by William Bourne. IMPRINTED AT LONDON BY T. EAST. for John Wight. [1580].
know the moon’s latitude. He included definitions of ‘Eccentricitie’ and ‘Parallax’, the errors in lunar observations induced by the semi-diameter of the earth and the proximity of the moon. The chapters dealing with these matters were all designed to facilitate longitude finding by observation. To assist in longitude determination by estimation he paid more attention to the problem of using the log and log-line, and included directions on how to keep a log or journal of the ship’s course and distance run. The result of these amendments was to bring the Regiment right up to date with the latest navigational practice and theory. Yet they did not alter Bourne’s original remarks that longitude could not then be found instrumentally. Masters of ships who called those who used instruments ‘star-shooters and sunne-shooters; and would ask if they had stricken it’, to use Bourne’s own words, were not going to bother about lunars. It was far more practical for them when approaching land to strike sail at night and to rely by day upon sight, soundings, birds, and the smell of the land.

It was in 1580 that, no route having been found to the north-west, another attempt was made by the Muscovy Company to find a North-East Passage to Cathay. Charles Jackman and Arthur Pett were each commissioned ‘Captain, master, and ruler’ of respectively the barks George, ‘of the burthen of 40 tunnes, with nine men and a boy’, and William, ‘of the burthen of 20 tunnes, with five men and a boy’. They were to find the passage which ‘is conceived to bee from Vaigats Eastwards, according to the description in plat of spirall lines, made by master William Borough’. Besides receiving charts drawn by Borough, both ‘spirall’ (circumpolar) and ‘plain’ (plane), they received instructions and notes from this distinguished navigator which opened with ‘When you come to Orfordness... note the time diligently... turning then your glasse where by you intend to kepe your continuall watch...’, and which went on to direct that, besides sounding at least every four glasses (2 hours) with the ‘Dipsin lead’ and noting diligently the depth and ground found, they were to sound ‘oftener’ when in coastal waters. Borough’s instructions continued: ‘And in keeping your dead reckoning, it is very necessary that you doe note at the ende of euery foure glasses, what way the shippe hath made (by your best proffes to be used) and howe her way hath bene through the water, considering withall for the sagge of the sea, to leewards, according as you shall finde it growen: and also to note the depth, and what things worth the noting happened in that time, with also the winde upon what point you finde it then, and of what force or strength it is, and what sailes you beare.’

The latitude of places and the variation of the compass were to be

1 The full instructions and the account of their voyage will be found in Hakluyt’s Principal Navigations, Hak. Soc., Extra Ser., Vol. 3.

An interesting example of telling the time by compass dial occurs in Hugh Smith’s narrative of Pett and Jackman’s voyage of 1580, in the above volume. The relevant extract reads: ‘... the last of May wee wayed our ankers about 3. a clocke in the morning, the wind being West southwest. The same day we passed Orfordnesse at an East Sunne, and Stamford at a West Sunne, and Yarmouth at a West northwest sunne, and so to Winterton. where we did anker al night.’
XXXVII. A PAGE FROM HALL'S JOURNAL OF 1578.
XXXVIII. Typical page of Robert Norman's *The Safeguard of Sailers* (1590).
observed often, and all the points that Bourne complained were lacking in charts—the elevations of the coast (by compass bearing and estimated distance) and tidal information including 'what force the tide hath to drive a ship in one hour, or in the whole tide'—all were to be diligently observed and 'set downe in the plats'. William Borough knew his art. He had been in the first voyage to Russia at the age of sixteen. He had made many more since then, and as we have seen he had greatly assisted the Frobisher voyages. In 1581 he was to become, and until his death in 1599 remain, Comptroller of the Navy. His sea experience, however, until the Cadiz expedition of 1587, was limited to the waters between La Rochelle, on the French Biscay coast, England, Narva in the Baltic, and Vaigats in the White Sea. He had never crossed the ocean, and he was distrustful of mathematicians without sea experience who yet discussed and criticized current navigational practices.

It was in 1581 that one of the first truly scientific books ever published in England appeared, and it was dedicated to William Borough. This was Robert Norman's *The Newe Attractive*, written 'to further the noble studie of Navigation and Hydrographic'. That Norman should have written it is all the more remarkable in that he was a practical man, no student, who after spending '18 to 20 years at sea' as a navigator, and in Seville, had settled down as an instrument-maker for Borough. As Norman’s title-page proclaimed, *The Newe Attractive* contained a short discourse on the lodestone, its location, varieties, colour, attractive properties, and so on, and also 'a newe discovered secret', that of dip—the declining of a magnetized compass needle below the horizontal plane. After dealing with theories on the attractive point, Norman described in his third chapter how 'rising alwaies to finish and ende thē, before I touched the needle I found continually that after I had touched the Irons . . . the North point . . . would bende under the Horizon . . . ', that is, the compass needle, when suspended at its mid-point would dip or incline downwards, with its north end down. His curiosity was finally aroused to the pitch of experimentation when a six-inch needle, despite the most careful making,

1 William Borough's chart of the Northern Ocean is reproduced in Hakluyt's *Principal Navigations, Hak. Soc.*, Extra Ser., Vol. 3.
4 The newe Attractiuie, containyng a short discours of the Magnes or Lodestone, and amongst other his vertues, of a newe discouered secret and subtill propertie, concernyng the Declinyng of the Needle, touched therewit under the plaine of the Horizon. Now first founde out by Robert Norman Hydrographer.

Hereunto are annexed certaine necessarie rules for the art of Navigation, by the same R.N.

*Imprinted at London by Ihon Kyngston, for Richard Ballard. 1581.*
Also

A DISCOVRS of the Variation of the Cumpas, or Magnetical Needle. Wherin is Mathematically shewed, the maner of the observation, effectes, and application thereof, made by W.B. [William Borough].

*And is to be annexed to The newe Attractiue of R.N. 1581.*

14*—A.O.N.
turned out to be spoilt. He therefore devised a series of experiments to find out the cause. By them he proved that the cause was neither a weighty matter nor an attractive power in heaven nor in the earth, as many thought, but some attractive power on the earth. He then devised a dip-circle and measured the angle of dip for London, which he gave accurately as 71° 50'. The discovery of dip excited for many years the hope that it would be able to be used for the determination of latitude, and thus avoid celestial observations and the accompanying calculations, or be useful in thick weather, just as it was hoped to use variation to determine longitude. Dip-circles or scales became part of the equipment of the most expert navigators from now onwards and until well into the seventeenth century.

Turning his critical powers to the problems of variation, Norman showed in his ninth chapter what Bourne had suspected, that variation was not 'by proportion', the theory upon which rested the current hopes of longitude-finding by variation. By this theory variation was supposed to be due to the eccentricity of the magnetic pole or 'attractive point'. This Mercator located 16° and William Borough 16 22' distant from the geographical pole on the meridian of longitude of St. Michael's in the Azores, along which meridian the variation was supposed to be nil. Martin Cortes had explained that, while under the prime meridian there was supposed to be no variation, 90° E and 90° W of it variation was supposed to be at a maximum—45° according to Bourne—the amount varying, owing to the eccentricity of the attractive point, according to the latitude. Consequently, as Coignet's diagram of 1581 makes clear, if you could find your latitude, which was easy, and your variation, which was not difficult, you could straightway find your longitude, for there were only two points on each parallel where a given amount of variation could be found. As these lay 180° apart—on opposite sides of the globe—confusion was unlikely. That was the theory. But Robert Norman pointed out that the observed vagaries of variation near N.W. America and N.E. Russia showed that, in fact, there was no such proportional variation. Despite this the theory died hard, as hard as did the belief kept alive by Medina's manual of navigation, which was first published in English this year, that variation was no natural phenomenon, but a casual error induced by the navigator. Norman had come to his conclusion after twenty years travelling the seas, and as a result of inquiring about variation in other places, and getting similar

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1 The diagram is in Michiel Coignet’s INSTRVCTION NOVVELLIE des pointts plus excellents & nécessaires, touchant l’art de nauiguer. Contenant plusieurs reigles, pratiques, enseignemens, & instrumens tresidones à tous Pilotes, maistres de nauire, & autres qui iournellement hantent la mer. Ensemble, Vu moyen facile, certain & tresseur pour nauiguer Est & Oëst, lequel iusques à present a esté incogniu à tous Pilotes. Nouuellement practiqué & composé en langue Thioise, par MICHEL GOIGNET, [B.M. Copy reads thus, but close examination appears to reveal two ink marks; without these, the word would be COIGNET, which would be correc] natif d’Anuers, Depuis reuex & augmenté par leisme Auteur, en divers endroict. A ANVERS, Chez Henry Hendrix. à l’enseigne de la fleur de Lis. Avec Privilege Royal. 1581.
values given him by none except men engaged on the Muscovy trade—the only navigators to give him reliable figures. However, Norman admits that probably ‘the greatest occasion thereof [that is, of the conflicting figures] is by lacke of exact Instruments for that purpose’. Realizing this, instead of lamenting the lack, he had sat down and devised ‘one verie necessarie’, that will be examined with William Borough’s contribution to the study of variation. Importance is added to The Newe Attractive by what appears to be the earliest diagram to show the effect of variation on compass direction. Norman drew a true meridian, marked ‘N’ and ‘S’, and a ‘Trew W’ and ‘E Trew’ line, and then a compass north and a compass south line and a ‘False W’ and ‘E False’ line. The ‘false’ or compass north line was deflected 40° to the east. In other words Norman was the originator of ‘the double fly’ method of explaining and indicating variation. It must have cleared many a fogged mind then, as it still does. Besides this practical aid to the navigator, Norman has in his tenth chapter what must have been equally valuable. This is a commentary upon ‘the common Compasses, and of the divers different sortes and makinges of them with the inconveniences that maie growe by them, and the plottes made by them’. In the ninth chapter he has already shown that the common compass very nearly indicated true north, because it ‘hath the Needle [as he calls the ‘wyres’] set in the Flice, half a pointe to the Eastwards of the North’ to allow for variation. He has also explained that others had it set off three-quarters or even a whole point, and others again had it set ‘directly under the . . . North of the Compass’, and that the latter were called meridional compasses. Now he distinguishes five sorts of common sailing compass. These, tabulated, were as follows:

### TABLE I

#### THE FIVE SORTES OF SAILING COMPASSES

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>Made in</th>
<th>Needle Set</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Levant</td>
<td>Sicily, Genoa,</td>
<td>Meridionally 0</td>
<td>Levant sea cards drawn with these</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Venice, Danzig,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flanders</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Flanders</td>
<td>Danzig, Flanders</td>
<td>(\frac{3}{4}) pt. E of N of Compass, 81° E</td>
<td>Sea cards and rutters of the Sound (Baltic) based on these</td>
</tr>
<tr>
<td>3</td>
<td>Flanders</td>
<td>Danzig, Flanders</td>
<td>1 pt. E of N of compass 111° E</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>English</td>
<td>England</td>
<td>(\frac{1}{4}) pt. E of N of compass, 84° E</td>
<td>Earliest sea cards of N.E. drawn with these</td>
</tr>
<tr>
<td>N.E. Voyages</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>N.W. Europe</td>
<td>Seville, Lisbon, La Rochelle, Bordeaux, Rouen, England</td>
<td>(\frac{1}{4}) pt. E of N of compass, 51° E</td>
<td>Used for sea cards of N.W. Europe, East and West Indies because ‘the middle hazard’s best’</td>
</tr>
</tbody>
</table>
By this information the master or mariner sailing by these different sorts of compass could guard against the 'greate perill' of using 'a Compasse of one Parishe, and a Plat of another', for, as Norman explained, these compasses had been long used and charts had been drawn 'every one according to the Compasse of that Country'. Many seamen used English compasses with Levant charts and as a result 'made but wide reckonyngs'. A Levant compass was a good compass with a Levant chart, Norman patiently explained. He went on to advise that, in default of using a compass similar to the one with which the chart was drawn, one with the needle set half a point east should be used, for most charts did 'not differ from this above a quarter of a point'.

In 1585 a second edition of The Newe Attractive was issued, and it now included a Regiment for the Sun 'exactlie calculated unto the minute' valid for thirty years, and given in the form used by Medina and Bourne, with rules on how to use the declination; tables of the conjunctions of the sun and moon and their oppositions, from Stadius's Ephemerides; the prime and movable feasts, a calendar, planetary tables, a table of fixed stars, and the equation of the sun and the declination of the sun according to the zodiac, all from Cortes; additions that no doubt made the book even more attractive to the purchaser.

Bound up with and forming part of The Newe Attractive was A Discours of the Variation by William Borough. Norman's discovery of 'the declynyng of the Needle', and dedication of The Newe Attractive to Borough, had given the latter the idea of enlarging the same work by treating the problem of variation 'both Practically and Mathematically', for the enlightenment of the simple and also the learned sort of mariner. This he felt to be all the more necessary since, as he truthfully remarked, although variation was the cause of many errors and imperfections in navigation, those who had treated it hitherto had given the methods of determining and applying it by no means so clearly as to avoid confusion. Although his object was to assist the practice of navigation by practising seamen, Borough himself dealt with variation in part mathematically, i.e. he showed how to calculate the sun's true bearing. He therefore hastened to explain that practical sea-

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1 The first English scientific book is generally considered to be Geoffrey Chaucer's A Treatise on the Astrolabe of 1391, because it is the first good description of the construction and use of a scientific instrument to be written for Englishmen in their own language. (Gunther, R. T., The Astrolabes of the World, 2 vols. (1932) p. vii). Chaucer's A Treatise on the Astrolabe was first printed in 1532, and frequently reprinted as part of his collected works.

Chaucer's work was, however, a translation whereas Norman's work was original, as well as being based on scientific principles, personal observation, experimentation, and deduction. It is usual to ascribe to Galileo the development of the scientific method in the seventeenth century. It will be seen that in England the principles underlying Galileo's methods had been in practice for a quarter of a century before the great Italian rose to fame.

Jean Rotz in his long treatise on the compass 'Tracté de l'aymant' dedicated to King Henry VIII had also commented on the off-setting of the wires of compasses.
men who did not understand ‘the doctrine of Lines and Triangles, which maie seem strange in our Englishe tounge’, and with which few seamen were yet acquainted, were to choose the method best suited to their capabilities. He then urged all seamen to lose no opportunity for observing and recording the latitude and compass variation of places, and pointed out that no abstruse instruments were needed. All that was required for finding the variation was ‘the newe instrument devised and explained by him’. As for position-finding, he did not advise the use of the globe. In his opinion either its manipulation was too difficult or it was otherwise not practicable for every mariner to carry one at sea with him. Sufficient for ‘a perfecte Mariner, besides running glasses, leades, lines, and such like appendaries’, was, in his opinion, a ‘plain’ [mariner’s] astrolabe and a cross-staff; for taking elevations; a topographical instrument for finding horizontal bearings and distances when making coastal surveys; his new instrument, of course; and ‘the sailying Compasse and Marine plat’. It is interesting to find within the space of some thirty years the once scorned and rejected ‘plat’ elevated to the dignity of being one of the two ‘most necessarie Instruments for Navigation’, the other being the compass. Despite his views on mathematicians on land, Borough advised all seamen and travellers to attain proficiency ‘in Arithmetic and Geometrie . . . the groundes of all Science and certain arts’ before attempting to practise navigation, and reminded them that there were now enough English books on the subject for an industrious and willing mind to attain to great perfection in them. By such study, he shrewdly commented, the navigator would be able not only to judge the works of others but also to improve on them. No longer would English sailors be dependent upon the charts of the Portuguese and Spaniards, whose chart-makers, relying on the reports of careless or ignorant seamen and not upon their own observations (a telling indictment of the results of the monopolistic system of the Casa de Contratación), were often in error. Instead they would themselves be able to draw charts of the coasts. Despite the faults cartographers still committed, Borough recognized that they did their best and praised their efforts, commending in particular Abraham Ortelius ‘for collecting together, and reducing to one comodious volume’, the various maps of the world made by various men. This was the Theatrum, first produced in 1570 and the first work to systematize cartographical knowledge.¹

In his first chapter Borough goes to the root of the mariner’s magntical

¹ Ortelius’s Theatrum Orbis Terrarum—1st ed. 1570. Mercator first used the name ‘Atlas’. Gerard Mercator (1512–1594) taught cosmography, geography and mathematics at Duisburg, 1559–63. There was then no modern atlas, only a few additions to the Geographia of Ptolemy. He worked on his modern atlas from 1564. In 1569 he produced his famous world map, or more properly chart with straight lined rhumbs, whereon he explained the purpose of its novel projection but not the means he had used to make it. His atlas was not completed in his lifetime owing to lack of engravers, the difficulty of collecting books and the need to earn his livelihood. The first part appeared in 1585, the second in 1589, and the third in 1595, a year after his death.
problem, how to find the variation, a problem skipped by both Cortes and Bourne. The clarity of Borough’s exposition of finding it by means of the sun’s equal altitude is admirable. The azimuth of the sun, he explains, is the angle between the meridian and the great circle that passes from one side of the horizon to the other through both the zenith and the actual position of the sun. Since the true meridian is always on the true north-south line, and since the azimuths of the sun upon equal elevations in the forenoon and afternoon are equally distant from the meridian, the middle point of the difference between two such azimuths will be the true meridian, and any difference resulting from the compass bearings of the azimuths will be the measure of the compass’s variation from the north. (This did not take into account the effect of the sun’s changing declination or of a ship’s change of position. Because of the crudity of the compasses these could, in fact, be ignored). While the earliest diagram of the effect of variation is Robert Norman’s in his part of *The Nece Attractive*, the first English printed illustration of an ‘Instrument of Variation’ is in William Borough’s. Indeed he shows two, one an improvement on the other, and the first of these he claims to be an improvement on the ‘Compass of Variation’ in common use. The latter was a sea-compass divided into 360°, with a thread placed cross-wise over the centre of the instrument to cast the shadow of the sun across the diameter of the compass-fly, and commonly used by English mariners at this time for finding the variation.  

The instrument of variation consisted of a board with a compass bowl sunk in it, the fly of the compass being painted on the bottom and the cross-like needle mounted on a pin without any fly. At the north point was affixed a vertical standard and plumb-bob, and from the top of the standard a string was brought down and attached to the board in line with the south point of the compass bowl. This was the chief shadow string. A rotatable verge-ring around the compass bowl carried a second string. In use the instrument was turned towards the sun until such time as the shadow of the chief shadow string fell across the north-south line of the bowl, and the verge-ring was then rotated until its shadow string was in coincidence. Then, the instrument being quite level, the sun’s altitude was observed, by astrolabe or cross-staff, and the ‘variation of the shadow from the North of the needle to the Westwards, or Eastwards’, was read and recorded. Several such readings would be taken in the forenoon. In the afternoon a similar number of readings, at the same altitudes of the sun, were again taken. William Borough gives as an example the results of the observations he made at Limehouse on 16 October 1580. The first of nine forenoon observations was taken at 17° elevation of the sun. The shadow then read 52° 35′ westwards of the north point indicated by the needle. In the afternoon, again at 17° elevation, the shadow was 30° 00′ eastwards of the needle’s north point. Thus ‘the Variation of the Needle from the Pole or Axis’ was 11° 17′ 1′ E. The mean result of all the eighteen observations was 11° 2′ or 11° 2″, ‘so that in a compass whose wiers are set directly under the

1 Hues, R. *Tractatus de globis* (1594).
Flowre de Luce, the North and by West, and South and by East points
doe show the true meridian’, explains Borough.

Forty-three years before, at dawn on a Saturday in April, João de Castro
had sighted Palma in the Canaries and, moved by an intense desire to
ascertain if on this island the compass did vary or, as popular report
asserted, did not, had hastened to set up his dial-plate and shadow instru-
ment, and to take two forenoon and two afternoon equal-altitude readings.
By this method he had found the variation 5½° E and, two days later, when
south of the island, to be 6° E. The difference of ½° he had attributed to
the movement of the instrument, which was appreciable, although, unlike
Borough’s, it was mounted in gimbals. He thus disproved the common
belief about variation at Palma, though it persisted none the less. The older
meridian compass, or ‘Compass of Variation’, had the needle attached to
the fly so that what was read off was the bearing of the true north; by
Borough’s modification what was read off was the amount of the needle’s
deflection. Thus he had eliminated a possible source of confusion, and this
was the improvement he claimed for it. In his final version the instrument
was greatly simplified. It now consisted of a board with a graduated semi-
circle marked on it, and a compass needle mounted in a slot countersunk in
the bisecting radius. Pivoting about the centre from which the semicircle
was struck was a radial arm on the circumferential end of which was
mounted the plumb-bob. The shadow wire ran from the top of the plumb-
bob standard to the pivot of the radial arm; at the base of the standard a cut-
away portion of the radial arm enabled the azimuth measurement to be read
off. It had the advantage that, once aligned north and south by the compass
needle, the instrument could be left, only the index arm having to be rotated
with the sun, to give the reading of the degrees of azimuth. For seamen it
had the disadvantage, like any instrument dependent upon a plumb-bob for
its accuracy, that it was suitable for observations on shore only. In any case
an instrument dependent upon two or more observations had drawbacks.
The sun might be obscured in the afternoon. Borough therefore explained
that the globe, if carried, could then be called in and the variation found
from only one observation. This he followed up by mathematical solutions to
the problem. These were unquestionably far above the head of the ordinary
navigator, and so were two later chapters wherein, as a result of finding the
variation at London to be 11½° E and dip to be 71° 50’, he determined
mathematically the location of the magnetic pole. These calculations were
amplified by beautifully executed geometrical figures which illustrated the
solution of the problem.

One of the most interesting portions of this work occurs in the tenth
chapter. This is devoted to the effects of variation on sailing and the shifts
ignorant seamen were put to in an endeavour to avoid the errors that could
arise from it. On the charts themselves, he explained, ignorance of variation
causd either the distortion of courses or the agreement of courses and the
disagreement of latitudes and distances. He cited the charts for Newfound-
land, whereon the course from Scilly to Cape Race was set at west 'due Weste', in accordance with the 'common sailyng Compasse', although Cape Race in 46° N lay 3½° south of the latitude of Scilly. The reason for this apparent discrepancy was, of course, that the compass wires were set on the fly ½ point to the east of north. Borough then commented scathingly upon the devices of the double latitude scale and of the oblique meridian introduced in the charts, 'to make a shewe', as he put it, 'of reformation of this error, (caused by the Variation and settyng of the wiers in the Compass)'. In an attempt to avoid the error in latitude arising from the use of charts drawn on compass bearing, some navigators used meridional compasses. As a result these, he explained, taking the courses given on the chart, found themselves 50 leagues to the north of Cape Race in nearly 49° N. Yet others, and these were the worst offenders of all, put a blank fly on the compass and altered it around 'as they judged the variation to have altered'. In charts for the north-eastern voyages to Russia the violent irregularities of the variation experienced along the coasts had led, Borough explained, to the charts being plotted, by bearings taken with the common sailing compass, 'with considerations of the variations at diverse places', that is, as plane charts corrected for variation. While this was an improvement, and though they seemed correct for navigation there, he admitted that by comparison with the delineation of the coastline on the globe the trend of the land and position of places were badly distorted. In Mediterranean charts errors in latitude still often amounted to three, four, or even five degrees, he declared, attributing the errors to 'a want of knowledge of the variation and the use thereof'.

On Mercator's famous world map, or, more properly, chart, in which by geometrical methods he had increased the degrees of latitude approximately in proportion to the distortion resulting from drawing the meridians as parallel lines, Borough had some illuminating comments. He is often represented as condemning the Mercator principle out of hand as impracticable for seamen's use. What he actually wrote was the 'defectes of the latitudes have been verie well reformed by the famous and learned Gerardus Mercator (whom I honour and esteem as the chief Cosmographer of the World) in his universal mapp, which though he have made with sayling lines, and dedicated to the use of Seamen, yet', and this is often overlooked, 'for want of consideration of the Variation, and partly by augmentyng his degrees of latitude towards the Poles, the same is more fitte for such to beholde, as studie in Cosmographie, by redyng authors upon the lande, then to bee used in Navigation at the sea'. This was particularly so, he went on, as even if Mercator had had 'the entire sailyng plat, that wee use for these partes', which he evidently had not had, if he had not known how the variation for those parts was incorporated in it he might have fallen into 'absurd errors'. In fact what Borough condemned was its use for navigation in north-eastern waters, and this chiefly on the grounds of the inaccuracy of the delineation of the coast. A very practical reason.

Apart from the confusions caused by variation just examined, Borough,
like Norman, lamented the additional one occasioned by the 'varietie of setting the wiers' on the compass fly so that, if a bearing was given, it had to be asked by what compass the observation was made. He therefore besought all mariners if they took bearings with 'compasses of divers setts' to reduce them all to a common standard and to note it in the chart, 'and not to make a confused mingle-mangle by joyning together all varieties of observations . . .'.

To Borough goes the credit for being the first Englishman to explain why rhumb lines, unless meridians or parallels of latitude, are spirals on the globe, though it was Michiel Coignet, already mentioned, the Flemish teacher, who published his work on navigation in 1581, based on Medina's, who first accurately described and illustrated them. It was in the course of criticizing his work that Borough gave his own explanation of rhumbs on the globe.

In the twelfth and last chapter on 'the application of Variation to the Use of Navigation' Borough bore out Robert Norman's refutation of the belief that variation was generally regular and certain all over the world because it appeared to be so in the North Atlantic. In support of this refutation he cited the fact that in 70° N he had found that as he went farther east the variation, which by the current hypothesis should have increased in an easterly sense, decreased and then became westerly, 'which strange varietye', he now took the opportunity to record, 'to the ends that the learned sorte might consider thereof' and, he reflected, 'Considerying it remaineth alwaies constant without alteration in every severall place, there is hope it may be reduced into method and rule.' Meanwhile, in order to assist mariners in the north-eastern navigations, Borough promised to reduce his records of variation on to a chart 'easy for the meanest capacities'. No such chart of Borough's is known, and over a century was to elapse before the first isogonic chart—a chart showing lines of equal variation—was to be produced. However, when it was, it was the work of an Englishman.1

In the second, 1585, and subsequent editions of The Neve Attractive the order of the last four chapters of Borough's treatise was rearranged. One important point there is to be noted about both Norman's and Borough's knowledge of variation: both believed, like all their contemporaries, that the variation of a place never changed. In this, through no fault of their own, they were mistaken. The secular change of variation could only be discovered as a result of accurately observing, recording, and publishing the variation at one, or more, places over a comparatively long period. Best had indicated this in 1578. Frobisher had been diligent to observe and record the variation, but Borough was the first man to do this, and to publish the full results. Without them, and without the inspiration of his and Norman's pioneer work of reducing magnetical phenomena into order, the discovery might have been indefinitely postponed, and Gilbert would not have been inspired to make his famous experiments

1 Edmund Halley, Tabula Nautica, 1702.
and to write his influential treatise on magnetism. The discovery by an English professor, Gellibrand, in 1633, of the secular change of variation was made possible because William Borough 'reduced into method' and published his observations of variation at Limehouse.¹

The publication of *The Newe Attractive* undoubtedly had an immediate and beneficial effect upon English navigation. Masters henceforth frequently observed and conscientiously recorded variation. The plotting of charts by true and not magnetic bearings became more general. The book was promptly recognized as 'most necessary for Navigation' and as being 'of an easie price, meete for every poore man's purse'.² Although *The Newe Attractive* had parts that were 'not meete for every man's understanding', its various editions indicate that it satisfied a popular demand. Indeed it remained a standard work on its subject into the eighteenth century.

Just how serious in practice the problem of variation was is well illustrated by a little-known anecdote of a sea-captain who had the reputation of being the greatest seaman of his age, Sir Francis Drake. In 1586, after his memorable voyage to the West Indies and sack of Cartagena, he sailed with his fleet for Cuba, and from Cape St. Antony put to sea for Virginia. After sixteen days, 'tossed with variable windes, they came at last within sight of land: but by no means could they discerne, or give any probable ghesse what lande it should be'. At last Sir Francis called a navigator from Southampton, probably Abraham Kendall, into consultation, and he, after making 'his observations according unto Arte, pronounced in laughing and disdainefull maner (because his advise was not taken in the setting of their course)' that the land they looked on was precisely that which they had looked on sixteen days before. The discovery was attributed by the *raconteur* to the Southampton man's 'knowledge of the Variation of the Compsse', as indeed it may well have been.³

Bourne, immediately after publishing his second edition of the *Regiment*, had set about the preparation of an improved almanac for seamen. In 1581, therefore, had appeared *An Almanacke and Prognostication for X. yeeres*, dedicated to the Lord High Admiral, the Earl of Lincoln. One great innovation Bourne claimed for it was that it contained the daily declination of the sun as in the *Regiment*, a feature no English almanac had previously contained.⁴ Bourne declared to Lincoln that he had specifically

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¹ Gellibrand, H., *A Discourse Mathematicall* (1635). The full title will be found on p. 423.
² Blundeville, T., *M. Blundevile His Exercises*. . . (1594).
³ Barlow, W., *The Navigators Supply* (1597). The full title will be found on p. 216.
⁵ Despite what Bourne wrote his *Almanacke* of 1567 and 1571 had daily declination-tables covering several (three) years.
written the almanac 'for the use of Seamen, for that they are often times
foorth, a yeere or two, so that it is necessary that they shoule haue
Almanackes for longer time then one yeere', and he hoped it would prove
as useful as The Regiment for the Sea had proved necessary and profitable
to seamen.

To the reader Bourne recommended this almanac for use in finding the
movable feasts and the judgment of the weather, not, he hastened to add,
that the ordinary weather prognostications which he included for common
use were of any real value, but because he had included how to judge the
weather 'by diuers significations of mine owne observation'—so that
Bourne must rank as one of our earliest meteorologists.¹

Probably as a result of the Frobisher voyages, John Frampton, as
already mentioned, brought out this year the translation of Medina's
navigation manual of 1545, entitling it, like Cortes's work, The Arte of
Navigation.² Written in the same year as Cortes's, it was in many respects
complementary to that work. But Medina was naive over variation, and
his descriptions of instruments were not as good as Cortes's. However, his
table of the sun's declination was straightforward and his illustrations of
how to hold instruments and apply the rules for finding latitude by
celestial observations were excellent. But that Medina's work did not com-
pare in Englishmen's eyes with Cortes's and Bourne's is shown by the fact
that this English translation was only once reprinted and no edition of his
Regimiento de Navegacion translated.³

¹ An Almanacke and Prognostication for X. yeeres, beginning at the yeere of
our Lorde 1581 and ending the yeere 1590, being calculated for the Meridian of
London. Wherein is set downe the change . . . [14th line] Written by William
Bourne, Student and Practitioner in the Mathematicall sciences. Imprinted at
Imprinted at London by Richard Watkins, and James Robertes. 1581.

² The Arte of Navigation, wherein is contained all the rules, declarations,
secrets, and advises, which for good Navigation are necessarie and ought to be
known and practised: made by Master Peter de Medina, directed to the right
excellent and renowned Lord Don Philippo, prince of Spain and of both Sicilies.
T. Dawson, 1581.

³ Regimiento de nauegacion Contiene las cosas que los pilotes ha de saber para bien
nauegar; y auisos que han de tener para peligros que nauegando les pueden
suceder . . . Por el Maestro . . . Sevilla. Simon Carpintro.—1st. ed. 1543; 1552;
1562; 1563. Medina's much fuller manual was in Spanish: Arte de nauegar
en que se contienen todas las Reglas, Declaraciones, Secretos, y Auisos, y a
la buena nauegacion son necessarios, y se deuè saber, hecha por el maestro Pedro de
Medina. Dirigida al serenissimo y muy esclarecido señor, don Phelipe princepe de
Espana, y de las dos Sicilias, &c. Con preuilegio imperial. [Colophon . . . 1545].

This manual was translated into French, 1554 (Lyons); 1569; 1573 (Rouen);
1576 (Lyons); and 1579 (Rouen and Lyons); into Italian, 1554 (Venice); 1569;
into Dutch, 1580 (Antwerp); 1589, 1592 and 1598 (Amsterdam); and into English,
1581 (London, and 1595). The Dutch edition published in 1580 was entitled De
A recent discovery is the manuscript *Instructions to be observed* by Thomas Bavin on Sir Humphrey Gilbert's projected voyage of 1582 to Virginia. It appears that Bavin was to have accompanied Gilbert with the object of surveying the almost unknown coast between Florida and Norumbega, as New England was then called. After enumerating the materials Bavin was to take for drawing charts, such as parchments, paper-royal, pencils, gum, and compasses, the instructions directed him to take an Ephemerides and 'a 24 or 40 hour flat watch clock', showing minutes as well as hours, or if possible three of them, and a universal dial by which to set them 'precisely from tyme to tyme by the Sonne'. By this means he was to find his longitude by the eclipse of the sun predicted for five minutes past four in the morning at London on the 19th June. These orders are of singular interest, for they are the earliest yet discovered to include chronometers as part of a navigator's equipment. On the other hand it has been pointed out that Bavin would have been unable to observe the eclipse from the Atlantic or America. Owing to the difference of time, it would have been over before sunrise—a fact that illustrates well the still imperfect grasp of astronomical phenomena by English seamen. No doubt the almanac Bavin was to use was Bourne's of 1581 'wherein was set doune the change, quarters, and fulles of the Moone, with the Eclipses that did happen in the said X yecres' from 1581 to 1590. Of equal interest to the instructions on the eclipse is the order that someone was always to attend Bavin with pen, ink, and paper, and others with a universal dial, cross-staff, and ephemerides when observing the latitude, and with 'the instrument for variation of the Compasse, the instrument for the Declynacion of the nedle and A saiieing Compasse'. Thus within a year of the publication of *The Newe Attractive* each of the two new navigational instruments described and illustrated in it were ordered to be used at sea. Furthermore, Robert Norman's device of the double fly for indicating variation was also seized upon and directed to be drawn upon the chart whenever and wherever the variation of the compass was observed.

If Bavin sailed on Gilbert's voyage of 1583, it is probable that he and his records perished with the loss of the *Delight*.

The rapidly increasing interest of Englishmen in the art of navigation at this time was further evinced in 1585 by the publication of John

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Zeevaert oft conste van ter Zee varen vanden Excellétem Pilote Meester Peeter de Medina Spaignaert, and was followed by Coignet's *Nieuwe onderwysinghe*, the signatures being continuous. It was used by Barents on his third voyage and was found by Captain Carlsten at Ice Haven in 1871, having been lying there since 1596. It is now in the Naval Museum at The Hague.

*(Times Literary Supplement*: 27 July 1922, p. 496 and N. Israel, Esq. of Amsterdam).

John Frampton dedicated his English translation to Edward Dyer, on 4 August, 1581.

1 See Appendix 14, also Taylor, E. G. R., 'Instructions to a Colonial Surveyor of 1582', *M.M.*, Vol. 37.
Blagrave’s *The Mathematical Jewel.* This was a book describing very fully the making and use of a planispheric astrolabe, with special features devised by Blagrave. He was a gentleman of Reading of an inventive mind, and of apparently adequate means, and with a great sense of public service. He claimed that the great virtue of *The Mathematical Jewel* was that it made of mathematics a ‘plaine and practike discipline’. In a chapter towards the end he explained the solution of problems involving spherical triangles. This, added to the cost of the book, which presumably was high, for the book was lavishly illustrated, must have discouraged many a prospective purchaser from buying both book and instrument. When ten years later Thomas Blundeville included a summary of the most important functions of the *Mathematical Jewel* in his highly popular *Exercises,* he made this astrolabe so well known that it remained in widespread use in England into the middle of the seventeenth century. A planispheric astrolabe such as this served almost as well as a celestial sphere for working out many astronomical problems. Indeed, to the initiated, it served as time-piece and portable mechanical almanac, enabling them to determine rapidly the hour of the day, the time of sunrise and sunset, the sun’s amplitude and many stellar problems. In Blundeville’s opinion, by the various

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1 THE MATHEMATICAL JEWEL, Shewing the making, and most excellent use of a singuler Instrument so called; in that it performeth with wonderfull dexterity, whatsoever is to be done, either by Quadrant, Ship, Circle, Cylinder, Ring, Dyall, Horoscope, Astrolabe, Sphere, Globe, or any such like heretofore devised: yea or by most Tables commonly extant: and that generally to all places from Pole to Pole.

The use of which Jewel, is so aboundant and ample, that it leadeth any man practising thereon, the direct pathway (from the first steppe to the last) through the whole Artes of Astronomy, Cosmography, Geography, Topography, Navigation, Longitudes of Regions; Dyalling, Sphericall triangles, Setting figures; and briefly of whatsoever concerneth the Globe or Sphere: with great and incredible speede, plainenesse, faciliteit, and pleasure:

The most part newly founde out by the Author; Compiled and published for the furtherance, as well of Gentlemen and others desirous of speculatife knowledge, and priuate practise: as also for the furnishing of such worthy mindes, Navigators, and traueylers, that pretend long voyages or new discoveries. By John Blagrave of Reading Gentleman and well willer to the Mathematickes; who hath cut all the prints or pictures of the whole worke with his owne hands. 1585.

Imprinted at London by Walter Venge, dwelling in Fleetelane ouer against the Maiden head.

Michel, H., *Traité de l’Astrolabe* (1947), is the best work on the invention, manufacture and manner of using astrolabes. The author classifies the various types (but does not discuss Blagrave’s) and explains their particular merits and limitations. A projection, devised by Juan de Roias Sarmiento, a pupil of Gemma Frisius, and published in 1550, was popular in the sixteenth and seventeenth centuries. It was based on the Catholicon. This projection of Roias was an orthogonal projection of the sphere on the colure of the solstices. It embodied features which simplified the solution of a number of astronomical problems. The description of Gemma Frisius’s Catholicon was not published until 1556 although the development of the Catholicon was made by Gemma Frisius before Roias produced his projection.
features Blagrave introduced into his astrolabe he had ‘as it were newly invented a third kind of Astrolabe . . . whereby were to bee wrought more conclusions than by any one instrument whatsoever’. His only criticisms of it from a navigational point of view were the failure to include all seven stars of the Little Bear, and the omission of stars in the southern hemisphere. Hitherto there had been two main patterns of planispheric astrolabe—which Blundeville described as Stöffler’s, and Gemma Frisius’s Catholicon. The stereographic projection of the sphere in the former was on the plane of the equinoctial. This meant that an appropriately engraved tablet had to be inserted whenever the observer changed his latitude. It was an astrolabe of this sort which Chaucer had described in his treatise of 1391. It had been invented in the sixth century. In the Catholicon, developed by Gemma Frisius in the 1540s from a little-known Moorish invention of the eleventh century, the stereographic projection was in the plane of the meridian, and so the instrument was suitable for universal use.\footnote{1} Blagrave’s was a development of the Catholicon (or universal astrolabe).

A tiny pocket-book, on the use of the celestial sphere, by Charles Turnbull, and apparently intended especially for seamen, also came out in 1585;\footnote{2} and three years later appeared another English work on the astrolabe—Robert Tanner’s \textit{A Mirror for Mathematiques}.\footnote{3} \textit{This} described an astrolabe of the Stöffler pattern which he described as ‘The Travailers Ioy and Felicitie’. Tanner also called his book ‘A Sure Safety for Saylers’. Like Blagrave’s, his astrolabe could be made in paper, wood, or brass, thus combining portability with cheapness or robustness. At the end of his book he included for seamen some rules for forecasting the weather by the state of the sun and moon. It is hard to say whether or not the works on astrolabes and the instruments themselves were much used at this

\begin{footnotes}
\item[2] A perfect and ease \textit{Treatise of the use of the coelestiall Globe: written as well for an Introduction of such as bee yet enskiffull in the studie of Astronomie; as the practise of our Countriemen, which bee exercised in the Art of Navigation. Compiled by Charles Turnbull: And set out with as much plainnes as the Author could: to the end it might of evry man be vnderstood.}\n\item[3] A Mirror for Mathematiques: A Golden Gem for Geometricians: A sure safety for Saylers, and an auncient Antiquary for Astronomers and Astrologians. Contayning also an order howe to make an Astronomical instrument, called the Astrolab, with the use thereof. Also a playne and most easie instruction for erection of a figure for the 12. houses of the heauens. A work most profitable for all such as are students in Astronomic, & Geometrie, and generally most necessarie for all learners in the Mathematicall artes. The contents of which booke you shall find in the next page.
\end{footnotes}

\textit{Imprinted at London for Symon Waterson [1585].}

\textit{Imprinted at London by J.C. and are to be solde by Richarde Watkins, 1587.}
time by seamen: their appearance at this conjunction was certainly symptomatic of the growing sense in England of the practical value of a knowledge of astronomy: as Captain Smith recommended the use of astrolabes and astrolabe quadrants it would seem that in the seventeenth century they were certainly taken to sea by responsible navigators.\footnote{An astrolabe quadrant was a quadrant engraved with the lines found upon the four quadrants of planispheric astrolabes but arranged so as to occupy its single quadrant. The lines were engraved for a given latitude.}

The various inventions and discoveries described by Robert Norman in *The Newe Attractive* were not his final contribution toward the improvement of navigation. By the 1580s Copland’s *Rutter of the Sea* had been in print for over half a century and, though still being reprinted, was little changed. By now the English North Sea trade was quite as important as the old Bordeaux one, and an up-to-date rutter was needed. The Dutch, with their peculiarly treacherous shores, had for long paid particular attention to the problems of pilotage. With the rise of Antwerp to commercial supremacy in the first half of the sixteenth century, Dutch rutters, mostly compiled by mariners from the northern coasts of the Low Countries, had come to the fore. By now Dutch rutters were the best—we have already cited Hubrigh’s extract in his *Almanack and Prognostication* of 1569—and English printers were now technically competent to reproduce a rutter, illustrated, like the continental ones, with woodcuts of coastal elevations. In 1584 therefore Norman published a translation of two Dutch rutters of northern waters under the appropriate title of *The Safeguard of Sailers, or great Rutter*.\footnote{See Pl. XXXVIII. The safeguard of Sailers, or great Rutter, Containing the Courses, Distances, Depths, Sounding[s], Floudes, and Ebbes, With the markes for the entrings of sundrie Harbours both of England, Fraunce, Spaine, Ireland, Flanders, and the Soundes of Denmarke, with other necessarie Rates of common Navigation: Translated out of the Dutch into English by Robert Norman, Hydrographer. At London Printed by John Windet, and Thomas Iudso[n], for Richard Ballard. Anno Domini. 1584.}

He dedicated it to Lord Howard of Effingham, who was to succeed the Earl of Lincoln as Lord High Admiral on the latter’s death in 1585. Norman was moved to produce this work by the sincere patriotism that inspired so many Elizabethan pioneers in navigation, the art, as he put it, by which ‘the Navy Royal [is] furnished, the Realme fortified, and the commonwealth enriched’. Thus on the eve of

The first English rutter to be illustrated with cuts of the coastline or, as Norman put it in his epistle dedicatory, ‘with the rising of sundry lands which by no Chart or Plat is expressed or knowne, but resteth only upon the relation of the experimented Traveeller’. The main part is a translation of the Dutch *Leeskaart boecck van Wisbey*, of 1566, *Dit is die Caerte van der sec, Antwerp*.

The rutter from Thames to Berwick is almost word for word the same as the rutter in Hubrigh’s *Almanack* of 1569. Indeed it is printed separately after the Address to the Reader and before the verses ‘In Commendation of the painefull Seamen’ and the Table for the Tides which precedes the safeguard.

The tidal information contains, of course, the special information concerning the Spitz—depths at high-water ordinary, neap (printed as ‘deer tides three fathams’ instead of ‘nepe times (sic) twoo fadoms’) and spring tides.
the first great maritime war in their history the English could not only boast of 'the common report that strangers make of our ships daily amongst themselves . . . that for strength, assurance, nimbleness, and swiftness of sailing, there are no vessels in the world to be compared with ours', but also deserved the reputation they enjoyed 'of being, above all the Western nations, expert and active in all naval operations'.

Finally, thanks to Norman, they were well equipped with the latest sailing directions—the first in English to be illustrated with wood-cuts of the coasts—for the waters in which they would have to fight the decisive battle for freedom from Spanish domination. As yet, however, their charts were all in manuscript and, it must be confessed, compiled from such diverse sources and observations that on the very eve of the Armada, on 6 July 1588, Howard, in the chops of the Channel, wrote to Walsingham from aboard his flagship, the _Ark Royal_, that, 'Whatsoever hath been made of the S[leeve, it] is another manner of thing than it was taken for; we find it by experience and daily observation to be an hundred miles over'.

Some months after the defeat of the Spanish Armada there appeared from the press the English edition of a book which was to revolutionize the charts of the navigator of the waters of north-west Europe. Indeed before long it was to set its stamp upon nautical charts in general, while the name by which it soon became commonly called, that of 'Waggoner', was to persist in both official and unofficial use in England far into the eighteenth century. _The Mariners Mirrour_ was the name given by Anthony Ashley to his translation of the _Spieghel der Zeevaerdt_ of Lucas Janszoon Wagenacr. Wagenacr had been born in 1534 or 1535 at Enchuyesen, a commercial port of some importance on the Zuiderzee. Early in youth he

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1 The first and second volumes of _Chronicles_, by Raphael Holinshed, William Harrison, and others. 1577.


3 See Pl. XXXIX. _THE MARINERS MIRROVR_ wherin may playnyly be seen the courses heights, distances, depths, soundings, fowds and ebs, rising of lands, rocks, sands, and shoalds, with the marks for thenrthngs of the Harboroughs Hauens and Ports of the greatest part of Europe: their Severall trafficks and commodities. Together with the Rules and instrumets of Navigation. _First made & set forth in diuers exact Seacharts, by that famous Nauigator LVKE WAGENAR of Enchuisen, And now fitted with necessarie additions for the use of Englishmen by ANTHONY ASHLEY_. Herein also may be understood the exploits lately atchiued by the right Honorable the L., Admiral of Englaad with her _Ma_ Nauie and some former services don by that worthy Knight Sr. FRA. DRAKE. [?1588].


_Cum Priuilegio ad decennium Reg. 1583 Maet et Cancellarie Brabantie_ Ghedruyt tot Leyden Christoffel Plantija voor Lucas Ianssz/Waghenacr van Enckhuysen Anno. M.D. LXXXV.
XXXIX. *The Mariners Mirrour* (?1588).
XL. ‘This Upper Half Circle’ from Wagenaer’s The Mariners Mirrour (?1588).
XLI. 'A General Carte ...' (?1588.)
XLII. 'The Coastes of England.' 1588.
went to sea. He became a pilot. Perhaps for twenty-five years he followed
the profession of the sea, somehow acquiring considerable education.
In the middle 1570s he retired, and by 1579 was a collector of maritime
dues in his native port. From this position, either because of incompetent
book-keeping, or worse, he was relieved in 1582; however, his fellow-
citizens never lost their faith in his essential honesty.¹ Since his retirement
from the sea he had been engaged upon his real life's work, the compilation
of a book to help and guide seamen sailing along the coasts of western
Europe. It involved the examination and perusal of numerous rutters or
leeskarten, of many manuscript charts and pilots' note-books, and, no
doubt on the basis of his own, their correction and rearrangement into
order. The result, published in 1584, was T'eerste Deel Vande Spieghel
der Zeevaerdt vande navigatie der Westersche Zee (The first Part of the
Mirror of the Navigation for Sailing on the Sea West [of the Zuiderzee]);
it was printed at Leyden by Christopher Plantin. Dedicated to William
the Silent, soon to fall victim to the assassin's knife, it consisted of a folio
collection of charts, engraved on copper plates, of the European contin-
ental coasts between the Zuiderzee and Cadiz, complete with appropriate
sailing directions. Encouraged by the enthusiasm with which it was greeted,
Wagenaer lost no time in completing the second part. This he published
in 1585 under the title of Het tweede deelvenden Spieghel der Zeеваerdt
inhoude de gheheele Noortsche ende Oostersche Schipvaert. (The Second
Part of the Mirror of Navigation including the whole navigation in the North
Sea and in the Baltic Sea.) Printed by Plantin, and dedicated to the States-
general of Holland, it brought Wagenaer a grant from them of £500.

The first title-page of the Spieghel der Zeevaerdt is a very fine copper-plate
engraving by Jan van Doetecum, showing various nautical instruments and
Dutch navigators and mariners either handling them or peering into the
mirror of the sea.² The dedication, commendatory verses, compendium,
and list of charts follow, and after them come thirty-five pages containing
a short treatise on cosmography and navigation, various lunar tables, a
four-year table of the sun's declination by Adrian Metius, with directions
for its use, a star-list, a table of the sun's right ascension, directions on how

¹ The life and works of Wagenaer have been ably reviewed by Gernez, D. 'Lucas
Janszoon Wagenaer: A Chapter in the History of Guide Books for Seamen', and

Besides both parts of the Spieghel der Zeevaerdt, Wagenaer produced the Thresoor
der Zeervaerd in 1592 which, besides keeping the information and charts of the
Spieghel up-to-date, included the charts and sailing directions of the northern
coast of Europe, the coast of Ireland, Scotland and the islands of the northern seas
and Arctic Ocean, and sailing directions without charts of the Mediterranean. In
1598 he published a book of sailing directions for voyages between the Canaries and
the White Sea, the Enchuyen der Zeervaerdtboeck, without any charts. Neither of these
works was translated into English. The date and circumstances of Wagenaer's death
are unknown, but from a petition by his wife to receive her husband's pension he
would seem to have died in 1605. In his will, dated in 1590, he named two sons and
six daughters. Nothing is known of them.

² See Pl. III.

15*—A.O.N.
to find the latitude, and how to graduate a cross-staff, and how to use it. This part is thus a brief but quite adequate navigation manual for the very simple sort of navigation still practised in northern coastal waters. It is followed by the courses and distances between numerous ports in western Europe, a table of latitudes of various places, a table of tides, and notes on soundings on the banks in different parts of the North Sea, Channel, and Bay of Biscay. Then begins the atlas of twenty-three charts delineated by Wagenaeer and engraved by Jan van Doetecum, each accompanied by a description of and the sailing directions for the coasts concerned. Thus this part is in effect an illustrated rutter. At the end is a list of geographical names in Dutch, French, Spanish, and English, and, to complete its utility, a table of the sun’s declination by Martin Everaert of Bruges.

The second part was also a folio with a very elaborate title-page engraved on copper plate. The epitome followed the dedication. Then came twenty-three charts, four of the English North Sea coast, four of the Norwegian coast, three of the Swedish, seven of the remaining Baltic coastline, one of the Danish Strait, two of the coast of Jutland, and two of the Frisian and German coasts of the North Sea. Each chart had its sailing directions, as in the first volume, and at the end of the book is the list of geographical names, and a table of the sun’s declination for four years. Such then briefly was Wagenaeer’s most famous work, for in 1585 the first and second parts, which had already gone through respectively four and three editions, were published bound together, as were all subsequent editions. In 1586 appeared the first Latin edition of both parts joined together. The first part was dedicated to Queen Elizabeth; the second part to the king of Denmark and Norway, Frederick II. The text of both was a Latin translation of the Dutch text, that of the second part being the work of Martin Everaert. Lord Howard was so impressed with Wagenaeer’s work, brought over by ambassadors from the Low Countries, that as Lord High Admiral he laid it before the Privy Council for authorization of its translation and publication in English. The task was entrusted, probably in 1586, to Anthony Ashley, the Clerk to the Privy Council. He consulted many seamen in the exacting processes of translation and overseeing of the re-engraving of the charts, completing his work in October 1588.

It is interesting to read in Ashley’s translation of Wagenaeer’s ‘Admonition to the Reader’ that, owing to the shifting nature of the coastal shoals off Holland, Friesland, and Jutland, ‘By the lawe of the Sea, such places are expressly forbidden to be entered without sounding, and therefore they are called Waters of Pilotage.’

After the tables of contents the section on ‘The Use and Practise of this booke’ pointed out that the special feature of the charts was the representation of the arisings and appearances of the coastline ‘to those which ran from the sea’. Masters were advised, on first approaching land, to note these features carefully, then to consider their best approach course, to ascertain the leading marks and the buoys to be passed, according to the indications on the chart, and not to fail to sound frequently.
‘An Exhortation to the Apprentices of the Art of Navigation’ on how
to attayne to the perfect skill and science of Navigation’, included the
sage advice that they should observe, memorize, and record the various
courses, bearings, distances, and soundings their masters employed in
entering and leaving port, ‘for that which any man either young or olde
excerciseth, sarcheth out and observeth himselfe, sticketh faster in memory,
then that which he learneth of others’.

In the star-tables Wagenaer observed that the fixed stars were best suited
for cross-staff sights. One of the diagrams in this part of the book is a large
‘Uranicall or Moveable compass of the Stars’ (planisphere) on which the
principal stars between the Tropic of Capricorn (23\(^\circ\) S) and the North
Pole are plotted, and on the periphery of which are marked the various
positions of the guards of Ursa Minor according to the Rule of the Pole
Star. The maximum correction is plus 3\(^\circ\). The accompanying text,
besides explaining the uranicall’s use for taking star-sights, explained how
it could also be used as a star-clock or nocturnal, taking as the hour-hands
either ‘the guards’, which were north at midnight on the 30th April, or
other suitable stars. The snag that the 30th April was the revised or Gregor-
ian date not in use in England was, however, not explained. For unwary
English mariners this omission was liable to result in an error of about
40 minutes, since by their unreformed calendar ‘the guards’ transited
north at midnight on the 19th.

The description and illustration of the making of a cross-staff, a simple
one of staff and cross without vanes, are of special interest; they explain
how to graduate different scales of the staff so as to get direct readings of
latitude by observation of either the sun’s altitude, the Pole Star’s or a
southern star’s, such as ‘the great Dogge’s’. For the sun’s observation one
side of the staff was graduated at the eye-end from 0° upwards to give
zenith distance; for the Pole Star’s, another side was graduated at the eye-
end from 90° downwards to give altitude; while for the southern star’s,
‘the Great Dogge’s’, yet a third side was graduated. This one was marked
from 16° (that star’s declination south) to 0°, and thence upwards, so as
to give altitude plus declination. Thus by applying, as appropriate, the
sun’s declination, or the Rule of the Pole Star, to the measured observations
of the sun or Pole Star, latitude was obtained directly. To the Great Dog’s
observation no correction was necessary to obtain latitude, for the declina-
tion was incorporated in the scale. Wagenaer helped the mariner consider-
ably by these instructions. They prevented him from getting muddled with
zenith distance, and enabled him to observe altitude as latitude when
taking different sorts of sights in various latitudes. They also confined his
calculations to the minimum. Wagenaer appears to have been the first
navigator to incorporate a zenith distance scale on a mariner’s cross-staff.

Another diagram of interest is a circular one of the distance (in Span-
ish, Dutch, and English leagues) to be run to raise or lay a degree of lati-
tude on various rhumbs, and the distance run east and west in the process,
incorporating a compass containing ‘a ready and short way to find the
tides along the coasts either within the havens or off-shore. It is, of course, a circular tide-table. On an inner circle of rhumbs next to the compass are the names of havens, on an outer circle the names 'off-shore'. For instance, the establishment of Plymouth is shown to be west by south, but high-water in the Channel south of Plymouth, that is off-shore of Plymouth, west by north, an hour and a half later. Used in conjunction with the accompanying explanation and tables of tides giving the time of high-water on each rhumb according to the age of the moon, the diagram made calculation of the tides quite easy.¹

A valuable innovation in this part of the book was 'A Shorte Instruction of the forme and fashion of Buyes, Beckons, and other markes' set up to show shoals, sands, or hidden rocks off the coasts of Holland, Friesland, and Zeeland (and, as a matter of fact, in the Thames), and their representation on the charts.² This is apparently the earliest printed description of such aids to navigation, and though, as we have seen, English navigators were already adopting definite cartographical symbols to denote different types of terrain, Wagenaer's symbols, since they were printed, can be taken as the first to initiate standardized symbols for buoys, sea-marks, safe anchorages, hidden and dangerous rocks, and greater rocks hidden by water. His work was also the first to give the date (1582) at which the system of buoyage as charted was in force; the first to give the information that the charted depths were in fathoms; and the first to give a tidal datum—'half flood or ebb'. Admittedly the last feature is open to criticism for the datum was not a good one, the difference in depth between half-flood at springs and at neaps being in many places considerable. Nevertheless it was the first attempt to systematize depths and tidal data. For this alone it is notable.

The purpose of the first chart of Wagenaer's atlas, that of western Europe, was to show approximately the area covered by the rest of the charts. It extends from the Canary Islands to the North Cape and from Iceland to Fiume on the Adriatic, and it has scales of latitude and of longitude on its borders, all the degrees of latitude and of longitude being of the same size (about 12.8 mm.). It is, in fact, a quadratic plane chart, and it is the only one in all of Wagenaer's works. It has the typical network of rhumbs and circular pattern of compass fles, and the pronounced elongation of land masses east and west resulting from the parallel meridians. Three scales of leagues, 20 English, 17½ Spanish, and 15 Dutch to a degree, are drawn upon it.³ All the following charts of the coasts of north-west Europe are compass charts, that is to say, plane charts without latitude or longitude scales, and drawn by compass bearing and distance. The accuracy of delineation of the coastlines is very variable. For instance, on the south coast of England the large inlets between Arundel and Portsmouth, including the important one of Chichester harbour, are entirely omitted. On the other hand it must be realized that where

¹ See Pl. XL. ² See Fig. 18. ³ See Pl. XLI.
information had evidently been available a feature of these charts is the deliberate distortion of the coastline by the enlargement of the entrances to rivers and harbours. The charts were intended for pilotage, not navigation, and the trickiest pilotage is always off river mouths and harbour bars and roadsteads. Since, using the unaided eye, occasional glances at the ship’s compass and frequent use of the lead and line were the master’s means of

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3  Fig. 18

THE BUOYS AND BEACONS IN THE WATERS OF PILOTAGE OF NORTH-WEST EUROPE, AS IN FORCE IN 1582, AND THE SYMBOLS INTRODUCED BY WAGENAER INTO HIS CHARTS (THE FIRST OF THEIR KIND) TO REPRESENT THEM, FROM The Mariners Mirrour (1588)

1. Buoys chiefly on right hand of fairways on sailing out, painted black with pitch or tar.
2. Beacons on the other side to mark sands, flats or shoals. The top-mark made of osiers.
4. Landmarks.
5. The buoys and beacons above, and safe anchorages, represented on the charts by these symbols.
6. Hidden and dangerous rocks represented in the charts thus.
7. Greater rocks hidden by water represented thus.

pilotage, it was logical to make most graphic the representation of those parts of the coast most important to him, the more so since the charts were intended to serve in place of memory. This is the reason also for the more numerous soundings found off ports. A good example of these charts is the one of the coast of England between the Scilly Islands and Plymouth. It shows both the enlargement of harbour mouths, the distribution of
soundings, and the sketches and notes of the elevation of the coastline, as seen from various points to seaward. Just how great was the need for such pictorial representations of the coast is well exemplified by this extract, only too typical of the time, from the Journal of Luke Ward, second in command of Edward Fenton's attempted expedition of 1582–3 to China, and captain of the Edward Bonaventure. He is writing of the return to England in 1583:

The 25 day of May wee went betwene the East northeast, and the northeast with a small gale till five a clocke in the afternoone: then had we sight of land, which rose ragged to the Northwards like broken land, we being about five leagues off, that yle bare Northeast by North of us, and the Northern most part bare North by East of us, with a rocke a sea bord: we then sounded and had fiftie and five fadome grey sand, and maze great store in it: so we stood to the Northeast till eight a clocke, and then behelde it againe being within four leagues of it, bearing as before, but we could not make it [out], for some thought it to bee the foreland of Fonteny, some judged it the yle of Ussant: then we sounded again in 55 fadome brown sand, and a little maze in it, at eight a clocke at night we went about, and stood off . . .

The 26 day we . . . saw the same land againe, and made it to bee the foreland of Fonteny, and the ragges to bee the Seames . . . [these are all south of Ushant and of Brest] but we drave to the Southwardes very faste, for the ebbbe set us a pace to leewards.

The 27 day having brought the land East Southeast on us, we made it to bee Syllly being before deceived, and went hence East by North . . . leaving the bishop and his clerks to the Southwestwards, which we before tooke to be the Seames.

At 7 a clocke in the afternoone we sawe the lands end of England, which bare East by North of us, and is 7 leagues off from Syllly.

Thus for two days these experienced navigators, because they were unable to identify the land they saw, beat about in the Soundings believing themselves to be to the south-west of Ushant when they were in fact off the Scillies!

Unlike many of the rutters, the sailing directions accompanying each of Wagenaaer's charts are clearly and simply written, and are arranged systematically following the coast, as in a modern pilot. They often include notes upon the products of the hinterland and upon the nature of the commerce of the ports.

In Dutch and Latin editions the sea was represented on the charts by wavy lines, and was decorated with ships and sea monsters. In the English charts the sea was left blank, but some sea monsters and the ships (some of them redrawn) were retained. The ships were useful because, as they

1 See Pl. XLII.
depicted the type of vessel met with off the various stretches of coast, they facilitated position-finding. Study of the craft reveals the diversity of the local types, and also provides an idea of the activities of some of them—off the East Anglian coast the famous herring fleets are depicted, off Land’s End a lively engagement between a merchantman and either a pair of letters of marque men—or of pirates.

Despite its cartographical defects, and these were no greater than was then common, except where, as explained, they were expressly introduced in order to facilitate pilotage, *The Mariners Mirrour* was a remarkable contribution to the art of navigation. Not only did it incorporate all the important information contained in a rutter but it amplified it with diagrams, elevations, and charts, and it contained in the simplest possible form the basic elements of position-finding by celestial observations. By incorporating visually a wealth of systematized and corroborated information, it brought for the first time within the ken, and from a financial point of view, within the pocket, of the small sea-trader numerous charts designed to assist him in position-finding in what were, broadly speaking, waters of pilotage. Its printed charts differed fundamentally both from the maps which, from the end of the fifteenth century, had begun to be printed for the information chiefly of geographers and merchants and statesmen, and from the portulan charts. The first complete one of these to be printed, Diogo Homem’s, had been engraved upon copper by the Italian Paulo Forlani, and published in Venice in 1560.¹ But because it was a portulan its chief use lay in direction-finding. Wagenaur’s were not the first charts published—by the early 1580s the Spaniards were engraving and publishing charts—but Wagenaur’s were the first ones for popular use at sea.² Their merit was that they eliminated the copyist’s errors, their virtue that they standardized hydrographical knowledge and included only observed facts essential for good pilotage, their achievement that they placed pilotage on a firmer scientific basis than ever before. The English edition furthered this process. The sea surfaces in the charts were left blank with the express purpose of facilitating amendment—a good example of the scientific spirit of inquiry, of the urge for recording methodically the results of accurate observation and then putting them to practical use, now thoroughly present in English seamen’s minds. In the words of the Secretary to the Privy Council, they now recognized that ‘there was very great reason to prefer it [the art of navigation] before al other artes or sciences whatsoever’.


Chapter Two

COMMERCE, COLONIZATION AND WAR

...it is not possible that any man can be a good and sufficient Pilot or skilful Seaman, but by painful and diligent practice, with the assistance of Art, whereby the famous Pilot may be esteemed worthy of his Profession as a Member meet for the Common-weale.

John Davis, The Seaman's Secrets, 1595.

A great helpe also would it be for the furtherance of skill, if those that are practisers in that Arte, and such as are Students of the Mathematiques, might often conferre together. For except there be a uniting of knowledge with practise, there can be nothing excellent. Idle knowledge without practise, and ignorant practise without knowledge, serve unto small purpose.


The 1580s were notable for a great increase in English maritime activities. Apart from those arising directly from the beginning of the war with Spain, these years witnessed the first attempts at colonization in the New World, renewed efforts to find the North-West Passage as well as the North-East Passage to Cathay, and Cavendish's circumnavigation of the globe. By the 1590s the English were fairly launched upon the exploration and exploitation of the wealth of the seven seas. The increased scope and scale of their maritime activities were matched by the publication of journals and of narratives of voyages—those of Frobisher's had set the fashion—and by a steadily increasing intellectual activity 'that there might grow increase of knowledge and ease in practise' of the art of navigation. Of the latter, Norman's and Borough's works were only the forerunners of what soon became, by comparison with what had gone before, a flood of publications on subjects mathematical, astronomical, and purely navigational; while, most significant of all, for the first time public lectures on the art of navigation began to be delivered.

As early as 1555 Richard Eden, in his translation of Peter Martyr's The Decades of the Newe Worlde, had pointed out that 'beside the portion of land pertaining to the Spaniards' in the New World, 'there yet remaineth an other portion of that main land reaching toward the northeast' uninhabited by Christians and perhaps giving access to the East Indies. Like Frobisher, Sir Humphrey Gilbert had long pondered this question of the North-West Passage. He had written on the subject in 1566, though publication had been delayed ten years.1 It was in 1576 that Richard Eden

had died, leaving uncompleted the revised edition of his translation of the
Decades which his literary executor, Richard Willes, was to bring out in
1577. The History of Travayle in the West and East Indies, already referred
to in the previous chapter, had been part and parcel of the original Frobi-
scher project, for it had contained the first detailed English descriptions
of China, Japan, India, and the East Indies, as well as the learned treatise
on the currents in the Atlantic. The descriptions of the east had been
designed to inform and to excite Englishmen about the possibilities of
commerce there, and the dissertation upon the currents had been intended
as an argument for the reality of the North-West Passage. This work, the
Frobisher voyages, and the various narratives of them had excited, for a
time, the wildest hopes. But bitter financial loss had quickly proved them
ill-founded and had made them short-lived—there had been scant possi-
bility of trade such as the Muscovy Company had been able to develop
to compensate for the failure to find a passage. Nevertheless, disillusion-
ment did not blunt the English appetite for exploration.

George Best, in his True Discourse of 1578, attributed the former ill-
success of the English to two causes: a lack of liberality in the nobility
and a general lack of navigational skill. Both these defects, he maintained,
had now been made good, and Drake’s circumnavigation of the world
pointed to many an ambitious and impoverished English gentleman the
moral of Best’s claim. Coming hard on the heels of the fiasco of the Frobi-
scher voyages his lucrative voyage inspired many a fellow-countryman to
equal him—for gain and glory—in navigational skill.

Indeed, in commendatory verses preceding the text of the True Reporte
of Gilbert’s ill-fated voyage of 1583 Drake encouraged his fellow country-
men to follow ‘The path to Fame’ and to seek ‘golde’ in the ‘New-found
Landes’ in the west.1 It was true that Drake had found no sign on the
Pacific coast of America of a Strait of Anian, or a North-West Passage
linking the Atlantic with the Pacific, yet, as he had not pushed far north,
the hope remained—particularly as Pett and Jackman had failed in 1580
to discover any passage to the north-east. The discovery of the North-
West Passage was to remain the dominant theme in English exploration
for the next fifty years.

1 A TRVE REPORTE, Of the late discoueries, and possession, taken in the
right of the Crowne of Englonde, of the New-found Landes; By that vaiaunt and
worthye Gentleman, Sir Humfre Gildr Knight, Wherein is also brefely satt
downe, her highnesse lawfull Tylte therevnto, and the great and manifolde Commo-
dities, that is likely to grow thereby, to the whole Realme in generall, and to the
Aduenturers in particular. Together with the easines and shortnes of the Voyage.
Seene and allowed.

At London, Printed by I.C. for John Hinde, dwelling in Paules Church-yarde,
at the signe of the golden Hinde. Anno. 1583.

The text is preceded by commendatory verses from various hands. Among them
are those quoted by Drake. John Hawkins, Martin Frobisher, and Richard Bingham
also contributed to the praise of the book and the enterprise it described ‘For
vaiaunt mindes .. while sluggardes lye at home’. See Pl. XLIII and Appendix 7A
for Drake’s Pocket Dials, and Appendix 12, for Drake as a navigator.
Scarcely had the stir of Drake’s triumphant return subsided before interest had been excited in another venture associated with the north-west. In 1582 had appeared Richard Hakluyt’s *Divers Voyages*. He had taken up Richard Eden’s earliest theme, pointing in his preface not only to the possibility of a North-West Passage but also to the fertility of the unclaimed lands, lying between Florida and Newfoundland, whose coasts had been visited by only three of four navigators, all foreigners, since their first discovery. This young man (he was now aged about thirty and in holy orders) had been inspired whilst still in his teens to devote himself to furthering the maritime affairs of the English nation. Once, on a visit to his uncle’s chambers in Lincoln’s Inn, his imagination had been fired by the maps, charts, globes, and navigational instruments he had been shown there—his uncle was then economic adviser to the Muscovy Company—and his bewitchment can still communicate itself to us in his prose. As well as becoming the chronicler of the Elizabethans’ achievements at sea, Richard Hakluyt the younger was destined also to become an expert in maritime economic enterprise. For a start, as a lecturer at Christ Church, Oxford, in the late ’70s, he had concentrated upon teaching his contemporaries the new cosmography and cartography. But with the publication of *Divers Voyages* he was out to instruct a wider audience, to give point to cartographical and geographical knowledge, and to indicate where it could be most profitably used. The unclaimed, unexplored part of North America was one region. In pointing this out he was in tune with the times. The next year, 1583, Humphrey Gilbert, on the strength of his charter of 1578, made the first whole-hearted attempt at colonization, the intention being to found not mere trading posts and naval advance bases against Spain, but ‘plantations’, so that ‘for the ten ships yearly employed on the Muscovy trade twenty should be employed twice yearly across the Atlantic’. This was the venture for which Bavin’s instructions had been intended to lighten the way. After taking possession of Newfoundland in the name of the queen, Gilbert had pushed on south to Nova Scotia. Losing his stores ship by stranding, he had been forced to return. Yet he had been full of hope and of assurances of his ability to put forth two fleets the following year, though no man could tell ‘what means he had at his arrivall in England to compass the charges of so great preparation’.

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1 *DIVERS* voyages touching the discoverie of America and the Islands adjacent vnto the same, made first of all by our Englishmen and afterwards by the Frenchmen and Britons. And certayne notes of advertisements for observations, necessarie for such as shall heerafter make the like attempt, With two mappes annexed heere-vnto for the plainer understanding of the whole matter. Imprinted at London for Thomas Woodcooke, *dwelling in paules Church-Yard*, at the signe of the blacke beare. 1582.

2 Williamson, J. A., *Short History of British Expansion*, (1945), p. 126. His attempt in late 1578 had resolved itself into a raiding venture, which had ended early in 1579 with the return of the expedition. The extracts given here from the account of Gilbert’s last voyage are from *Voyages and Colonising Enterprises of Sir Humphrey Gilbert*, Hak. Soc., Ser. 2., Vols. 83, 84.
But 'I will hasten to the end of this tragedie', for he was as proud as he was sanguine and brave, and of that temper that becomes the more obstinate the more it is reasoned with. Having decided to return, 'the vehement perswasion and intreatie of his friends could nothing availe, to divert him from a wilful resolution of going through in his Frigat'—a vessel of 10 tons, called the Squirrel—'which was overcharged upon their deckes, with fights, nettings, and small artillerie, too cumbersome for so small a boate, that was to passe through the Ocean sea at that season of the yere, when by course we might expect much storme of foule weather'. For 'when he was entreated by the Captaine, Master and other his well willers' in the 40-ton Golden Hind, 'not to venture in the Frigat, this was his answer: 'I will not forsake my little company going homeward...''

By that time we had brought the Islands of Açores South of us, yet wee then keeping much to the North, until we had got into the height and elevation of England [to run down the parallel] we met with very foul weather and terrible seas breaking short and high Pyramid wise. The reason wherof seemed to proceed...of diversitie of winds, shifting often in sundry points.... Howsoever it commeth to passe, men which all their life time had occupied the Sea, never saw more outrageous Seas. We had also upon our maine yard, an apparition of a little fire by night, which seamen do call Castor and Pollux...which they take an evil signe of more tempest...

Monday the ninth of September, in the afternoone, the Frigat was neere cast away, oppressed by waves, yet at that time recovered and giving foorth signes of joy, the generall sitting abaft with a booke in his hand, cried out unto us in the Hind (so oft as we did approch within hearing) We are as neere to heaven by sea as by land.

The same Monday night, about twelve of the clocke, or not long after, the Frigat being ahead of us in the Golden Hinde, suddenly her lights went out, whereof as it were in a moment, we lost the sight, and withall our watch cryed, the Generall was cast away, which was too true. For on that moment the Frigat was devoured and swallowed up of the Sea...

Gilbert's death did not end his schemes, for his half-brother, Walter Raleigh, then took up another, that of planting a colony in the region advocated by Eden and Hakluyt on the more southerly part of the North American seaboard. Gilbert's survey had been lost when he had perished, so a further reconnaissance party was dispatched in March 1584 under Philip Amadas and Arthur Barlow. Following the only known route to the American coast, that by way of the Canaries and West Indies which took advantage of the clockwise wind and drift current systems of the North Atlantic, they came after little more than two months' sailing to what are now the coasts of North Carolina. Climate, vegetation, and inhabitants had appeared delightful. After taking formal possession, the explorers had returned to render their reports. Raleigh was knighted, and the land
was named Virginia in honour of the queen. The next year the first party of colonists was taken out to Roanoke by Sir Richard Grenville, who six years later was to win immortal fame by his death in battle with the Spaniards off the Azores. But the colonists quarrelled with the natives and quitted when Drake, hot-foot from his Caribbean raid, called in 1586 before the relief ships, led by Grenville, arrived. However, Raleigh dispatched yet another expedition, this time including women colonists. This was in 1587. John White sailed as governor. His charts of the coast have survived, the earliest English detailed charts of North America, but of the colonists only the mounds of their fort remain. Then the war put an end to Elizabethan attempts at colonization.

The war put an end also to exploration to the north-west. Since the Frobisher voyages attempts in the higher latitudes had ceased, but in 1585, the year that Drake was waging war in the Caribbean and Raleigh planting Virginia, John Davis was selected by William Sanderson, a wealthy London merchant, to lead an expedition to find the North-West Passage to Cathay. John Davis was to be the last as well as the most gifted of Dr. Dee's pupils. For Dr. Dee, who was to live until 1608, gave up navigation and became devoted chiefly to astrology when, in 1583, he left England to spend five years abroad on the Continent. John Davis had been born, probably in 1550, at Sandridge in the parish of Stoke Gabriel, where the lovely Dart wraps it round on three sides. Stoke Gabriel was the home of the Gilbert as well as of the Davis family. Humphrey, the second Gilbertson, born in 1539, had been the man of valour, the man of vision, and the navigator who had first attempted colonization. He must have been an inspiration to the young John Davis, though it was Humphrey's accomplished younger brother, Adrian, who appears to have been John Davis's intimate friend, as was the dazzling Walter Raleigh, the young Gilbert's half-brother. John Davis in his voyages to the north-west had the political support of Walsingham, and the practical support of these two and John Dee. William Sanderson as 'the greatest adventurer with his purse' had the choice of who was to be the captain and chief pilot of the voyages. He chose John Davis because he was 'a man very well grounded in the principles of the arts of navigation'. He must have chosen him too for his qualities as a master, qualities so admirably defined by William Bourne. All his life long John Davis proved himself an inspiring leader of men.

In my first voyage [recounted Davis], being without experience of the nature of those climates, and having no direction either by chart, globe, or other certaine relation in what altitude that passage was to be searched, I shaped a Northerly course ... and ... fell upon the shore which in ancient time was called Groenland ... the land being very high and full

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1 White, John, THE pictures of soundry things collected and counterfeited according to the truth in the voyage made by St. Walter Raleigh, knight, for the discoverie of LA VIRGINEA. In the 27th yeare of the most happie reginie of our Soueraigne lady Queene ELIZABETH. And in the yeare of our Lorde God. 1585. British Museum Dept. of Prints & Drawings, 1906.5.9.1(1). (MS.).
of mighty mountaines all covered with snow, no viewe of wood, grasse or earth to be scene, and the shore two leagues off into the sea so full of yce as that no shipping could by any means come neere the same. The lothesome viewe of the shore and irksome noyse of the yce was such that it bred strange conceites among us.

There were twenty-three men in the larger bark, of fifty tons, and the names of the vessels were like music, for the one was named 'the Sunneshine of London' and the other 'the Moonshine of Dartmouth'.

The 19 of July we fell into a great whirling and bursting of a tyde, setting to the Northwards... The 20 as we sayled along the coast the fogge [which had pestered them for two days] brake up [John Janes, the merchant borne for bargaining, recorded in his journal], and we discovered the land [the south-west shore of Greenland], which was the most deformed rockie and mountainous land that ever we saw... and the shoare beset with ice a league off into the Sea, making such yrkesome noise as that it seemed to be the true pattern of desolation, and after the same our capitaine named it, The land of Desolation.

The weather was cold when the wind blew from the land, yet otherwise it was not very cold, 'but the aire was moderate like to our April-weather in England'. To encourage the men 'the capitaine and master tooke order that every messe, being five persons, should have halfe a pound of bread and a kan of beere every morning to break fast'—cold comfort indeed by modern standards. From here, finding they were embayed, they sailed 'to the Northwestward, hoping in Gods mercy to finde our desired passage, and so continued above foure dayes', until they sighted land 'in 64 degrees 15 minutes of latitude bearing Northeast from us'—they had crossed the mouth of what is now known as the Davis Strait and reached the continental shore. Here they found coast which was free of ice, and here they met Eskimos and huskies, and discovered 'withies also growing like low shrubs & flowers like Primroses', and saw that the 'cliffes were all of such oare as M. Frobisher brought from Meta incognita' that lay 2° to the south of them, as Davis could have learnt from Thomas Ellis's *True report of the third and last voyage of Frobisher*, published in 1578. The 1st August they had a fair wind, and proceeded towards the north-west for their discovery. Some days later they 'discovered land in 66 degrees 40 minutes of latitude, altogether void from the pester of ice' and 'anker'd in a very faire rode', which Davis, thinking of home, called, nostalgically, 'Totnes rode'. It lay 'under a brave mount, the cliffes whereof were as orient as golde' and they called it Mount Raleigh! 'The sound which did compasse the mount was named Exeter Sound. The foreland towards the North was called Diers cape'—after the poet. 'The foreland towards the South was named Cape Walsingham'—it lies in latitude 66° 37' N, and longitude 60° 50' W.

Retreating before the advance of winter, Davis partly explored Cumberland Sound before he set course for home. On his return, in a brief note
to Walsingham, he reported 'that the north-west passage is a matter nothing doubtfull, but at any time almost to be passed, the sea navigable, voyd of ice, the ayre tolerable, and the waters very depe'.

Davis's next year's voyage was made 'with a ship of an hundred and twenty tunnes named the Mermayd', the 60-ton Sunshine, 35-ton Moonshine, 'and a pinnesse of tenne tunnes named the North starre'. Sending one ship to explore the eastern coast of Greenland, Davis pressed on to the west with the Mermaid and the Moonshine. In Gilbert's Sound, on the west coast of Greenland, which had been named the year before, they put together a pinnae shipped over in parts and explored the fiords before going north to 66° 33' N. Here, still on the eastern shores of the Davis Strait, Davis graved and revictualled the Moonshine, and leaving the Mermaid to return home sailed west, discovering land in 66° 19' N. '70 leagues from the other from whence' they came. They had crossed the Davis Strait but, coasting south, failed to recognize their last year's landfalls. They sighted 'The Cape of Gods mercy' which they had named the year before when they had 'perceived that we were shot into a very fair entrance or passage'—Cumberland Sound. Though they did not recognize the Cape, they reported once again, 'Here wee had great hope of a through passage.' However, on going on shore 'to the toppe of a very high hill I perceived', reported Davis, 'that this land was Islands, so at faire of the clocke in the afternoone wee weyed anker, having a fair North northeast winde . . . and so shaped our course to the south, to discover the coast, whereby the passage may be through Gods mercy found'. Sailing as far as 54° N they caught cod in great quantities and 'had a perfect hope of the passage, finding a mightie great sea passing betweene two lands West . . . but the winde was directly against us', so they could not explore it. It was in fact a bay on the coast of Labrador. In stormy weather they made their passage back to the West Country. 'I stand in great doubt of the pinnesse', wrote Davis to William Sanderson, on arrival at Dartmouth, and added, 'God be mercifull unto the poore men, and preserve them, if it be his blessed will', for Henry Morgan in the Sunshine had reported that a month before, on 'the third day' of September, 'at night we lost sight of the North starre our pinnesse in a very great storme, and lay a hull tarying for them the 4 day, but could heare no more of them . . .'.

Davis, still confident of success, persuaded William Sanderson to finance a third venture. Thus on 19 May 1587

about midnight . . . two Barkes and a Clincker, . . . the Elizabeth of Dartmouth, the Sunneshin of London, and the Clincker [clinker-built vessel, called the Helene of London] weyed their ankers, set saiyle, and departed from Dartmouth for 'the discovery of a passage to the Isles of the Moluccas, or the coast of China.

Crossing to Greenland they attempted to assemble a pinnace for exploration, but the natives damaged it. When the adventurers had resolved perforce to use it instead for fishing, like the two barks which had been
provided to defray the expenses of the expedition in this manner, 'John Churchyard one whom our Captaine had appointed as pilot . . . told them that the good ship'—the Clincker—'which we must all hazard our lives in, had three hundred strokes at one time as she rode in the harbour',—that she was leaking to the extent that three hundred strokes of the pump were needed to keep her dry. This 'disquieted' the crew until John Davis 'determined rather to end his life with credite, then to return with infamie and disgrace'; then 'all agreed . . . to live and die together, and committed themselves to the ship'. Coasting up the western shores of Greenland, on the 30th June 'wee tooke the heigh, and found our selves in 72 degrees and 12 minutes of latitude both at noone and at night, the Sunne being 5 degrees above the Horizon', recounted John Janes.

At midnight the compasse set to the variation of 28 degrees to the Westwards . . . the Sea open all to the Westwards and Northwards, the land on the starboard side East from us, the winde shifted to the North, whereupon we left that shore, naming the same Hope Sanderson, and shaped our course West, and ranne 40 leagues and better without sight of any land.

Headwinds and ice banks, when the ship did reach the western shore, prevented further search to the north-west so they returned to the Greenland coast to await more favourable conditions. Proceeding from here 'there was some fault either in the barke, or the set of some current for we were driven sixe points [67 1/2°] beyond our course West', in 67° 45' N, and a day or so later sighted Mount Raleigh. 'At 12 of the clocke at night, we were thwart the streights which we discovered the first yeere'—Cumberland Sound. They spent the next week—it was now the end of July—exploring the strait and discovered it to be but a gulf. Proceeding south they passed and named Lumley's Inlet, and on the 31st 'a Headland, which we named Warwicks Foreland' and that 'day and night . . . a very great gulfe, the water whirling and roaring as it were the meetings of tydes with 'a very forcible current Westward'. On the 1st August they 'fell with the Southermost cape of the gulf, which we named Chidlie's cape, which lay in 61 degrees and 10 minutes of latitude', and is the southern outpost of the strait leading into Hudson's Bay.¹

Frobisher's fleet on its 1578 voyage had thought themselves to be off the south-east coast of Greenland (north of the 'Queenes Foreland', as they called what Davis knew as Queen Elizabeth's Foreland, and which according to Baffin, he called Cape Farewell), when 'by a swift current comming from the Northeast', they were 'brought to the Southwestwards of their course many more miles than they thought possible could come to passe' and 'made a point of land which some mistook for . . . Mount Warwicke' so that 'the expertest Mariners began to marvell, thinking it impossible that they could be so farre overtaken in their accounts . . . Howbeit

¹ See Pl. XLVI.
many confessed that they found a swifter course of flood then before they had observed. And truely', it was remarked,

it was wonderfull to heare and see the rushing and noise that the tides do make in this place with so violent a force that our ships lying a hull were turned sometimes round about even in a moment after the manner of a whirlepoole, and the noisy of the streame no lesse to be heard afarre off, then the waterfall of London Bridge.

Lying in doubt as to their position, for fog and ice prevented any certain landfall and the taking of any sight, 'Christopher Hall chiefe Pilot of the voyage' expressed the opinion that they had never been there before and Frobisher led some of the ships 'above sixtie leagues within the saide doubtfull and supposed straights' before he turned back, reluctantly, to go mining the ore—the supposed gold—in Frobisher Sound.

The 'mistaken straits' of Frobisher, the 'furious overfall' of Davis, were one and the same. However, Davis could not certainly know this, for time was against him. He had to rendezvous with the fishermen in 54° N. Being arrived there he found no sign of their ships, nor any promised beacon on any headland, and 'having in his ship but little wood, and only halfe a hogshead of fresh water' set course 'to returme for his owne countrey'. On the following day, the 17th August, 'we met a ship at sea, and as farre as we could judge it was a Biskaine: we thought she went a fishing for whales; for in 52 degrees or thereabouts', John Janes reported, 'we saw very many'. A month later they were in Dartmouth harbour 'giving thanks to God for their safe arrivall', and on the 16th September Davis, 'all weary', wrote to Sanderson:

I have made my safe returme in health, with all my company, and have sailed three score leagues further then my determination at my depart
ture. I have bene in 73 degrees, finding the sea all open, and forty leagues betweene land and land. The passage is most probable, the execution easie, as at my comming you shall fully know.

But the next year was Armada year. Then Walsingham died. The shadow of war hung over the land. Men's thoughts—though not John Davis's—turned to other ways of reaching the east.

The war which to all intents and purposes had broken out in 1585, by legitimatizing the capture of Spanish ships and goods at sea, encouraged exploration, and trade with the east, by way of the South Atlantic. Thus although it contributed to putting an end to Arctic exploration and curtailed, until the seventeenth century, the development of Arctic navigation, it encouraged enterprises involving long voyages in tropic seas, and the solution of problems associated with equatorial navigation. Also by concentrating the English warships and letters of marque men into the seas between the Azores, Cadiz, and the Channel for the interception of Spanish and Portuguese shipping, it brought to the fore the imperfections of the plane chart. The unsuitability of the latter for accurate position-finding in these latitudes became peculiarly, and frustratingly, evident. Under the
XLIII. Pocket Dials by Humphrey Cole, dated 1569.
XLIV and XLV. **Nocturnal and Tide Computer by Humphrey Cole.**

(Undated, between 1570 and 1590).

Humphrey Cole was probably born about 1520 and died in 1591. The earliest tide computer of English workmanship surviving appears to be that incorporated in Humphrey Cole’s pocket dial reputed to have once been Drake’s. This is dated 1569. (See Plate XLIII.) The earliest English illustration of one was probably in Bourne’s Almanac of 1567. This instrument was therefore probably made between 1570 and 1590. The 30-day scale instead of the more accurate 29¾-day one suggests that it is of the earlier period. Cole’s earliest dated instrument is a Universal Portable Dial of 1568, though he may have been the maker of two universal dials, signed and dated ‘V.C. 1557’, and clearly based on Leonard Digges’s *Prognostication* of 1555.

The Nocturnal indicates 10 p.m. on 27th May. Note the toothed edge to the hour dial to enable the hours to be counted off from midnight. It is designed for use with the guards of Ursa Minor. This also suggests that it dates from the 1570s rather than the 1590s.
stress of war the need for something better became urgent and two solutions were found. One comprised the manufacture and use of larger globes, the other the calculation and adoption of an improved chart projection. Meanwhile in 1584 Stephen Borough, the most sagacious of the Elder Brethren of the sea, had died. Dr. John Dee, for thirty years the expert adviser behind the scenes of English maritime enterprise, had gone abroad. William Borough was busy on the Navy Board. Richard Hakluyt was in Paris, whither he had gone as chaplain to the English ambassador in order to study maritime affairs in the next best place to Lisbon and Seville, which were forbidden territory to an English heretic parson. In Paris he had found a mathematical lectureship in full swing, and we find him this year writing to Walsingham, so influential as the queen’s secretary, urging the establishment of a lectureship of navigation in the city of London, where it would be well calculated to attract seamen, and of a mathematical one at Oxford, where the more learned sort of men could study the theory of navigation and the application of mathematics to its problems.1

Despite his advocacy nothing was done for several years. As so often in the history of England, it took the stress of war to create what had been long desired in peace. By the late ‘80s there were so many different currents of opinion flowing towards the same end, the establishment of a mathematical lectureship in close touch with the needs of the day, that it does not surprise us to learn that in 1588 there was ‘started a mathematical lecture within the Leadenhall whereof Thomas Hood was the first Reader’.2 The mantle of John Dee had fallen upon a worthy disciple. Educated as became the son of a merchant tailor, at the Merchant Taylors’ School, which he entered in 1567, Thomas Hood had matriculated at Cambridge six years later as a pensioner of John Dee’s old college, Trinity. Although the Edwardian Statutes of 1549 had given greater prominence to the importance of mathematics in the university curriculum, those of Elizabeth of 1572 had omitted mathematics from the undergraduates’ prescribed course. Nevertheless, the blight had not yet fallen upon the university, for here young Thomas Hood became Bachelor of Arts in 1577, Master of Arts in 1581, a Fellow of his college, and a very competent mathematician. As such he was first commissioned by Thomas Smith and John Wolstenholme, city financiers and merchants, whose munificence and energy in fostering maritime enterprises was to become almost proverbial, and by Lord Lumley, to lecture privately on the application of mathematics to navigation, probably in 1587. The subjects he now taught publicly in the Leadenhall included ‘geometry, astronomy, geography, hydrography, and the art of navigation’. The impetus necessary to start the lectures off—Hood gave his opening address on 4 November 1588

1 See Appendix 16B.
in the house of Master Thomas Smith—was provided by the Spaniards and their Armada—'We have scene them on our coastes and heard the thunder of their shot', he declaimed. The citizens of London, alarmed by the imminence of invasion, with the consent and under the supervision of the Privy Council, had levied bands and organized a militia to resist any later attempts, and as part and parcel of the scheme had instituted the mathematical lectureship so that their captains should be as proficient in the art of war as their professional contemporaries, not least in theoretical instruction. But Hood's lectures, which were authorized for two years, were attended not only by 'those yong gentlemen, whome comonlic we call the captains of this citie, for whose instruction the Lecture was first vndertaken', but also by 'all other whome it pleased to resort vnto', Hood explained as his first term of office drew to an end. It is clear from his published works that the latter were mostly men of the sea. How satisfied Thomas Digges must have felt when thinking upon his theme in Stratio-
ticus. 'When', declared Hood at the opening lecture, 'I call to minde the great commoditie that wil henceforth arise vnto our Realm in that this day there is a platforme laied for the better increase of the Mathematicall science, then do I begin to be somewhat glad. Yea,' he declaimed with eloquence becoming the occasion, 'I triumph, indeed I leape for joy!'

Arithmetic, geometry, and astronomy formed the substance of his lectures on navigation, as the laying together of three strands forms a rope. The instruction, it is true, was not on the permanently endowed official basis Stephen Borough and Hakluyt and others so greatly desired; nevertheless it was given in a manner well suited to the country's needs and to the capacities of its students of navigation.

Hood was a 'Mathematicall Lecturer in the Citie' with such success that his friends and students importuned him to put his lectures forth in print, and some he did. They show that he made both original and practical contributions towards furthering the art of navigation. In 1590 Tobie Cooke published Hood's lecture on The Use of the Celestial Globe in Plano, set foorth in two hemispheres . . . ('The Hemispheres are to be sold in Abchurch Lane at the house of Th. Hood'), dedicated to Lord Lumley.1

1 See Hood's address contained in A COPIE OF THE SPEACHE: MADE by the Mathematical Lecturer, unto the Worshipfull Companye present. At the house of the Worshipfull M. Thomas Smith, dwelling in Gracious Street: the 4. of November, 1588. T. Hood. Imprinted at London by Edward Allde. [1588], and in his dedication in The Elementes of Geometrie, 1590.

Hood's petition for the continuance of his lectures and the guarantee of his salary is to be found in B.M. MS. Lansdowne 101 (12). It can be dated between September 1589 and April 1590, because both Walsingham and Sir Thomas Heneage signed it.

2 THE VSE OF THE CELESTIAL GLOBE IN PLANO, SET FOORTH IN TWO HEMISPHERES: WHEREIN ARE PLACED ALL THE MOST NOT[a]ble Starres of heauen, according to their longitude, latitude, magnitude, and constellation: Whereunto are annexed their names, both Latin, Greeke, and Arabian or Chaldee; Also their nature, and the Poeticall reason of each seuerall Constellation. Moreover, in this booke is set downe the declination of the Starres
Hood stated that he had first given the lecture three years before to Lord Lumley, Thomas Smith, and others, and that the book was an acknowledgment of his indebtedness to them for setting up the lectureship. He explained that he had projected the sphere in plano so that the latitude and longitude of stars could be found out, 'because usually, especially which have any particular name, with their right ascension, and the degree of any signe wherewith they come to the meridian, the time of the yeare wherein they may be seene there.

Set forth by Thomas Hood, Mathematicall Lecturer in the citie of lo[n]don, sometimes Fellow of Trinitie Colledge in Cambridge. The Hemispheres are to be sold in Abchurch-lane at the house of Th. Hood. Imprinted at London for Thobie Cooke. 1590. Examples of Hood's two planispheres are in the British Museum.
in little globes, there wanteth a fit instrument to find them out', and because they could not be found out for certain stars on the ordinary globe because of the way in which it was mounted. What in fact Hood had produced were exquisitely coloured planispheres for the northern and southern hemispheres, the first English planispheres printed. They were welcome because if the mariner had these planispheres, he could dispense with a much more expensive celestial globe or planispheric astrolabe.

Apart from his inaugural lecture Hood's first printed work was a pamphlet on a cross-staff of novel design which he had devised. So great was the success of this pamphlet that 'he was desired by his acquaintance, to take the like paynes in the Jacobs Staffe'.

This he did and, also in 1590, had the two pamphlets printed. These too he dedicated to his patron, Lord

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1 The use of the two Mathematicall instrumentes, the crosse Staffe ... and the Iacobes Staffe, [2 parts, within separate titles], For Tobie Cooke and Robert Dexter, 1590.

[Book Prices Current, 1924 & S.T.C.].

Second edition [B.M.]:

The use of the two Mathematicall instruments, the crosse Staffe, (differing from that in common use with the mariners:) And the Iacobes Staffe: Set forth Dialogue wise in two brief and plaine Treatises: the one most commodious for the Mariner, and all such as are to deal in Astronomicall matters: the other, profitable for the Suruyor, to take the length, height, depth, or breadth, of any thing measurable. Set forth by Th. Hood, mathematicall Lecturer in the Citie of London. Newly reviewed, and the second time imprinted. The Staues are to be sold in Marke lane, at the house of FRANCIS COOKE. Imprinted at London by Richard Field for Robert Dexter. 1596.

This general title-page is followed by one for the second part of the book, as follows:

THE VSE OF THE IACOBS STAFFE.

Imprinted at London by Richard Field, for Robert Dexter. 1596.

This is the same as that of the first edition (1590), except that in the latter case the imprint is that of Tobie Cooke and Robert Dexter. (B.M. This copy has no general title-page, and has been wrongly bound, with the part on the cross-staff without a title-page—coming second instead of first).

Hood's cross-staff was an L-shaped instrument with a shadow vane. It was beautifully simple, having only six parts, the yard, transom, shadow vane, brass sockets, and two socket screws. Yard and transom were of wood, square in section and of equal length. Both were marked with equal graduations for almost all their length. The transom was graduated from 0° to one end to 45° at the other, a portion of this end being left ungraduated; the yard was graduated from 90° at one end to 45° at the other, the extremity of which was also left ungraduated. Transom and yard were joined together by the brass sockets, 'square wise, at right angles', which fitted over their ungraduated ends and held them securely by means of the two screws. The vane was fitted either to the yard or to the transom according to whether the sun's elevation or zenith distance was to be measured. To take a sight, the observer pointed the staff at the horizon below the sun with the transom vertical.

He could then let the transom drop down through the socket until the vane, sun's shadow and eye—or palm—end of the staff were in coincidence or, if the sun's altitude was above 45°, instead of lowering the transom to achieve coincidence he could slide it along the staff; or again, he could hold the staff as before, but with the
Lumley. The book came to the notice of the Lord Admiral, Lord Howard, and he in turn extended his favour and patronage to Hood. It was to Howard that Hood dedicated his treatise on the cross-staff in the second (1596) edition of the book. Hood’s cross-staff is of great importance in the chain of developments that led up to the modern sextant. It was perhaps the first nautical instrument devised to measure the sun’s altitude by indirect observation. The various methods were lucidly explained by Thomas Hood and clearly indicated in the diagrams accompanying his pamphlet. The great point about his staff was that the observer when shooting the sun needed to look at only one object, the horizon under the sun, and did not have to look at the sun itself. Further, though the staff was of the size of the conventional cross-staff, the graduations, besides being equal, were much larger than those of the usual cross-staff, where the size differed according to the size of the angle measured. It had, however, several limitations, to which he was alive, such as that it could not be used as a shadow staff for finding the height of the stars ‘by reason their beame is so weake that it cannot cast a shadow . . . ‘; that considerable skill was needed to keep the instrument level with the horizon beneath the sun, and tilted neither to the right nor to the left; and that it was desirable to have a second observer to read off the sun’s elevation in this critical position at the moment that the sun crossed the meridian. Nevertheless, that seamen thought well of the principle of Hood’s invention is proved by the variety of shadow-staves and back-staves incorporating it that were soon developed and marketed.

The Elementes of Geometrie, a short text-book for the use of his students, rounded off Hood’s published works in 1590.1

Hood’s next published work, again written in the favourite dialogue form, appeared in 1592 and was on The Use of both the globes, Celestiall and Terrestriall. It was specially written at the request of William Sanderson for a treatise concerning the use of the pair of globes which he had recently had constructed.2 The need for such a treatise was real enough, for the transom vertically downwards and next to him. Another method was to set transom and staff with their 45° marks in coincidence and, holding the staff level with the horizon and the transom in the vertical plane, to read off the angle cast by the sun’s shadow on the scale. See Fig. 19.

1 THE ELEMENTES OF GEOMETRIE. Written in Latin by that excellent Scholler, P. Ramus. Professor of the Mathematicall Sciences in the Universitie of Paris: And faithfully translated by Tho. Hood, Mathematicall Lecturer in the Citie of London.

Knowledge hath no enemie but the ignorant. LONDON. Printed for John Windet, for Thomas Hood, and are to be sold in the Staplers Chappel within Leaden Hall, where the Mathematicall Lecture is read: or in Marklane at the house of Francis Cook. 1590.

2 THE Vse of both the Globes, Celestiall, and Terrestriall, most plainly delivered in forme of a Dialogue. Containing most pleasant, and profitable conclusions for the Mariner, and generally for all those, that are addicted to these kinde of mathematicall instrumentes. Written by T. Hood Mathematicall Lecturer in the Citie of London, sometime fellow of Trinittie Colledge in Cambridge.

Imprinted at London at the three Cranes in the Vintree, by Thomas Dawson. 1592.
globes were now, as Hood put it, 'in the handes of many with whom I have to do', and from another source we learn that a special cheaper and smaller set of globes had indeed been produced specially for the use of students.\(^1\)

William Sanderson, the wealthy merchant who had chiefly financed John Davis's voyages to the north-west, was typical of the growing numbers of English merchants who saw that by promoting the study of the art of navigation England could become the storehouse of the world. Just as Thomas Smith financed to a great extent Hood's mathematical lectures on navigation, so Sanderson commissioned a mathematician to construct terrestrial and celestial globes for the use of seamen and the enlightenment of students. He found an English mathematician equal to the task in Emery Molyneux. All the leading spirits in maritime affairs, Raleigh, Hakluyt, John Davis, to name but three, were known to him and he was known as a highly competent instrument-maker. Thus, when Sanderson wanted globes made—the framework designed and the gores projected—in order to show the English the world according to the latest discoveries, and in order to facilitate exploration and navigation in northern waters, Molyneux was a natural choice, particularly as John Davis recommended him. Hakluyt, in his preface to his *Voyages* of 1589, compiled to tell the world something of the maritime achievements of the vanquishers of the Armada, referred to the coming forth of the globes.\(^2\) The actual engraving and printing of the gores

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\(^1\) TRACTATVS DE GLOBIS ET EORVM VSV, Accommodatus iis qui Londini editi sunt Anno 1593, sumptibus Gulielmi Sandersoni Ciuis Londinensis, Conscriptus à Roberto Hues, LONDINI In aedibus Thomae Dawson. 1594.

\(^2\) Hakluyt, R., THE PRINCIPAL NAVIGATIONS, VOIAGES AND DISCOVERIES OF THE English nation, made by Sea or ouer Land, to the most remote and farthest distant Quarters of the earth at any time within the compasse of these 1500 yeeres: Devided into three several parts, according to the positions of the Regions wherunto they were directed.

The first, containing the personall trauels of the English vnto Indaca, Syria, Arabia, the riuers Euphrates, Babylon, Balsara, the Persian Gulfe, Ornuz, Chaul, Goda, India, and many Islands adjoyning to the South parts of Asia: together with the like vnto Egypt, the chiefest ports and places of Africa within and without the Streight of Gibraltar, and about the famous Promontorie of Buona Esperanza.

The second, comprehending the worthy discoueries of the English towards the North and Northeast by Sea, as of Lapland, Scricinia, Corelia, the Baie of S. Nicholas, the Isles of Colgoieve, Vaigats and Nova Zembla toward the great river Ob, with the mighty Empire of Russia, the Caspian Sea, Georgia, Armenia, Media, Persia, Boghar in Bactria, & divers Kingdoms of Tartaria.

The third and last, including the English valiant attempts in searching almost all the corners of the vaste and new world of America, from 73 degrees of Northerly latitude Southward, to Meta Incognita, Newfoundland, the maine of Virginia, the point of Florida, the Baie of Mexico, all the Inland of Nova Hispania, the coast of Terra firma, Brasil, the river of Plate, to the Streight of Magellan; and through it, and from it in the South Sea to Chili, Peru, Xalisco, the Gulfe of California, Nova Albion vpon the backside of Canada, fuertther then euery Christian hithero hath pierced. Whereunto is added the last most renowned [sic] English Navigation, round about the whole Globe of the Earth.
was entrusted to the gifted and celebrated Dutch engraver and cartographer, Jodocus Hondius of Amsterdam, who was then a fugitive in England. It was these globes—the first ever made in England, and the second (it would appear) designed especially for use at sea—which were completed after four or five years' labour, in 1592. Molyneux is also reputed to have written a treatise on *The Globes Celestial and Terrestrial set forth in Plano* and Sanderson to have published it at the same time.\(^1\) Hood's description of the use of the globes is good, but the dialogue form in which it is written is not the most suitable. The master is apt to be verbose, and the arrangement does not make it easy to refer quickly to specific points. The result is that his book has been outshone by a more learned description written a year later by Robert Hues, and, much to Hood's annoyance, published in 1594. Its text was in Latin with the title *Tractatus de Globis et Eorum Usu* ('A learned Treatise of Globes, both Celestiall and Terrestriall with their several uses' as the first English translation of 1638 entitled it.) Hood's book on the globes, besides having the distinction of being the first English work to describe the manner of using a terrestrial globe for the solution of navigational problems, despite its verbosity, had the advantage of being in the vernacular. The English seaman who wanted to profit directly from Hues's book had, until 1638, either to be a Latin scholar or a linguist (a Dutch version first appeared in 1597 and a French one in 1618). Although Hues's *Tractatus* was of no direct use to the plain mariner, there were by now plenty of navigators, like Sir Robert Dudley or the Earl of Cumberland, with sufficient Latin at their command to benefit from it. Indeed, anyone who had pretensions to science was competent at Latin, for it was still customary to write scientific treatises in that language. For that reason the 'students of physics' or 'of mathematics' in the city who, either on their own behalf or on that of the growing number of booksellers, chart and instrument-makers, taught navigation to the unlearned, could pass on to their students the gist of Hues's work.

Hues had been born in the year of the first English voyage to the northeast, 1553, in a Hertfordshire village, Little Hereford. At the age of eighteen he had gone up to Brasenose College, Oxford, and in 1578, having removed to St. Mary Hall, had taken his degree. He had been then an excellent Greek scholar but, after a visit to the Continent, his interests had changed. Henceforth he had devoted himself to geography and mathematics. He had thoroughly mastered those sciences and had then taken to the sea. He had voyaged around the world (1586–88) with Thomas Cavendish, and


\(^1\) See Pls. XLVII and XLVIII. No copy of Molyneux's treatise is known, but Robert Tanner published, *A briefe Treatise for the ready use of the Sphere* (1592).
in 1591 he had set out on Cavendish's ill-fated expedition to the Pacific. That by now Hues had become an experienced navigator is evident not only from his description of the use of globes but also from his references to observations made by himself at sea. He made it clear that he had observed the stars in the northern and in the southern hemispheres and the variation of the compass in the North and South Atlantic. In fact Robert Hues coupled theoretical knowledge with practical experience to a degree hitherto rare. Henceforth such qualifications were to become common amongst English navigators.

Because, unlike Hood, who appears never to have gone to sea, Hues combined mastery of the practice as well as of the theory of navigation, his treatise is of particular interest. He began with a word on the physical features of the navigator's ideal globe, placing emphasis on the 'true and exact description of places' and requiring that the globes should be sufficiently large without their weight being cumbersome. From this point of view the Molyneux globes, he found, surpassed all others.

The globes are indeed superb. Each is two foot two inches in diameter. Mercator's, which had been the largest hitherto, had measured only sixteen inches. Molyneux's are exquisitely wrought and beautifully mounted on a circular wooden base with six pillars supporting a broad wooden horizon ring. In this, and at right-angles to it, slides a brass meridian ring on whose poles the globe is mounted. A brass Horarius and Index Horarius, or hour circle and hour pointer for measuring the hour angle or time, which can be mounted on either of the poles, are fitted to each globe. Conspicuous on the terrestrial globe are numerous rhumb lines and the tracks of Drake's and Cavendish's voyages round the world.¹

Hues dedicated his Tractatus to his friend Sir Walter Raleigh. It was in his preface that he explained the virtues of the Molyneux globes, an explanation that he coupled with proofs that the earth is a sphere. Then followed his treatise in five parts.

The first part treats of the features common to both globes; of their frames; of the circles described upon their surfaces, such as the equator, parallels of latitude and meridians of longitude, and the ecliptic; of the three recognized positions of spheres defined as right, i.e. with the poles vertical, parallel, i.e. with the poles horizontal, and oblique, i.e. with the poles

¹ The globes are described in Tractatus de Globis, Hak. Soc., Ser. 1., Vol. 79 and in Stevenson, F. L., Terrestrial and Celestial Globes, Vol. 1 (1921). These are globes of the 2nd (1603) edition. In addition to the pair belonging to the Middle Temple, London (now in Buckland Abbey), there was a pair in the Royal Museum, Cassel. A terrestrial globe of the 1st edition has recently been discovered in the library of Petworth House, the Sussex seat of Lord Leconfield, a descendant of the Earl of Northumberland. It may well have belonged to Henry Percy, ninth Earl of Northumberland, 'the wizard Earl' (1564–1632), who employed Hues and Hariot, and a third mathematician Warner in his scientific researches. Petworth was one of the Earl's residences, and much of his collection of books and charts was housed here until sold in recent years. See Wallis, H. M., 'The First English Globe', Geog. Jour. Vol. 117 and 'Further Light on the Molyneux globes', Geog. Jour., Vol. 121.

XLVII. Celestial Globe by Molyneux, 1603.
XLVIII. *Terrestrial Globe by Molyneux, 1603.*
XLIX. Thomas Hood's Chart of the N.E. Atlantic, 1592.
at any other angle to the horizon circle; of vertical circles, that is great circles drawn from the vertical point overhead to the horizon and referred to by seamen as azimuths; and of the quadrant of altitude, the thin brass strip graduated to 90° which could be attached to the meridian ring for determining azimuths, and was the device which made the terrestrial globe of practical value to the seaman.

In the second part of his treatise Hues dealt with subjects 'proper to the Celestial Globe'. These were such matters as the planets, the stars and their constellations, both northern and southern, the zodiac and 'the other stars which are not expressed in globes'.

In the third part Hues briefly described the lands and seas delineated on the terrestrial globe, reviewed the bounds of geographical discovery in his day, and discussed the problem of determining the size of the earth and the measurement of a degree. Of the latter, after reviewing the measurements of various authorities, he was forced to conclude that there was 'so great diversity of opinions concerning the true measure of the earth's circumference, let it be free for every man to follow whomsoever he please'.

In his fourth part Hues speaks of the practical uses of the globe. Besides its purely astronomical and geographical uses, the globe, he explained, was invaluable in the art of navigation because, 'by it there is an easie and ready way laid downe, for the finding out both of the place of the Sun, the longitudes, latitudes, and positions of places, the length of dayes and houres, declination, Ascension, both Right and Oblique, the Amplitude of the rising and setting of the Sunne and Starres and many other like things'. He admitted that it was now well understood that all these things could be performed far more accurately by mathematical methods, but the calculations, being 'tedious and prolix', instrumental methods continued to be the only practical ones. It was because it could be used 'with little or no knowledge of the Mathematickes at all' that the best instrument was the globe.

Hues, as a practitioner of the art of navigation, regarded this fourth part of his treatise as one of the most valuable. This was because it consisted of exact instructions on how to manipulate the globes in order to find out the answers to the various problems already briefly enumerated. In the course of his description he had a scathing word on would-be determiners of longitude using 'sunne dials, or clocks, or hour glasses, either with water or sand, or the like', for, although their worth had been disproved long since, 'there are a kind of trifling Imposters that make public sale of these toys or worse . . . to the great abuse and expense of some men . . . who are perhaps better stored with money than either learning or judgement'.

In the first four parts of his Tractatus Hues had in the main merely traversed the ground surveyed by Hood. It was in the fifth and last part of his Tractatus that he introduced something quite new, a detailed explanation 'of the Rombes that are described in the Terrestrial globe and
their use. This part, though written by Hues, had originally been promised by another accomplished mathematician with sea experience, Thomas Harriot. Born at Oxford in 1560, Harriot had been a contemporary of Hues at St. Mary Hall, Oxford, and had taken his Master’s degree in 1579, since when he had been employed by Walter Raleigh upon research into navigational problems. He had accompanied Sir Richard Grenville on his voyage of 1585 to Virginia, in the course of which he had made a chart of the coast. The fruits of his scientific knowledge and navigational skill were, however, always closely confined to the sea captains employed by Raleigh and have only become known in recent years. Although Mercator had included rhumb lines on his terrestrial globe, the use of these special lines was still not well understood, chiefly because on the plane chart, with which most navigators were more familiar, the rhumb lines were represented by straight lines. Now Hues, in a short but brilliantly lucid treatise, discussed first the general characteristics and significance of rhumb lines in navigation, and then their particular use when represented on a globe, in the solution of various navigational problems. He dealt first with the simple problem of two places situated on the same meridian but in different latitudes; next with that of two places on different meridians but in the same latitude (although because there was as yet no ‘certaine way of observing the difference of longitude’, the distance between places based on difference of longitude was still never used); finally, with that of ‘those places that differ both in Longitude and Latitude’. In his explanation he showed how, by knowing two of the four differences between places, ‘the differences of longitude, and of latitude and the distance, and rumbe by which the voyrage is performed . . . the rest might readily be found out’. Then followed six fundamental propositions, all of which of any practical value might be performed by the globe, and none of which had been so neatly summarized before (see Table 2).

Each proposition was explained in full with examples, though of the six the third was to all intents and purposes ‘insoluble’; the impossibility of knowing differences of longitude accurately necessitated ‘long and tedious practice’ for its solution. Others, because they depended upon ‘the like supposition of difference of latitude (sic)’, Hues had included not so much for their practical use, which was little, as ‘for exercise sake onely’—they could be worked out easily.

This ended the treatise, but the third edition, published at Amsterdam two years later by Jodocus Hondius, was annotated by the distinguished Dutch cosmographer and historian Isaac Pontanus (1571-1639), while the fifth (Heidelberg, 1613) contained a geographical index giving a list of place names with their latitudes and longitudes. The prime meridian for this list, as it was on the globe, was St. Michael’s in the Azores.

Hues’s Tractatus de Globis remained the standard work on globes for nearly a century. Dutch translations appeared in 1597, 1612, 1613, 1617, 1622, and 1623, a French one in 1618, English ones in 1638, 1639, and

1 See Appendices 16C, 16D and 20.
1659, while eight Latin editions, apart from the original one of 1594, appeared between 1611 and 1663. The last date is a good indication of the period when terrestrial globes really began to be supplanted as navigational instruments by the more general use of charts on 'Mercator's projection'.

The fact that an English translation of Hues's work was so long delayed can be explained by the prior publication of Hood's treatise on the globes, by the publication in the year Hues's *Tractatus* appeared of John Davis's *Seamans Secrets* with an excellent chapter on the globe, and by the publication in 1613 of Edward Wright's manuscript of 1600, *Description and use of the Sphere*. This work, while in no way comparable to Hues's for content, or to Davis's for practical value (it was confined to the celestial

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1 THE DESCRIPTION and use of the Sphaere Devided into three principal Partes: WHEREOF The first intreateth especially of the circles of the vppermost moeuable Sphaere, and of the manifould vses of every one of them seuerally: The second sheweth the plentifull Vse of the vppermost Spheare, and of the circles therof ioynly: The third conteyneth the Description of the Orbes whereof the Sphaeres of the sunne and moone haue beene supposed to be made, with their motions and vses.

By EDWARD WRIGHT.

The contents of each Part are more particularly set downe in the Table.

LONDON. Printed for John Tap; dwelling at S. Magnus corner. 1613.
sphere), nor even to Hood’s, did fill the place of the celestial section of Hood’s work which was by then out of print. But a further explanation lies in the use of universal planispheric astrolabes and in the fact, to be examined later, that in the seventeenth century the English rapidly developed the art of mathematical navigation. This enabled instruments so cumbersome and relatively inaccurate and expensive as the astrolabe and the globe to be dispensed with, the more readily as the cheaper printed planisphere was on the market, a nautical almanac was being published regularly, and charts on which accurate plotting was possible were procurable.

The Molyneux globes, Hood’s, Hues’s, and Wright’s treatises, and Davis’s chapter on globes, mark the end of the first phase in the development of the art of navigation; we can call it the empirical phase, the phase of trial and error or, to paraphrase John Davis, the phase of navigation by geometrical methods. Yet there was no clean-cut line, rather was there a gradual transition by the leading navigators in the next half-century from reliance upon simple geometrical instruments and the minimum of mathematical calculation to increased reliance upon mathematical calculation, and mathematical tables and instruments designed to simplify the processes of calculation. English science, after the Armada, having at last been mobilized for the solution of navigational problems, primarily in the interests of greater fighting efficiency, continued to be called in during the subsequent period of peace in the seventeenth century, in the interests primarily of mercantile efficiency.

John Davis had rounded off *The Seamen’s Secrets* by publishing in 1595 *The Worldes Hydrographical Discription*.1 In this work, dedicated to the Privy Council, he had put succinctly the advantages of continuing the search for a North-West Passage. The persistence of this theme, from the time of Cabot to the final disillusionment in the year of Captain Smith’s death, marks its importance as a stimulus to the quest for perfection in the art of navigation. It was in *The Worldes Hydrographical Discription* that John Davis claimed that Emery Molyneux had been chosen, solely on his advice, to make the first pair of English globes. He claimed this in developing his argument for the north-west exploration, protesting that the objection that it could not be undertaken ‘for lack of curious lyne’d globes to the right use of Navigation’, that is with rhumb lines, in these high

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1 **THE WORLDDES HYDROGRAPHICAL Discription.** Wherein is proved not onelie by authoritie of writers, but also by late experience of travellers and reasons of substantiall probabilitie. that the worlde in all his Zones Clymats and places, is habitable and inhabited, and the Seas likewise vuniversally Navigable without any naturall anoyance to hinder the same whereby appeares that from England there is a short and speedie passage into the South Seas, to *China, Molucca*, *Phillipina*, and *India*, by Northerly Navigation, to the renowne honour and benifit of her Maesties state, and Community. Published by I. Davis of Sandrugd by Dartmouth in the Countie of Deuon. Gentleman. Anno 1595. May 27. Imprinted at London by Thomas Dawson dwelling at the three cranes in the vitetree. And are there to be sold. 1595.
latitudes was now groundless. He agreed that the rapid convergence of the meridians rendered a plane chart of the region worse than useless, but ‘now that we have globes in the most excellent perfection of arte, and have the use of them in as exquisite sort as Master Hues in his book of the globes use, lately published, hath at large made knowne’, he argued that navigation in high latitudes was quite simple. His arguments on this subject help to explain the increased writing, invention, experiment, and tuition in navigation that marked the 1590s. While it is perfectly clear that the war with Spain was an important contributory cause, it is also clear that navigational research and teaching were no less the result of a carefully prepared and well-conceived scheme designed to facilitate the discovery and exploitation of the North-West Passage to Cathay. Davis’s voyages of the ‘8os, financed largely by Sanderson, and encouraged wholeheartedly by the Government in the person of Walsingham; the painstaking and laborious preparation of the Molyneux globes, paid for by Sanderson, on a scale sufficiently large for general navigational use in northern waters; Hood’s lectures, and popular treatise on the use of the globes, paid for by Sanderson; and Hues’s more learned treatise of a year later; Davis’s own careful description of the use of the globes in The Seamans Secrets, a year after that, can be seen now to have been all produced or financed with an eye to furthering this scheme. That it was not put to the final test as originally intended, Davis ascribed chiefly to the death of Walsingham, early in 1589, but the war must in any event have had much to do with preventing its completion. It is further evidence of the northern passage scheme and of the effect of the war on it that in 1603, the year the war ended, a second edition of the globes was issued, with amendments incorporating Barents’s recent exploration in the north-east, round Novaya Zemlya, and also that the search for the North-West Passage was resumed. But we are anticipating events. In the year that Hood had produced his work on the globes, 1592, the ephemerides in Bourne’s Regiment for the Sea had become out of date. In anticipation of this Hood had prepared new ones covering the twenty-year period 1592–1612, and these he had brought out in a new edition of the Regiment in 1592.1 Except for the addition of a declination table of the sun according to its position in the zodiac, a dedication to the Earl of Cumberland, and a short preface ‘To the Reader’ the text of Bourne’s work was unchanged. According to Hood, the Regiment had already been reprinted three times, though actually five editions appear to exist. Hood’s edition of 1592 gave a new lease of life to the Regiment, and there were subsequently at least six more English editions, in 1596, 1601, 1606, 1611, 1620, and 1631. It was in 1594 that the first of three Dutch versions came out—the last appeared in 1609.

1 A Regiment for the Sea, Containing verie necessarie matters for all sorts of men and traualiers; whereunto is added an Hydrographicall discourse touching the fiue seuerall passages to Cattay; written by William Borne, Newlie corrected and amended by Thomas Hood; who hath added a new Regiment, and table of declination. Imprinted at London by T. Est, for Thomas Wight. [1592].
Bound up with and forming a part of the 1592 edition of the Regiment was The Marriners guide, a treatise by Hood himself.\textsuperscript{1} As usual it was in dialogue form. It was a treatise wherein the use of the ‘plaine Sea Card was brieflie and plainely delivered, to the commoditie of all such as had delight in navigation’. The 1596 and later editions notify on the title-page the inclusion not only of The Marriners guide but also of ‘a perfect Sea Carde by the said Thomas Hood’ a unique example of which survives.\textsuperscript{2}

Hood made clear that in describing the plane chart he was not trying to justify ‘this kind of projection’. It was, he said, indisputably erroneous because the meridians meeting with the parallels made perfect squares, whereas what should be formed were ‘trapezia’, but that plane charts had to be used until the need for a truer projection could be met. Hood was one of the first writers on navigation to mention using a ruler and that, ‘if you pleased you might draw a line with a fine blacke lead’, and he was also the first English writer to explain that the navigator could keep his plot on a large scale on ‘a blank skin and lines’, that is to say, on a plotting chart, and could transfer his position from it on to a smaller sea-chart by bearing and distance from a given point. The trend was towards more accurate and scientific navigation. The old practice of ‘pricking’ the chart with compasses was gradually to give way to the new one of ‘laying-off’ a position with pencil and ruler, and the old method of course-finding by compasses and rhumb-lines to the use of protractor and ruler.

Concerning the actual chart, Hood advised that the diagram of ‘Leagues to run on a compass point to raise or lower a degree’ (of latitude) and diagram of the ‘Rule of the North Star’ should both be shown on the sheet with, on the left-hand side, a scale of latitude and, on the right-hand side, various scales of leagues—one of 20 English and another of 17! Spanish leagues to a degree. On the surviving copy of the ‘sea carde’ that accompanied The Marriners guide not only are all these features to be found but also the workings of the various examples of ‘pricking the card’ given in the text. Signed and dated by Hood and the engraver Ryther, the chart is a beautiful example of what must be the first printed English plane chart.

\textsuperscript{1} The Marriners guide. Set forth in forme of a dialogue; wherein the use of the plaine Sea Card is brieflie and plainely delievered, to the commoditie of all such as haue delight in Navigation. Written by Thomas Hood. The contents of the booke are set forth in the page following.

\textsuperscript{2} Ignoti nulla cupidio. Imprinted at London by Thomas Est, for Thomas Wight, 1592.

Gabriel Harvey, who evidently bought a copy, wrote his name on it, and added these words: ‘The most sensible & familiar Analysis of the Sea-Card, that euer yet cam in print.’ The Marriners guide was bound in as an appendix to Hood’s edition of Bourne’s Regiment. It was also published separately.

\textsuperscript{2} See Pl. XLIX. The original is in a volume of miscellaneous papers entitled Sea Tracts, Vol. II, in the Pepysian Library, Magdalene College, Cambridge. Another example of Hood’s cartography is his manuscript chart of the West Indies preserved in Sir Robert Dudley’s own copy of his Arcano del Mare (Secrets of the Sea) at Florence. It was reproduced by Kunstmann in the atlas to his Die Entdeckung Amerikas (1859).
designed expressly for navigation and instruction. Ryther, as remarked earlier, was the accomplished craftsman who engraved amongst other things the charts of the progress of the Armada up the Channel, including the various sea-fights on the way, which illustrated Lord Howard’s dispatch of the Armada campaign. Ryther’s engravings of Hood’s chart of 1592 is a delicate piece of work, and as a sailing chart much superior to Hondius’s engraving of the coasts of north-west Europe in The Mariners Mirror. Hood’s chart extends from the north of Scotland and the tip of Denmark to the Cape Verde Islands, and from the Azores to the Strait of Gibraltar. The mother compass of the rhumb network that covers the chart is drawn W.S.W. of Cape St. Vincent with peripheral compasses on the sixteen principal rhumbs. The ‘Rule of the North Star’ is engraved round the compass (which is enlarged for the purpose) on the N.N.W. rhumb. ‘The Distance to Raise or Lay a Degree’ is on the opposite, S.S.E., rhumb, the compass on which is also enlarged.

Preserved in the National Maritime Museum, Greenwich, is a signed and dated manuscript chart by Hood, drawn in 1596, of the coasts between Flanders, Southern Ireland, and Finisterre—the north-west point of Spain. Besides being of interest as an example of an English MS. plane chart of the Soundings and the Channel, it merits attention because it incorporates some of Bourne’s longed-for tidal information exactly in the form he desired. The establishment of various principal ports and capes is shown by letters of the alphabet against their names, the key being provided by a compass-fly with lettered rhumbs. Thus, for example, the ‘E’ standing against the ports on the Spanish Biscayan coast will be found on the lettered compass-fly to indicate 3 o’clock, the establishment of that port. As Hood had revised Bourne’s Regiment as recently as 1592 and a new edition had come from the press in the year the chart was drawn, the inclusion of these data and in this form on a chart by Hood is perhaps not surprising. Jacques Devaulx of Havre had already produced a chart with tidal establishments in his manuscript—Les Premières œuvres de Jacques Devaulx, Pilote en la Marine of 1583. However, he had shown each establishment by the arabic numeral of the hour of high-water and not, like Hood, by a letter. A curious feature of Hood’s establishments is that they were confined to the continental coastline, that is between Cape Finisterre and the Scheldt. Devaulx included the establishment of points on the coasts of southern England and Ireland. Although Hood was not the first hydrographer to include tidal data on his charts, he appears to have been one of the first English ones to do so, and his chart to be the oldest surviving English one to contain tidal data.

1 These charts have been reproduced: Ryther, A. Lord Howard of Effingham and the Spanish Armada with exact facsimiles of The Tables of Augustin Ryther, A.D. 1590 (Printed for the Roxburghe Club, 1919.)
2 See Pl. L.
Of Mercator's chart Hood had this to say in *The Marriners guide*:

I judge it to be an excellent worke in respect of the projection thereof, and might (by enlarging of it) be made most fitte and convenient for the saylors' use. . . . It differeth from the common carde in that you may trulie measure the distance between east and west . . . it is therefore the best card that ever I saw extant, wherein you may keep an account of your longitude.

Hitherto it had been the problem of drawing charts on Mercator's pro- jection that had proved insoluble. Already however, unknown to Hood, who said he had written a book on the use of the chart (it was never published), the problem had been solved; the 'daily wish' of many excellent seamen had at last been fulfilled and by Englishmen. It was the result of the impact on navigation of mathematics, still truly called by the Elizabethans 'the ground of arts', the name given it in their oldest primer. It was to make obsolecent Hood's plane charts and *The Marriners guide*, though they represented respectively the quintessence of English plane chart production for close on a century and the definitive work on their use.

The 1596 edition of the *Regiment* was a reprint of that of 1592. This, with a book on arithmetic, seems to mark the end of Hood's activities as a lecturer on navigation, though precisely when that occurred is not clear. In the following year he became a Doctor of Physic. However, he continued to be interested in navigational matters, apparently to his death, for in 1598 he invented a mathematical instrument called the Sector which simplified various mathematical problems involving proportions, and published a book on it which will be considered in a later chapter.\(^1\)

In 1601, 1606, and 1611 Hood brought out new editions of the *Regiment*, recalculating the ephemerides and revising the examples for the use of the tables. In the 1611 edition, in commenting upon the errors in the declina-

\(^1\) THE MAKING and use of the Geometrical Instrument, called a SECTOR. Whereby many necessarie Geometrical conclusions concerning the proportionall description, and diuision of lines, and figures, the drawing of a plot of ground, the translating of it from one quantitie to another, and the casting of it vp Geometrically, the measuring of heights, lengths, and breadthes may be mechanically performed with great expedition, ease, and delight to all those, which commonly follow the practise of the Mathematicall Arts, either in Suryaying of land, or otherwise.

Written by *Thomas Hood*, Doctor in Physicke, 1598. The Instrument is made by Charles Whitwell, dwelling without Temple Barre against S. Clements Church. LONDON Printed by *John Windet*, and are to solde [sic] at the great North dore of Paules Church by *Samuel Shorter*.

Hood makes it clear that it was Ramus's *Geometry* (which he had translated and published in 1590) which inspired him to invent the Sector. Galileo invented it simultaneously in Italy, chiefly for military purposes. (*See Gunther, R. T., Early Science at Oxford* (1923), Vol. 1, pp. 55–57).

Hood translated Urstisius's *Elementa Arithmetica*, Basle, (1579), and published it in 1596 under the title *Elements of Arithmetique most methodically delivered*, London, (1596).
The Seamans Secrets.

A Table shewing the Order how the Seamen may keep his Accounts, whereby he may at all times distinctly examine his former practices, for in every 24 hours, which is from noon to noon, he doth not only lay down his Latitude, with the Corse and Leagues, but also how the Wind hath blown in the same time. The first Column is the months and days of the time; the second is the observed Altitude, the third is the Horizontal Corse or motion of the Ship; the fourth the number of Leagues that the Ship hath sayled, the fifth is a space wherein must be noted, by what Wind those things have been performed; and the next great space is to lay down any brief discourse for your memory.

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A brief


In the second edition of Hakluyt’s Voyages (1599–1600) is an example of Davis’s journal for 1587. (See Plate XLVI.) These appear to be the earliest surviving examples of Elizabethan log books in columnar form.

Note that longitude is not logged and that there are two methods of recording variation.

The outermost disc is engraved as a compass fly and clock, with the twenty-four hours of the day. The middle disc is graduated clock-wise into 29\(\frac{1}{2}\) divisions, representing the age of the moon. The pointer at 29\(\frac{1}{2}\) is the moon pointer. The inner disc is the sun disc; the radiating lines and symbols engraved on it indicate the relative positions of the sun and moon.

The computer, set to a port with an establishment of S.E. by E., or High Water on days of Full and Change at 8 o'clock, has been adjusted to indicate the time of High Water there when the moon is 11 days old. This has been done by setting the sun pointer to 11 on the moon dial. It then indicates High Water on the clock dial as occurring between W.S.W. and W. by S. or at 4:45 o'clock.
LIII. IVORY PRESENTATION CROSS-STAFF AND RULES AND SCALES OF C. 1695.
tion caused by neglecting the effect of longitude, he promised a fuller explanation in ‘his book called the Mariners ease which was shortly to come forth’. But The Mariner’s Ease never appeared. Probably death cut Hood’s promised labours short, as it had old William Cuningham’s, in whose steps he had so faithfully trodden.¹

On 3 September 1594 a book, The Seamans Secrets, author John Davis, was entered by Thomas Dawson, printer, at Stationers’ Hall.² Dedicated to Lord Howard the ‘Lord High Admiral and Captain General of Her Majestie’s Seas and Navie Royale’, John Davis claimed of this small treatise of navigation that it was ‘but a brief collection of such practices as in his several voyages he had from experience collected.’

In the course of his foreword he made two points that are of special interest in following the growth of the art of navigation in England. He was writing, it will be recalled, in 1594, forty years after the first English-led expedition to Cathay, which had been organized by Cabot and undertaken by essentially foreign-trained Englishmen. Now, Davis maintained—and he was an expert mathematician, widely travelled and experienced—Englishmen were second to none either as navigators or practical seamen, and many hundreds were as competent as he himself. They had, indeed, come a long way in less than half a century, and on long voyages some of them now made an attempt at great circle sailing.³

The success of John Davis’s Seamans Secrets was due in great measure to his treatment of the art of navigation. Despite some obscurities that seem to be caused by hurried composition, his work gives in the briefest compass the clearest picture of the art of navigation at this time. ‘There are’, he wrote, ‘three kinds of Navigation, Horizontal, Paradoxall, and sayling upon a great Circle, performed by Corse and Traverse.’ ‘A Corse’ he defined as ‘that Paradoxal line which passeth between place and place’,

¹ Johnson, F. R., Astronomical Thought in Renaissance England (1937) states that Hood’s lectures ended in 1592. It seems more likely that they ended when Gresham College was opened six years later.

² THE SEAMANS SECRETS, Devided into 2. partes, wherein is taught the three kindes of Sayling, Horizontal, Peradoxall, and sayling upon a great Circle: also an Horizontal Tyde Table for the easie finding of the ebbing and flowing of the Tydes, with a Regiment newly calculated for the finding of the Declination of the Sunne, and many other most necessary rules and Instruments, not heretofore set forth by any.

Newly published by John Davis of Sandrudge, necrere Dartmouth, in the County of Devon. Gent.

Imprinted at London by Thomas Dawson, dwelling at the three Cranes in the Vinetree, and are these [sic] to be solde. 1595.

³ Examples are to be found in the journal and the rutter of Abraham Kendall, Robert Dudley’s navigator, in The Voyage of Robert Dudley, to the West Indies, in 1594, Hak. Soc., Second Ser., Vol. 3. Abraham Kendall followed a great circle course for part of the voyage of 1594. John Davis in The Worlds Hydrographical Discrsion, London, 1595, wrote ‘for Horizontal paradox and great circle sayling I am myselfe a witness in the behalfe of many that we are not ignorant of them’, and referred to The Seamans Secrets in proof of this.

17—A.O.N.
or 'which is described by the ship’s motion upon any point of the compass';
a traverse as 'the . . . alteration of the ship's motion upon the shift of
winds . . . by the good collection of which Traverses, the ship's corse is
given.'

He was the first writer to define course and traverse succinctly and to
distinguish clearly the three forms of sailing now practicable: horizontal
or plane (plain) sailing; paradoxal or rhumb line sailing; and great circle
sailing. His definitions thus merit attention. 'Horizontal [plane] Navigation
manifesteth all the varieties [changes] of the ship's motion within the
Horizontal plain superfices [on a plane chart], where every line [meridian]
is supposed parallel', he wrote.

Paradoxal Navigation, demonstrateth [on circumpolar charts] the
true motion of the ship upon any corse assigned . . . neither circular nor
strait, but concurred or winding . . . therefore called paradoxal, because
it is beyond opinion that such lines should be described by plain
horizontal motion.

Great circle navigation he considered as 'the chiepest of all the three
kinds of sayling', and defined it as one 'in whom all the other are con-
tained . . . continuing a corse by the shortest distance between places not
limited to any one corse.'

Because 'Horizontal Navigation . . . was of the greatest sort only
practised', John Davis devoted the whole of the first book to its art.
The instruments necessary for a skilful seaman, were, he laid down:

A sea compass, a cross staff, a quadrant, an Astrolaby, a chart, an
instrument magnetical for finding the variation of the compass, an
Horizontal plain sphere, a globe and a Paradoxal compass.

He then qualified the list with:

But the sea Compass, Chart and Cross Staff are instruments sufficient
for the Seaman's use . . . for the Cross Staffe, Compass and the chart
are so necessarily joined together as that the one may not well be without
the other . . . for as the Chart sheweth the courses, so doth the com-
passe direct the same, and the cross-staffe by every particular observed
latitude doth informe the truth of such course, and also give the certaine
distance that the ship hath sayled upon the same.

Davis's reply to the question 'How doth the Pilot conduct his ship from
place to place?' puts the technique of plane (horizontal) sailing into a nut-
shell—the good observation of latitude, careful reckoning of the mean
course steered (corrected for variation), and careful estimation of the dis-
ance run. As of these three things 'the pilot had only his height [latitude]
in certain', he always laid off his course and distance sailed and then
brought 'his Corse and observed altitude to agree . . . for . . . by his
Corse and height he found the truth of his distance'. Clearly the mariner
still had little faith in log and log-line. He relied upon the accuracy of two instruments: his compass and his cross-staff; upon his skill at shooting the sun and the stars; and upon his judgment in allowing by experience for the 'many impediments that so disturbed the expected conclusion of his practice, as that they agreed not with the true positions of Art'. The impediments were contrary winds constraining him to traverse upon all points of the compass, the leewardliness of the ship so 'that she might make her way 2 or 3 points from her caping', 'the disorderly handling of the storage' unknown to the pilot, sudden 'variation of the compass', and 'the nature of his sayling, whether before the wind, quartering, or by a bowling, or whether with lofty or low sails [under full sail or reduced canvas], with the benefits or hindrances of the Sea, tyde gates, streams and forced let thereof, etc. . . '. Here then is the explanation of the intense efforts now being made to improve the methods of determining variation and the accuracy of celestial observations.

Besides dealing with chart work Davis included an example of the way in which he wrote up his ship's journal on his voyage of 1593. This was the first of such printed examples and must have been of real value, for blank logs do not seem to have been printed commercially before 1702. Hakluyt, in the third volume of the second edition of his *Principal Voyages* (1600) by reprinting Davis's traverse book for the voyage of 1587, undoubtedly helped to get the lay-out of log-books standardized. In Davis's traverse-book of 1593 course and distance run during the 24-hour period from noon to noon were entered—he had therefore dropped the 'hour' column of the 1587 book showing the hours sailed on a course—and the latitude, wind direction, and remarks. These now included the variation and latitude actually observed. Under the headings 'course' and 'distance' only the mean course and distance run were entered. These were the results of casting up the entries made on the log-board each watch, themselves the mean results of the helmsman's traverse board, and then making corrections for the estimated amount of leeway made, and of the effects of variation and of currents or tidal streams experienced during the period. Davis did not here explain that civil time, that is with the day commencing at midnight, was kept while in sight of land and that when land was lost from view the navigator changed to nautical time, keeping his reckoning from noon to noon, since his last known position was generally from his noon-sight, and that his new day started twelve hours before the civil day, at 12.00 (noon), and not 24.00 (midnight) civil time.

Davis paid a great deal of attention to the correct calculation of the tides. This part of his book followed logically enough his description of the compass, the first instrument dealt with, and is notable for the inclusion of 'An Horizontal Tyde-Table', an instrument which was evidently extremely

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1 See Pl. LI. The first East India Company's log with a printed form is for a voyage of 1702–1703, see *The Voyages of Sir James Lancaster*, Hak. Soc., Ser. 1, Vol. 56, p. 277. The logs of British warships were still ruled and captioned in manuscript in the eighteenth century. See Pl. XLVI. for Davis's 1587 log.
popular by now. Davis gave numerous examples of the various tidal problems that it could be used to solve.¹

It was after dealing with the tides that Davis tackled the problem of celestial observations. Besides giving examples of how to calculate the latitude from an observation of the sun’s meridian altitude, he included examples of how to find the sun’s declination when east or west of the meridian for which the declination tables were calculated. For instance an observation of the sun’s meridian altitude taken on a day in March, in a position 90° W of London, had to have 5' added to the declination given in the tables. Of equal value, and showing his deep interest in northern navigations, was his demonstration of how to calculate the declination for an observation of a northern transit of the sun—in the example he gave it involved a correction of 11½', so that in explaining these refinements of navigation he was still being essentially practical. For those interested in mathematics he gave the explanation of how the declination could be found by the use of the sine tables, but he gave no examples, 'sith this plain way before taught is sufficient', he wrote, 'because Seamen are not acquainted with such Calculations'. Important is his illustration and explanation of the method of finding the correct position of the eye-end of the cross-staff on the observer's cheek so as to avoid parallax, the error induced in a sight when the end of the cross-staff did not coincide with the centre of the eye when making the observation. The explanation is the earliest printed in English. The illustration, often erroneously reproduced as an example of a mariner taking a sight, is the earliest English one of a cross-staff with more than one transversary. It was Michiel Coignet who had first illustrated the cross-staff with more than one, actually with three transversaries, in his work of 1581 on navigation. The transversaries were usually referred to as 60', 30', and 15' transversaries and were used in conjunction with appropriate scales marked on different sides of the staff. Such cross-staves became popular in the 1580s. In the seventeenth century four transversaries were frequently supplied with every staff, 90', 60', 30', and 10'. Then each of the four sides of the staff was graduated appropriately for use with one of the transversaries. The graduations were generally from 90' to 30', 60' to 20', 30' to 10', and 10' to 3'.²

¹ See Pl. L.II. For instance, he gives these instructions for finding high tide at London (Seamans Secrets, 1595, fo. B.1):  

1. When the Moone is 12. daies olde, I desire to know the time of full Sea at London.

1. A. To answere this question, I first looke through all the pointes of the Compasse of my instrument, untill I finde where London is written, for when the Moone commeth upon that point of the Compasse, it will then be full Sea at London: therfore I place the index of the Moone vpon the same point, which I finde to be Southwest or Northeast, there holding the index not to be moued, then I turne the index of the Sunne untill I bring the twelfth daye of the Moones age to the Index of the Moone, and then the index of the Sunne sheweth me that at 12 of the clocke 36. minutes past, it is full Sea at London, the Moone being 12. daies olde.

² See Pl. L.III.
By the introduction of the multi-transversary cross-staff greater accuracy of observation was made possible, for the different scales could be made very much larger than for the single transversary designed to cover as wide a range of observations as possible. It also made possible the elimination of eye parallax, as Davis explained. On the other hand the additional transversaries meant more equipment and expense and, perhaps for this reason, where in the second book of the Seamans Secrets Davis illustrated the method of graduating a cross-staff, he selected one with a single transversary and sliding sight vanes. Such a staff had been first shown (without an explanation of how to graduate it) by Bourne twenty years earlier. In Davis's model the staff was graduated from 90° to 30°, the transversary from 30° downwards. His explanation of how to graduate it was perfectly clear. Its disadvantage was that, unlike the multi-transversary cross-staff, it afforded no means of avoiding eye parallax. With that instrument parallax could be avoided by taking the staff and fitting two crosses, say, the 60° and 30° ones, to it, the 60° cross at its 30° mark and the 30° cross at its 30° mark. The navigator had then two crosses of different lengths but both measuring an angle of 30°. If then the staff was set 'to your Eye, moving it from place to place about your Eye, until at one instant you may see the ends of both Crosses', the navigator knew he had no parallax and that he had therefore found the correct spot on his check-bone on which to rest the eye-end of the cross-staff. 'Which', continued Davis, 'when you find, remember ... for so must your staff be placed, and your Body ordered in all your Observations.' On the heaving deck of a 50-ton bark in mid-Atlantic the navigator had indeed need to be skilful and well practised if he were to have confidence in his sights.

Although Davis showed the means by which to avoid parallax, the error evidently worried him. Indeed the whole problem of sun sights exercised his mind. Because of the length and brightness of the nights in high latitudes in summer time star sights were impracticable, only sun sights could be taken. Hence their importance. It will probably never be possible to prove that Hood’s cross-staff gave Davis the idea of his back-staff. Indeed the boot may have been upon the other foot, since Davis’s northern navigations almost coincided with the starting of Hood’s lectures. However that may be, Davis eliminated the possibility of parallax and the handicap of glare in sun sights and the supreme difficulty of sighting simultaneously two widely separated objects, such as the sun and the horizon, by devising a back-staff of great simplicity. It consisted of a graduated staff, a half-cross in the shape of an arc of a circle of the radius of the staff with a fixed vane, and a brass horizon vane with a slit in it at the fore-end of the staff. Laying the staff on his shoulder, standing with his back to the sun, the horizon vane pointed at the horizon, the observer slid the half-cross backwards or forwards until the shadow of its vane fell across the slit in the horizon vane at the very moment that the horizon itself was visible through the slit. Thus the observer had to look at only one point in the sky, the horizon, and that away from the sun, and yet he observed the sun’s altitude and the
horizon simultaneously. Moreover, as the graduations ran only from 15° to 45° he could read the result off very accurately. It was simplicity itself.\(^1\)

Apparently Davis improved his back-staff as a result of his attempted voyage to California via the Strait of Magellan. On such a voyage a back-staff with graduations up to 45° could have been of only limited use; he therefore devised an improved version. This also he illustrated in the *Seamans Secrets*, but he did not describe it in detail. With this back-staff, observations of up to 90° altitude were possible. It had two half-crosses. The upper one, with a shadow vane, was the chord of a circle, the lower one, in the form of an arc of a circle, was graduated and fitted with a sliding sight vane. In use, the shadow vane was first adjusted approximately, and then the sight vane precisely. One of the great features of this back-staff was that it could be used in equatorial waters, where hitherto the navigator, because of the limitations of the cross-staff, had often been forced to rely upon the unstable astrolabe. This back-staff of Davis's was only 3 feet long, the longest transversary only 14 inches in length, yet both degrees and minutes were engraved clearly.\(^2\) With only a few structural modifications it was to remain in popular use for two centuries and not begin to be displaced by any other until in the 1730s an efficient reflecting quadrant was devised.

In devoting half his book to plane sailing, navigation using the plane chart, John Davis was fully conscious of the errors of the plane chart and of their causes. However, he considered the use of the plane chart deserved great attention, as 'for the coasting of any shore, or Country, or for short voyages, there was no Instrument more convenient'. Indeed in theory the plane chart, provided the pilot went out and returned by the same course, was as good on long voyages as on short ones. It was just there, however, that the difficulty lay: no pilot making a long sea voyage ever did return by the same course as he went out on, or by one anything like it. As the long sea routes were dictated by the wind systems and sailing qualities of the ships, the rule in the North Atlantic was, as we have seen, 'out with the trades'—down the eastern and across to the southern part of the North Atlantic—and 'home with the westerlies'—up the western and across the northern part. In short the outward and homeward courses were far from reciprocal. Nevertheless, a thorough grasp of plane sailing made other forms easier to understand and to practise.

Before going on to consider what Davis had to say of the other forms of sailing, we should remark that he included in the *Seamans Secrets* 'a particular sea chart of our Channel commonly called the Sleve', though no copy of this chart has survived, on which to practise the exercises he had given. It was evidently for use at sea too, because it was, he said, 'an Instrument most commodious and necessary for all such as seek the Channel coming out of the Sea'. Much of it was based on his own surveys—the Scillies, for instance, of which, detained by contrary winds in '85, he had

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\(^1\) See Pl. LIV.  
\(^2\) See Pl. L.V.
described 'the situation of all the lands, rocks, and harbours to the exact use of Navigation', with a 'scale thereunto convenient'. The rest was from surveys by other expert pilots. He claimed for it that with its aid and by the 'altitude' and 'depth' he had at no time missed 'the true notice of his Ships being', and had ever made his landfalls 'without terror'. In the absence of any surviving charts by Davis, the contemporary plane one of the Soundings and Sve by Hood is of particular interest.

Davis proceeded next to make known the use of the globe. Despite Hood's and Hues's treatises on the use of the celestial and terrestrial globes, John Davis's brief sketch of the use of the terrestrial globe by seamen was outstanding, probably because he was the only one of the three who was a professional navigator. Davis was indeed the first English professional navigator to write on the art of navigation at all—Borough's pamphlet had been on only one aspect of navigation.

'The use of the Globe is of so great ease, certainty, and pleasure', wrote Davis, 'as that the commendation thereof cannot sufficiently be expressed.' This was because of all instruments it alone gave accurately the true distance and angle between places, the circular motion of any course or traverse, and the latitude and longitude of positions. Distance was measured on the globe, he explained, by the aid of 'a pair of circular compasses', that is compasses with curved legs and not the straight legs of the type used for pricking the chart, and the courses from place to place were ascertained by the movable and flexible quarta altitudo in conjunction with the winds of the compass marked on the horizon ring. This latter point Hues had made, but it was in his amplification of it that Davis showed his skill and knowledge of the navigator's needs. He went on to explain what Bourne had baldly stated, that the secret of navigating by means of the terrestrial globe lay in 'rectifying the globe', that is to say in adjusting it to the ship's position. This consisted in adjusting the elevation of the pole so as to correspond with the ship's latitude and then rotating the globe until the meridian corresponding to the ship's longitude was under the fixed meridian ring. This brought the ship's position on to the highest point on the surface of the globe, the zenith. The globe thus rectified, the bearing of a place from the ship's position was ascertained by moving the sliding end of the quarta altitudo until it was over the ship's position at the zenith. With the sliding end held here, the flexible 'quarter circle' was then swung round until it passed over the desired position. Where its free end touched the horizon ring it indicated the course or bearing. This much, too, Hues had explained. Where Davis struck a new note was in going on to point out that it was only near the ship's position, near the zenith, on the relatively plane upper surface of the globe that this bearing indicated the course which, if followed, would lead to the desired position. In other words he explained why plane sailing could be practised successfully only over short distances. He showed that the bearing could not be the navigable course to a distant position, by explaining how to trace out on the globe the track of a ship steering a given course over a long distance. He cited the example
of a ship steering a course of north-west, and showed how, by rectifying the globe after every 20 or 30 leagues of sailing on this course, the resultant track was a spiral line which passed north of the desired position. A navigator who practised such sailing was, he said, practising paradoxal sailing. Paradoxal sailing could be used for places up to 45° apart without great error, but for places farther apart, explained Davis, great circle sailing had to be practised for the best results. This was because great circle sailing enabled the navigator to steer his ship along the shortest route between two places, a fact whose demonstration on the globe he then expounded. Great circle sailing differed from paradoxal sailing in that, after each rectification of the globe the *quarta altitudo*, too, was rectified, by positioning it over the new zenith, and a new course was steered, the course indicated by the free end of the flexible ‘quarter circle’ after its realignment with the point of destination. The result of steering such a succession of courses was that the ship’s track, when pricked off on the globe, approximated very closely to a great circle. Because of the novelty of the method Davis was very careful to stress that the navigator attempting great circle sailing must strenuously resist the temptation to follow a course which the wind direction at the time made apparently more favourable.

It was because the navigator or student of navigation, by following on the globe the description of plane sailing, paradoxal sailing, and great circle sailing, could ‘manifestly understand the difference of Horizontal, Paradoxal, and Great Circle Navigation’ that Davis held the globe in such esteem. It was the only instrument by manipulation of which enlightenment could so easily follow. One of the chief merits of the Molyneux globes was that their large size made them particularly suitable for instruction, and made it possible for the navigator to find his latitude with a tolerable degree of accuracy by a variety of sun or star sights, besides the usual meridian altitude ones. The fact that Davis described how to find latitude by the simple manipulation of the globe, by observation of the sun’s rising or setting, by its elevation on any bearing, by two observed azimuths and altitudes regardless of variation, by two sun-sights and the difference of time between them, by the known fixed stars observed on the horizon, or even one on the horizon at any time, indicate that such methods were now on occasion practised. It must be remarked, however, that the journals of these times that have survived do not record such observations. Their accuracy depended in great part upon the correct calculation of declination. This in turn depended upon the conversion into time of the difference in longitude between the ship’s position and the meridian for which the declination tables were calculated, a problem skated over so far by all the manuals. Bourne, it will be recollected, had originally stated that his declination tables would do for most navigations as far as the West Indies. In his revised edition he had not been very much clearer on the question of correcting ephemerides for difference of longitude. We must conclude then that, although Davis claimed to have confined his
The Seamans Secrets.

How is the use of this Staff?

The use of this Staff is altogether contrary to the other, for the center of this Staff where the brass plate is fastned, must be turned to that part of the horizon which is from the Sun, and with your back toward the Sun, by the lower edge of the half cross, and through the slit of the plate you must direct your sight only to the Horizon, and then moving the Cranibary as occasion requireth, until the shadow of your upper edge of the Cranibary do fall directly upon the same slit or long hole, and also at the same instant you see the horizon through the slit, and then the Cranibary sheweth the height desired.

LIV. Captain John Davis's 45 Back-staff of 1595.
The Seaman's Secrets:

Early placing of the Staff to the eye, which demonstration I have found, and have had the Instrument in practice, always under the Sun, as in other Climates, but because it hath a large demonstration, with manifest use, I here omit to manifest the same, purposing to write a particular Treatise thereof, notwithstanding his form and use, by picture I have thought good to express.

This Staff is a yard long, having two half crosses, the one circular, the other square, the longest not 14 inches, yet the Staff both contain the whole 90 degrees, the shortest degree being an inch and a half, whereas the minutes are particularly very sensibly laid down, by which Staff not regarding the parallel of your sight, nor looking upon the Sun, but only upon the Horizon, the Sun's height is most precisely known, as well and as easily in the Zenith, as in any other part of the heaven. As which Instrument (in my opinion) the Seaman shall not find any short, and in all Climates of so great certainty, the Invention and demonstration whereof I may boldly challenge to appertain unto myself (as a portion of the Talent which God hath bestowed upon me), I hope without a bane or offence to any.

LV. Captain Davis's 90° Back-staff or Quadrant of 1595.
LVI(a). Horizontal Plane Sphere by Humphrey Cole, 1574.
LVI(b). Armillary Sphere by Humphrey Cole, 1582.
subject-matter to practical methods, these other celestial observations, while recognized as theoretically possible, were rarely practised. The problem of longitude-finding was in itself a serious deterrent.

It will be recalled that the instruments John Davis considered necessary for a skilled mariner included an instrument for finding the variation of the compass, an 'Horizontal plain Sphere', for coastal survey work, and 'a Paradoxal Compass'. What was a paradoxal compass, and for what was it used? Dr. John Dee made several obscure references to it in his writings, claiming to have been its inventor. Of other writers on navigation up to this time only John Davis mentions it and he nowhere describes it, so that the paradoxal compass wears an aura of mystery. It is no coincidence that only Dee and Davis mention it. Both were interested in navigation in high latitudes and Davis was the pupil of Dee. Now it was for navigation in northern waters—for use on the voyage to Cathay via the North-East Passage—that, in 1552 or 1553, Dr. Dee had designed 'the Paradoxal Compass in playne'. In The Seamans Secrets John Davis had promised to publish a paradoxal chart 'with all convenient speed', together with an explanation of its use (he never did) on the grounds that 'it will best serve the Seaman's purpose, being an instrument portable, of easie stowage and small practise performing the practises of navigation as largely and as beneficially as the Globe'. Richard Polter, whose Pathway to Perfect Sayling will be discussed in the next chapter, makes it clear that the paradoxal compass and the paradoxal chart were one and the same 'instruments', namely a circumpolar chart. Thus a paradoxal compass was a chart constructed on what is today known as the zenithal equidistant projection, which is as much as to say that it gave a bird's-eye view of the world from above one or other of the poles. This projection has the virtue of involving decreasing distortion of the land areas in the higher latitudes. This is at once evident if the polar areas of a globe are visualized. On such a chart the pole is at the centre and the meridians are drawn as straight lines radiating from it. Generally every tenth or fifteenth meridian is shown. The parallels of latitude are represented as equally spaced con-

1 See Pl. LVI(a).
2 In connexion with these and in particular Dee's references in The British Complement of the Perfect Art of Navigation, London (1577), it is to be noted that Anthony Linton in Newes of the Complement of the Art of Navigation, London (1609), quotes on p. 12: Sir Humphrey Gilbert Knight, who saith of himselfe in these words, viz. 'I haue deuised to amend the errors of vsuall sea Chards, whose common fault is to make the degrees of Longitude in euery Latitude of one like bignesse. And haue also deuised therein a spherick Instrument, with a Compasse of variation, for the perfect knowing of the Longitude'.

Nordenskiöld, A. E., Facsimile Atlas (1889) p. 94, cites the Ptolemy edition of 1463 as being on this projection.

centric circles, every 5°–10° apart, centred upon the pole. The chart generally extends to 50° N latitude. Indeed the chart Dr. Dee drew for Sir Humphrey Gilbert in 1582 has survived and is just such a chart.¹ The chart that Captain Luke Fox carried on his voyage in search of the North-West Passage in 1631 is identical (apart from errors and omissions in the delimitation of the coastlines) with the British Admiralty’s modern chart of northern waters drawn on the zenithal equidistant projection. Dee probably called the chart a ‘compass’ because when drawn to cover all the polar regions the chart was circular, and the meridians radiated like the rhumb lines on a compass-fly; he evidently called it a ‘paradoxal’ compass because of the paradox that an apparently straight rhumb line on a plane chart becomes a spiral line winding towards the pole when pricked off on a circumpolar chart—Frobisher, it will be recalled, carried several ‘charts with spiral lines’ on his first voyage to the north-west in 1576. Doubtless Dr. Dee had drawn them too. The projection appears to have been first used in the late fifteenth century in a reproduction of Ptolemy’s maps. But in adapting charts to it Dr. Dee claimed to have been original. Perhaps, pondering the problem of drawing charts for the use of the navigators on their intended voyage of 1553 over the roof of the world to Cathay, and contemplating the while one of Mercator’s terrestrial globes that he had brought back from the Continent in 1547, Dee suddenly perceived that a circumpolar chart of the northern region would be indistinguishable from the circumpolar gore that Mercator had designed to cover the polar region on his terrestrial globe. However that may be, Portugese and Spanish hydrographers, faced with the problem of producing


Hence the date of Dee’s invention of the paradoxal compass (circumpolar chart) must have been 1552 or 1553, that is, in time for the first Muscovy voyage (1553), for which it was probably designed. In the Advertisement to the Reader he refers to its invention as ‘now, aboue, 20 yere sins’, and adds in a marginal note that ‘M. Steuen and M. William Borough, two of the chief Moscovy Pilots (after the incomparable M. Richard Chancellor his death) can be sufficient witnesses, also’. The work is actually a long and closely reasoned thesis on the need for a Royal Navy.

See Part I, Chapter 2, for Mercator’s originality in devising circular gores for his terrestrial globe of 1547.

For details of the Muscovy trade see Willan, T. S., ‘Trade between England and Russia in the second half of the Sixteenth Century’, E.H.R. Vol. 63. This comprises an interesting account of the variety, value and volume of the Muscovy Company’s fleets (1553–1603), and recounts the company’s Baltic trade to Narva, between the years that it was a Russian port, 1558–81. The ships sailed from England in April–June, and returned in September–November. See also Wretts-Smith, W., ‘The English in Russia during the second half of the Sixteenth Century’, Transactions of the Royal Historical Society, 4th Ser., iii, where it is shown that the importance of this trade was such that ‘the fleet that defeated the Spanish Armada was largely rigged with Russian cordage and cables’.
practical navigational charts of high latitudes in the southern hemisphere for Magellan's voyage of 1519-22 around the world, had found the solution in the circumpolar chart. Thus, in fact, but almost certainly unknown to Dr. Dee, because of the veil of secrecy over such matters, his invention had been anticipated by more than thirty years. The paradoxical chart alone made confident navigation in high latitudes possible. The gross distortions of the coastline in plane charts covering these high latitudes made them virtually useless for navigation over large distances out of sight of land, and on exploratory voyages such as Chancellor's, Frobisher's, and Davis's; as for globes, their small size—Mercator's was the largest available—rendered them equally impractical for navigational plotting.

Owing to the radiating meridians of the paradoxal chart it was impracticable to draw in geometrically a comprehensive system of mother and satellite compasses with radiating and intersecting spiral rhumb lines for course-finding. Whereas on the plane chart with its network of apparently straight rhumb lines the navigator could do all his chart work quite satisfactorily with two simple two-legged compasses, on the paradoxal chart he could rarely do more with them than lay off distances. If, for instance, the navigator drew on a paradoxal chart with the aid of a piece of string a straight line from Kinnairds Head in north-east Scotland, in a direction of N 25° E, it ran roughly parallel with the north-west coast of Norway, then across the Barents Sea and just north of Novaya Zemlya. Yet being to all intents and purposes a great circle, it crossed successive meridians at different angles. How, without rhumb lines on the chart, could the navigator determine the angles? How could he when bound, say, for the White Sea, and wishing to follow this track, find what courses he would have to steer to keep on it? Or, if he was bound for Spitzbergen, how could he plot the one course which, if followed without alteration from Kinnairds Head, would lead him there when every meridian was at a different angle from its neighbour and there was no convenient network of rhumb lines for ascertaining direction? He could do so by using the radiating meridians as the rhumb lines of a compass centred on the pole, and if he had sufficient geometrical skill, use them as a means of finding or plotting the course angle in terms of degrees and not of points or winds, or he could use a protractor. This is what Dr. Dee, in fact, taught. He designed a 'New Sea Compass', graduated peripherally with a scale of degrees as well as of the rhumbs of the wind, for use with the chart, and also prepared a Canon Gubernaticus: An Arithmetical Resolution of the Paradoxall Compass for calculating differences of latitude and of longitude and for plotting rhumbs on the chart.

What brought the paradoxal chart into much more general use in the seventeenth century was the publication at the end of Elizabeth I's reign of the invention of the protractor for measuring angles, and of tables akin to

1 See Destombes, M., 'The Chart of Magellan', Imago Mundi, Vol. 12. where the chart is reproduced.
2 See Pl. LVII, and Appendix 8B.
those of Dr. Dee for plotting the spiral rhumb lines. The tables made it possible to plot the ship's track, the protracter to measure her course by inspection. Both English inventions heralded the advent of a new form of navigation. Dr. Dee's 'Paradoxal Compas' continues in use to this day for navigation in arctic waters, a fact which emphasizes further the extreme importance in maritime history of the expedition of 1553, and the scrupulous and inspired care with which it was planned and prepared. Of the new navigation Davis wrote, in The Seamans Secrets: 'All these practises of sayling before mentioned, may in a general name be aptly called Navigation Geometrical, because it wholly consisteth of geometrical demonstrative conclusions'—the emphasis that all the teachers and writers on navigation laid on geometry will be recalled—'but there is another knowledge of Navigation which sweet skill of sayling may well be called Navigation Arithmetical, because it wholly consisteth of calculations... distinguishing corses... upon every degree of the horizon and... the distance of any Traverse for any particular elevation... it giveth longitudes and latitudes to the minute... and... every particular distinction of any alteration whatsoever, that may in Navigation be required to a most wonderful precise certainty....'

As yet, however, the labours of arithmetical calculation, as Hues had explained, ruled out arithmetical navigation as a practical method. Davis could only recount its possibilities and its perfections. Yet, within thirty years Scottish and English mathematicians were to devise the means whereby it could be practised by all and sundry with the merest smattering of arithmetical knowledge and skill.

To Thomas Blundeville, a country gentleman of Norfolk and an enthusiastic student of mathematics, astronomy, and navigation, appears to go the distinction of devising the protracter. In 1589 he published A Brieve Description of Universal Mappes and Cardes, and of their use, in the course of which he wrote:

for mine owne part, having to seeke out, in these latter Maps, the way by sea or land to any place I would use none other instrument of direction then half a Circle divided with lines like a Mariner's Flie. Truly, I do thinke the use of this flie a more easie and speedy way of direction, then the manifold tracing of the Maps or Mariners Cards, with such a number of crosse lines, as commonly are drawn therein...

His illustration showed the half-circle engraved with rhumbs of which the middle one was marked with a cross to indicate either east or west. Apart from this invention, that Blundeville was a man of great mental

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capacity as well as of some originality was proved by his production, in 1594, of a fat quarto volume of 350 pages entitled: Mr Blundeville His Exercises . . . verie necessarie to be read and learned of all young Gentlemen that . . . are . . . desirous to haue knowledge as well in Cosmographie, Astronomie, and Geographie, as also in the Arte of Navigation.¹ That it met a need was shown by the appearance of a second edition, 'corrected and augmented by the author' only three years later, by that of a third in 1606 and a fourth in 1613, the eighth and last, appearing in 1638.²

Blundeville's Exercises have a triple interest. They consist of a series of treatises on the mathematical, astronomical, and navigational knowledge necessary for a young man wishing to master fully the art of navigation as practised in the closing years of Elizabeth I's long reign. Besides some

¹ M. BLUNDEVILE His Exercises, containing sixe Treatises (1594). The full title is given on p. 57.

The list of the six treatises contained in the book is as follows:

First, a verie easie Arithmeticke so plainlie written as any man of a mean capacitie may easilie learn the same without the helpe of any teacher.

Item the first principles of Cosmographie, and especially a plaine treatise of the Sphære, representing the shape of the whole world, together with the chieftest and most necessarie vses of the said Sphære.

Item a plaine and full description of both the Globes, as well Terrestriall as Celestiall, and all the chieftest and most necessarie vses of the same, in the end whereof are set downe the chieftest vses of the Ephemerides of Iohannes Stadins, and of certaine necessarie Tables therein contained for the better finding out of the true place of the Sunne and Moone, and of all the rest of the Planets upon the Celestiall Globe.

Item a plaine and full description of Petrus Plancius his vnuersall Mappe, lately set forth in the yeare of our Lord 1592, containing more places newly found, aswell in the East and West Indies, as also towards the North Pole, which no other Map made heretofore hath, wherevnto is also added how to find out the true distance betwixt anie two places on the land or sea, their longitudes and latitudes being first knowne, and thereby you may correct the skales or Tronkes that be not trullie set downe in anie Map or Carde.

Item, A briefe and plaine description of M. Blagraue his Astrolabe, otherwise called the Mathematicall Jewell, shewing the most necessarie vses thereof, and meetest for sea men to know.

Item the first & chiepest principles of Navigation more plainlie and more orderly taught than they haue bene herebefore by some that haue written thereof, lately collected out of the best modern writers, and treaters of that Arte.

² M. BLUNDEVILE His Exercises, containing eight Treatises, the titles wherof are set downe in the next printed page: which Treatises are verie necessarie to be read and learned of all young Gentlemen that have not been exercised in such disciplines, and yet are desirous to haue knowledge as well in Cosmographie, Astronomie, and Geographie, as also in the Arte of Navigation, in which Arte it is impossible to profite without the helpe of these, or such like instructions. To the furtherance of which Arte of Navigation, the said M. Blundeuile speciallie wroate the said Treatises and of meere good will doth Dedicate the same to all the young Gentlemen of this Realme.

The second edition, Corrected and augmented by the Author.

Imprinted at London by John Windet, dwelling at the signe of the Crosse Keyes, neere Paules Wharffe, and are there to be solde. 1597.

The two additional treatises were: 'a briefe description of vniersall Maps & Cardes', and 'the true order of making Ptolomie his Tables'.

original contributions of his own to the art of navigation, Blundeville in his treatise was the first Englishman to describe the use of the tables of the three trigonometrical functions—sine, tangent, and secant—calculated at the close of the fifteenth century by Peuerbach and Regiomontanus to facilitate astronomical calculations, and included in the Exercises.¹ The culminating treatise, of Navigation, What it is, and in what order the Principles there of are, was a compendium of the art of navigation 'according to the Rules of [the] best moderne writers in that Art'.² Blundeville studied all—Cortes, Medina, Bourne, Norman, Borough, Coignet, Hood—and then composed this treatise touching on every aspect of the art. He drew freely upon the works of the various writers for definitions, illustrations, examples, and tables, and thus presented to the student an authoritative and up-to-date synthesis of the theories and practices of the art of navigation in the 1590s. Only occasionally did Blundeville contribute original material of his own, as when he observes that though 'broad' astrolabes are truer, yet they offer too wide an area to the force of the wind: the 'narrow and weighty' astrolabes of the Spaniards are to be preferred.³ Another of his original contributions is the suggestion that an indexed tide-table to serve for all places might be compiled: in other words he envisaged tide-tables on modern lines, which were not to appear until the nineteenth century.

By drawing upon Coignet's treatise of 1581, Blundeville brought before his readers one of the latest continental manuals on navigation, and he

¹ Since tables had existed in ancient times but they were extremely tedious to use, being based on the ratio between the diameter and the chord of a circle, and involving the use of astronomical fractions. Those calculated by Peuerbach (1423–61) and his pupil Regiomontanus (1436–76), Professors of Astronomy at Vienna, were based on the relation between the semi-diameter and half-chord of a circle and avoided the use of astronomical fractions. Their work and that of continental scholars in the sixteenth century resulted in the simple tables of natural sines, natural tangents, and natural secants that Blundeville reproduced, which are in common use today.

² A new and necessarie Treatise of Navigation containing all the chiefest principles of that Arte. Lately collected out of the best Moderne writers thereof by M. Blundevile, and by him reduced into such a plaine and orderly forme of teaching as every man of a meane capacitie may easily vnderstand the same. They that goe downe to the Sea in ships, and occupie their busines in great waters: These men see the worikes of the Lord and his wonders in the deepe. Psalm. 107.

³ Last treatise in first edition (1594) of Blundeville's Exercises.

'Of sea-astrolabes Blundeville observed: 'broad Astrolabies, though they be thereby the truer, yet for that they are subject to the force of the wind, are nothing meet to take the Altitude . . . vpon the sea, wherefore the Spaniards do commonly make their Astrolabies or rings narrow and weighty, which for the most part are not much above five inches broad and yet do weigh at least foure pound, and to that end the lower part is made a great deale thicker than the vpper part towards the ring or handle. Notwithstanding most of our English Pilots that bee skilfull, make their Sea Astrolabes or rings six or seuen inches broad, and therewith very massie and heauie, not easie to be moued with euerie wind, in which the spaces of the degrees be the larger, and thereby the truer.'
extracted from it much interesting material, including a nocturnal, or 'Rectifier of the North Star' which combined the means of finding the time by the guards with the means of finding the 'rule of the North Star'; an illustration of the true nature of a rhumb line; and another of the theory of longitude-finding by variation based on the assumption that variation on any given meridian had a constant value.¹

Besides the 'chiefest Principles of Navigation' Blundeville's *Exercises* comprised a simple arithmetic; the use of the sphere; a full description of Mercator's celestial and terrestrial globes, with notes on the differences between them and Molyneux's; the use of Johannes Stadius's ephemerides; a full description of Peter Plancius's world map of 1592; and the description of Blagreave's astronomical astrolabe, *The Mathematicall Jewel* (already referred to). In addition to the foregoing Blundeville included his 'briefe description of universall Maps and Cards'; and directions how to construct maps on various projections. The geometrical tables already mentioned were printed as an appendix to his arithmetic.

It was at the end of the chapter describing the method of laying down latitude, longitude, and distance scales in 'the Mariners Card drawn after the old manner' that Blundeville developed the hint in the chapter heading that there was a 'new manner' of drawing charts, one designed to do away with the grave faults of the old one. Mercator, in his world map, 'made the spaces of the Parallels of Latitude to be wider every one then another from the Equinoctial towards either of the Poles', explained Blundeville, and went on, 'by what Rule I know not unless it be by such a Table, as my friend Master Wright of Caius College in Cambridge at my request sent me (I thank him) not long since, for that purpose, which Table with his consent, I have heere plainly set downe together with the use thereof'. And then followed the first printed table of meridional parts (at 1° intervals) to enable the parallels in the mariner's card to be drawn 'in truer sort than they have beeene drawne heretofore', and the first explanation of how to use it so as to produce a chart on 'Mercator's projection', the projection chiefly used to this day for all navigation between the polar circles. Blundeville's explanation, however, was too brief, for it would seem that little if any practical attention was paid to this novel projection at the time by navigators.

Hood's 1596 edition of Bourne's *Regiment* was appropriately matched by a new edition in the same year of the *Arte of Navigation*.² Since its first

¹ See Pls. XX(a), XXI and XXIV.

² THE ARTE OF NAVIGATION Contayning a breife description of the Spheare, with the partes and Circles of the same: as also the making and vse of certaine Instrumentes. Very necessarie for all sortes of Sea-men to vnderstand. First written in Spanish by Martin Curtis, and translated into English by Richard Eden: and lastly corrected and augmented, with a Regiment or Table of declination, and divers other necessary tables and rules of common Nauigation. Calculated (this yeare 1596. being leap yeare) by J.T. Imprinted at London by Edw. Allde for Hugh Astley, by the assignes of Richard Watkins, and are to be solde at Sainct Magnus corner. 1596.
publication in 1561 it had been reprinted in its original form five times. It is indicative of the growth of navigation in England that, while eleven years had elapsed before the second edition had been needed, no less than four editions had been called for between 1579 and 1589, and an up-to-date edition was now needed; the examples, for instance, were still for the year 1545. John Tapp, who re-edited the book in 1596, omitted Cortes’s and Eden’s Prefaces, and explained the changes he had made. These included the addition of a new declination table for the sun in the Medina-Bourne manner for a twenty-year period (1596–1615), and an almanac of movable feasts good until 1629, revised examples for the year 1596, and the amplification of the chapter on tides by drawings for a horizontal tide-table. Cortes’s descriptions and definitions of the various tides, as the clearest hitherto, were reprinted unchanged. In the conjunctions and oppositions [the periods of the new and full moon when the moon is between the earth and the sun, and the earth is between the moon and the sun, respectively] they increase and decrease much, which the mariners call high spring tides’, he explained, adding: ‘the greatest increase of all they call the high springs’. (These occur during March and September at the equinoxes when the sun and the moon have no declination. They are now known as equinoctial tides. Solstitial tides, which occur in June and December, are the lowest spring tides.) ‘In the quarters of the moone [when the moon is in quadrature] they increase and decrease but little’, he continued, ‘which the mariners call nepe tides, lowe water, dead water, or lowe floodes’ (these occur about seven days from new and full moon). Like the Regiment, the Arte of Navigation continued in current use into the middle of the seventeenth century, for in each subsequent edition Tapp brought the ephemerides and examples up-to-date.

In 1597 the new chart projection was again briefly illustrated in a book. This was Barlow’s The Navigators Supply—a book mentioned in an earlier chapter in connection with the compass, and one which dealt with other important navigational matters.

1 John Tap’s Preface to his 1630 edition of Cortes, of which the title-page is as follows:
THE ART OF NAVIGATION. First, written in the Spanish Tongue by that Excellent Marriner and Mathematician of these times, MARTINE CURTIS. From thence Translated into English by RICHARD EDEN: And now newly Corrected and enlarged with many necessary Tables, Rules, and Instructions, for the more easie attaining to the knowledge of Navigation. By IOHN TAP. London. Printed by B.A. and T. Fawcet, for J. Tap. 1630.

2 THE NAVIGATORS SVPPLY. Containing many things of principall importane belonging to Navigation, with the description and use of diverse Instruments framed chiefly for that purpose; but serving also for sundry other of Cosmography in general: the particular Instruments are specified on the next Page.

Below is a reproduction of the instrument called ‘the Travellers’ Jewel’, with the following sentences to the right: If any man desire more ample instruction concerninge the use of these instruments, hee may repayre vnto John Goodwin
William Barlow held ecclesiastical preferments successively at Winchester and Salisbury. In *The Navigators Supply* he declared that as a young man he abhorred the sea. However, learning that navigation was grounded upon mathematics, little by little he perfected himself in these arts, conferring often 'with some of the skilfullest Navigators of our land'. He thus learnt their greatest needs and so was able to invent instruments to meet them. He wrote *The Navigators Supply* to describe his inventions. Barlow was later to be one of the tutors to the young prince Henry, heir to the throne, when James I succeeded Elizabeth I, and was to make with Gilbert, who died in 1603, many advances in the study of magnetism.

*The Navigators Supply* treated of the compass in general, the compass of variation, the Traveller's Jewel, the pantometer, the hemisphere, the traverse board, and ended with 'a friendly advertisement to the Navigators of England'. The work was dedicated to the Earl of Essex. Concerning the compass, Barlow's description was clearly a paraphrase of Cortes's, yet we can believe the compass was but little if at all changed since Cortes's time, because, referring to the 'errors that dayly are committed in the making and framing' of it, Barlow specifically said, 'Let no man mistake me; I speake not save onely of ordinarie Compasses (being the most that ever I saw) such as are in common use, and are sale-ware for Masters.' It is comforting to learn that although the English made compasses so badly, 'their staves and Sea Cardes were neate and fine and their Astrolabes tolerable'. Surviving examples of these instruments certainly come up to this standard, so they can be taken as typical.

Barlow was not content with finding fault in the compass. He devised a better model with well-made needles, flattened on the fly side, and with a capital that screwed on and held the wires in place, so that removal of the fly for examination, and for cleaning and retouching the needle, was easy. This operation was very necessary if the compass was to give reliable service. Not only did the ordinary needle, being of iron, lose its magnetism in course of time but it was liable to become rusty and so to discolour the fly. The latter, being of paper, was prone to warping. If it warped, it became unbalanced. It is true that the form of the compass needle was designed to prevent this, its length giving rigidity to the north-south axis of the fly and its breadth (through the double-bowing of the wire) rigidity to the east-west axis, but the limited support given along this axis could and often did result in warping. Only in compasses with a fixed fly and in
dwelling in Bucklersburyte teacher of the grounds of these artes. The instruments are made by Charles Whitwell, over agaynst Essex houwse, maker of all sortes of mathematicall instruments, and the graver of these portraytures.

Under the reproduction appears a verse from the 107th Psalm:

'They that goe down to the Sea in Ships, and employ their labour in the great waters, They see the Workes of the Lord, and his wonders in the depe. Psalm. 107.'

Attention may be drawn to this very early advertisement of navigational instruments.

18—A.O.N.
instruments of variation and other instruments embodying a visible needle was the plain arrow-shaped compass needle to be found.

Barlow’s mariner’s compass was on the lines of his compass of variation. The latter was a great improvement on the instruments which Norman and Borough had devised for finding variation. Indeed Barlow’s model remained in use virtually unchanged up to the nineteenth century. This was no doubt in part because it could also be used, as Barlow was careful to point out, for taking bearings of ships and of objects on shore. Barlow’s compass appears to be the first devised for common use at sea with a verge ring for taking accurate bearings.¹

Amongst the information Barlow gave on compasses was that to overcome dip the compass-makers now made the needle’s pivotal point ahead of the centre. This they did by filing down the needle after touching. When the north end of the fly tipped up it was, he explained, the sign that, provided the compass had been made in the locality, the needles needed retouching.

The Traveller’s Jewel, the hemisphere, and the pantometer, which Barlow described and illustrated, had been devised more for general use than for strictly navigational purposes. The Traveller’s Jewel was really a small variation compass with the addition of a quadrant by means of which the sight could be set to the latitude and, as a result, the time of day be found. It was the equivalent of a universal equinoctial dial. The pantometer was chiefly devised for finding the variation on land, although it could equally well serve for surveying generally; while the hemisphere was to all intents a portable skeleton globe on whose graduated brass circles and plates the solution of problems of time, altitude, declination, latitude, etc., could be found as easily as on a globe.

Barlow’s compass, with its improved needle mounting, its verge ring and its sight bar, marked a definite step forward in the art of navigation. Linked with the compass were his traverse board, plotting ruler, and plotting quadrant.² These he had invented for enabling the ship’s position to be plotted independently of a chart. Barlow’s traverse board, which he described and illustrated in detail, seems to have been the first example of a plotting board, complete with appropriately scaled edges, ruler, and quadrant or protractor, ever devised. With ‘a faire sheet of large paper’ such a plotting board, until the automatic pilot came into general use recently, was constantly used at sea, particularly in warships. Barlow’s description of how, after plotting the various traverses, the navigator transferred his position from the board to the chart, has a quite familiar ring. It was Barlow who first published for the navigator descriptions of the instruments necessary to enable him to follow out John Davis’s advice on plotting.

In the course of his ‘friendly advertisement’ Barlow described the three principal map and chart projections in use, though his paradoxical charts

¹ See Pl. VI. ² See Fig. 20.
were of two kinds. One had the degrees of latitude larger near the Equator than near the pole;\textsuperscript{1} in the other the reverse applied.\textsuperscript{2} He did not describe the intermediate projection which in practice navigators used—the zenithal equidistant one. This, however, does not rob of its value his explanation of how upon such charts, by means of his quadrant, ‘it is a verie easie matter to describe the spirall line of a shippes course . . . with a thinne

\begin{center}
\includegraphics[width=0.5\textwidth]{quadrant}
\end{center}

\textit{Fig. 20}

\textbf{WILLIAM BARLOW’S BRASS QUADRANT OR PROTRACTOR}

(After the drawing in William Barlow’s \textit{The Navigators Supply}, 1597)

It is divided into the rhumbs of the winds, and was ‘for the Traverse Boorde and the tracing of a spirall course’, that is a rhumb-line course, on a circumpolar or paradoxal chart.

Ruler moveable upon the Pole or centre of your Carde’. It is the first printed description of the method carried out by the navigators using this type of chart to this day.\textsuperscript{3}

In the last year of the sixteenth century there appeared a book that set the seal on the supremacy of the English in the theory and practice of the art of navigation at this time. It contained a brilliant summary of all the

\textsuperscript{1} Stereographic polar projection.

\textsuperscript{2} Orthographic polar projection.

\textsuperscript{3} It is interesting to find in one of the latest manuals of navigation, namely, Dutton, \textit{Navigation and Nautical Astronomy} (1948), a chapter on polar navigation (Chapter XVIII, Sections 1801–09) that discusses the problems of polar navigation and the advantages and disadvantages of various chart projections such as are described by Barlow. See also Section 116 of the same work, ‘Polar Charts’, p. 13.
chief contemporary practices of navigation together with a critical examination of their faults, and either the actual means for eliminating them or else sound guidance on the measures necessary to do away with them. *Certaine Errors in Navigation* was the work of Edward Wright.\(^1\) Wright has already been mentioned as a mathematician. He had been born in 1558 at Garveston, a Norfolk village, had probably been educated at Hardingham School, and at the age of eighteen had gone up to Cambridge. There he had taken his B.A. in 1580–81, his M.A. in 1584, and from 1587 had held a Fellowship of his college.

In 1589, on the morrow of the Armada, he had been ‘called forth to the public business of the nation, by the Queen’ to help, as a skilled mathematician and cosmographer, in improving the art of navigation. England was going over to the offensive. Wright’s task had been to sail with the Earl of Cumberland on a raiding mission to the Azores (the aim of which had been to intercept the Spanish treasure fleet and ships) and to put his theories on navigation into practice. In the course of the voyage, of which he was the chronicler, Wright had met John Davis, who had joined the expedition for a time, at Fayal.

Although rich prizes were taken, the expedition did not achieve its main objective, and, what was almost worse, instead of the adventurers getting home in time to spend Christmas snugly and convivially in port, as they had planned, they were forced by contrary winds, high seas, and bitter weather to spend miserable weeks at sea, and a cheerless storm-tossed Christmas off Land’s End.

Although militarily the expedition had been disappointing, it was a most pregnant naval operation. The experience Edward Wright had gained on it, in conjunction with his mathematical calculations, had brought so vividly before him the current errors in navigation that he had at once set to work to rectify them. By 1592 he had completed and submitted to the Earl of Cumberland the draft of what was subsequently published as his *Certaine Errors*. Wright’s most important correction, his chart projection, now known as Mercator’s, besides having been published in part by Blundeville in 1594 and again in 1597 by Barlow, both times with permission, had fallen with the rest of his draft into the hands of Abraham Kendall. Kendall had been an extremely competent navigator and was the instructor of the gifted young Robert Dudley, later known as the Duke of Northumberland and the author of an encyclopaedic work on navigation.\(^2\) Kendall, who had piloted Dudley’s expedition of 1594 to Trinidad

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1 Certaine ERRORS IN NAVIGATION, Arising either of the ordinarie erroneous making or vsing of the sea Chart, Compass, Crosse staffe, and Tables of declination of the Sunne, and fixed Starres detected and corrected. By E. W. Printed at London by Valentine Sims. 1599.

2 DELL’ARCANO DEL MARE, DI D. RVBERTO DVDEO DVCA DI NORTVMBRIA E CONTE DI VARVICH, LIBRI SEI; Nel primo de’ quali si tratta della Longitudine praticabile in diversi modi, d’inuizione dell’Autore, Nel Secondo, delle Carte sue generali, e de’ Portolani rettificati in Longitudine, e Latitudine, Nel Terzo, della Disciplina sua Marittima, e Militare. Nel Quarto,
and Guiana, had died with Drake off Porto Bello early in 1596 on the expedition in which both Drake and John Hawkins had met their end. When the expedition had returned, Kendall's manuscript copy of Wright's work had been handed to the Earl of Cumberland for perusal in the belief that it was an original work by Kendall. Wright, to whom the Earl had referred it for critical examination, had promptly identified it as a copy of his own work. While he was bursting with indignation over this plagiarism, Hondius, to whom Wright had shown details of his map projection in the strictest confidence, had published maps of the four known continents on Wright's projection, and without any acknowledgment to Wright. All this had been too much for him; he felt bound to put his material together for publication. Thus it was that in 1599 appeared, together with the narrative of the Earl of Cumberland's voyage of 1589, _Certaine Errors in Navigation, Arising either of . . . erroneous making or using of the Sea Chart, Compasses, Crosse Staffe, and Tables of declination of the Sunne and fixed Stars detected and Corrected_, and dedicated to the Earl.

Wright prefaced his _Certaine Errors_, which he called an application of 'Mathematicall studies to the use of Navigation', with a lengthy introduction to the reader. Besides recounting the various vicissitudes of his work before publication he summarized the errors in navigation observed by him and described and corrected in detail in the body of the work. The sea chart, the best means the mariner had to know the course from place to place, was so faulty in the geometrical lineaments of the meridians, parallels, and rhumbs, Wright reckoned, that it might cause the mariner to err one, two, even three whole points of the compass (and in northerly navigations even more) in choosing the course. And in finding the distances between places, the errors might be from one-half to four times as much. 'The Compasse (the chiefest instrument for keeping the course shewed by the chart)' by neglect of variation might cause errors of from one to two points in the course to places, particularly in areas where the variation was greatest, as off Florida, Nova Francia (Scotia), and Newfoundland. Despite the double scale of latitude, designed to convey correctly the courses between places, the long and short of all this was, he concluded, that 'the ordinary charts were in many places much like an inextricable labyrinth of error, out of which it would be very hard for a man easily to unwinde himself'. Wright instanced the experience of many practised and competent navigators who in following their usual practice in sailing from the West Indies to the Azores 'often fell in with those Islands when, by their account, according to the chart they should have bene 150 to 200 leagues to the Westwards of them'. He also cited his own experience of how, in 1589,
sailing from the Azores to Ushant, they had sighted land, 'when by account of the ordinary chart we should have beene 50 leagues short of it'. Of course Edward Wright remarked that many careful navigators ignored the direct course between places, practising parallel sailing instead. While he recognized that this practice of 'running down the parallel' was the safest and surest way, in view of the handicaps imposed by cartographical errors and navigational practicabilities, he pointed out that the route followed had the disadvantage of being longer than was in theory necessary. Summing up the faults of cartography he concluded that hydrographers had given up as hopeless the attempt to reconcile on the plane chart the latitude of places and the bearing and distances between them, and that in this they were quite wrong. Because concurrence was impossible on the plane chart, it did not follow, he stated, that it was so by using other ways and means of drawing out the chart.

As for celestial observations, Wright reckoned that failure to allow for parallax, the eccentricity of the observer's eye when using the cross-staff, might cause an error of from 10' to more than 1" 'if the altitude were great, the staff small and the eccentricity of the eye large'.

This parallax could be really serious, since the cross-staff, as Davis had explained, was the principal instrument used for checking and correcting, by observation of the sun's, or a star's, meridian altitude, 'the account of the course, kept by direction of the compasse upon the chart'. However, continued Wright, even if accurate observations were made, it was impossible for accurate position-finding to result so long as the tables of declination of the sun and fixed stars were themselves inaccurate. Unfortunately, he remarked, all were. Even Robert Norman's solar declination tables recommended by William Borough as accurate to 1' he had often found to be incorrect by from 10' to 12'. The star tables were worse—even the Pole Star's. Indeed in the books of navigation that were most common amongst English mariners, he states that the distance from the pole was 38' too much. This, of course, was a censure of the uncorrected reprints of Cortes's, Bourne's, and Medina's works. It was no marvel, he therefore exclaimed, that the

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1 See Fig. 21.
2 Figs. 2, 4 and 15. The error arose from the failure to correct the rule for the precession of the equinoxes.
mariners complained that they could not make their observations of the latitude by the sun and by the Pole Star agree. Other stars’ positions he had found to be out by as much as 3° 38′ (a formidable error even by the general run of contemporary standards of observations). The facts, he claimed, had been checked not only by himself but also by Tycho Brahe, the great Danish astronomer, and the English Sir Christopher Heydon, on large instruments on which it was possible to read accurately to 30″.

Besides the rectification of all these errors the greatest work, Wright pointed out, still remained to be done, the reduction of all places to the proper latitudes and longitudes and the charting of them according to those positions and according to their true bearings.

Perhaps because in Spain King Philip III had only a year before offered subsidies and a substantial reward for the discovery of the means of finding longitude, Wright hoped for some success when he pleaded for an endowment for English research on the problem. However, none was forthcoming. But the hope was to live on in England and, before the seventeenth century was out, was to be fulfilled in the form of the Royal Observatory at Greenwich, established specifically for the solution of the problem of longitude determination at sea.¹

In introducing his new chart projection Wright forestalled accusations that he had stolen another man’s work by admitting that it had been Mercator’s well-known map of the world which had first prompted the idea of ‘increasing the distance of the parallels, from the equator towards the Poles, so that at every point of latitude in the chart a part of the meridian had the same proportion to the same part of the parallel as in the globe’. He further avowed that it was neither from Mercator, nor any other man that he had learned ‘the way how this should be done’.²

For practical navigators of the ordinary run the greatest virtue of the chart projection explained by Wright was that on it the spiral rhumb line became a straight line. True, the rhumb-line course was not the most direct. The shortest track lay on a great circle, and it was impossible to determine from a chart on Wright’s projection the series of courses necessary for steering along a great circle track. But this was not going to worry the ordinary navigator. His preference was for simplicity in navigation, and nothing could be simpler than following a rhumb-line track. Whereas hitherto the mariners had found the bearing between places ‘for the most part by estimation only’, they could now find it accurately on the chart to the nearest rhumb by the old method of using two compasses, or by the

¹ The Royal Observatory, to quote from the original warrant for the payment of the first Astronomer-Royal’s salary, was established ‘for rectifying the tables of the motions of the heavens, and the places of the fixed stars, so as to find out the so-much desired longitude of places for perfecting the art of navigation’.


² Wright explained his projection in terms of a bladder blown up inside a cylinder, a very good analogy. See Pl. LX.
new ones of drawing a straight line with lead between the places, and finding the rhumb parallel to it with one pair of compasses, or else of laying a long ruler on the two places and using the compasses to find the parallel rhumb. Moreover, for the first time distances could be measured accurately, straight off the chart, or else be calculated mathematically. Although, provided the geographical position of places were correct, the course between them was readily ascertained, the method of finding the distance was not quite fool-proof. The old plane chart had fixed scales of degrees of latitude and of leagues, and sometimes of longitude. Wright's had only two scales, the fixed scale of longitude and the changing scale of degrees of latitude. To measure off the distance between places the latitude scale in the vicinity of the latitude of the places had to be used. This was a very simple rule, but ignorance of the principle of the projection by unmathematical navigators frequently resulted in their ignoring it even over a century later. If the distance had been over-measured, and the ship as a result reached the coast unexpectedly at night, the result could be disastrous. Also, unless a globe was constantly kept in mind, the great enlargement of the sea-areas and land-masses in the higher latitudes was forgotten, and a false idea of the world's hydrographical description engendered. But these disadvantages of the projection need not be serious, particularly as, unlike those of the plane charts, they were not irremediable faults but limitations that could be overcome. However, above 80° latitude the distortions became so extreme that the projection never was, and still never is, used for navigation in the highest latitudes. Wright's table of meridional parts, calculated at 10' intervals made it possible to plot as straight lines the spiral rhumb lines of paradoxical charts up to 80° of latitude.1

When Wright expressed the view that, as a result of his chart projection, the greatest cartographical need remaining was for the accurate determination of the geographical position of places, he was correct. One of the reasons why his chart projection was slow in coming into general use was because although it was drawn quite correctly it often led mariners astray through the false geographical positions ascribed to places. Other reasons were, of course, the inherent conservatism of mariners, the traditional practices of hydrographers, the labour of redrawing charts on the new projection, and the expense of engraving new plates. It was probably not until Captain Smith's death in 1631 that the first printed chart of the Atlantic on Wright's projection was published. Nevertheless the most accomplished English navigators were soon using MS. charts on Wright's projection, particularly those concerned with navigation in the Atlantic and in northern waters; as we shall see, Henry Hudson drew one on his fateful voyage of 1610–11, and East India Company navigators were using charts on Wright's projection by that time.2 Skilled navigators could readily grasp

1 See Pl. LVIII and Pl. LIX.
2 This 'Mercator's chart' of Hudson is reproduced in Henry Hudson the Navigator, Hak. Soc., Ser. 1, Vol. 27, with a full explanation of the circumstances attending its publication in 1612. A circumpolar chart of the northern regions
LVII. Luke Foxe's Circumpolar Chart of 1631.
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LIX. The First Printed Table of Meridional Parts for every 10 Minutes of Latitude, 1599.
the principle upon which Wright’s projection was based and so avoid its pitfalls. For them the beauty of it was that for the first time they had the use of charts on which they could plot accurately their track in latitudes where the old plane charts’ errors had made themselves increasingly apparent, that is to say, in latitudes outside the tropics. While the projection in its practical form was, as Wright claimed, essentially an English development, it was one peculiarly well suited to the navigational needs of English and other northern navigators such as the Dutch and French.

Wright concluded his preface on a mathematical note. He claimed that charts could be better understood by a man with even only slight mathematical knowledge, and by implication no nautical experience, than by any mariner ignorant of mathematics even ‘though he had spent his whole life in sailing over all the seas in the world’—also that the same applied to all other nautical instruments and tables. He added, somewhat sourly, that despite this, because he was no professional seaman, a work such as his was bound to be critically received, while a work by a master mariner (by implication ignorant of mathematics) would be greeted with enthusiasm and followed with reverent devotion. A decade or two earlier his complaint would have been justified. Such had been Thomas Digges’s experience. But through the influence of the Digges, father and son, of John Dee, and the Boroughs, William Bourne, and Thomas Hood, mathematics had been gaining, if not many students, at least respect amongst seamen, and Certaine Errors received immediate recognition from mariners as well as from mathematicians.

Wright’s Certaine Errors was so packed with learning, was such an able survey of navigational practice at the close of the sixteenth century, and by its chart projection introduced such order out of the former cartographical confusion, that it and his other work merit fuller attention than can be devoted to it in a survey of this scope. Suffice it to say here that the table he gave for drawing a chart on his projection was made out to the nearest 10°; that in the course of his explanation he defined the paradoxal chart, ‘whose principall use may be in our northerly navigations and discoveries’; that in his chapter on variation he warned of the danger of deviation, and also stated that he had devised a better instrument for variation determination, his ‘Mariners rings’; that in his chapter on the cross-staff he gave the rule for determining and applying the correction for ‘ocular’ parallax and the first table of corrections for height of eye above sea-level ever printed, and the first table for correcting the sun’s

engraved by Jodocus Hondius in 1611 for Pontanus’s history of Amsterdam is also reproduced. It is a good example of a paradoxal chart.

John Daniel’s chart of Spitzbergen copied by Gerritszoon and published in 1613 is remarkable for being on a circumpolar projection; it extends between 66° N and 82½° N, with a double network of rhumbs. These spiral lines were probably drawn in by using Wright’s table of rhumbs.

John Daniel drew an Atlantic chart on Mercator’s projection used by Captain Peyton on a voyage to India in 1615.
parallax, together with the earliest observations included in a navigation manual upon the effects of refraction on celestial observations. The error for height of eye might be ‘five or sixe minutes or more in a tall shippe’,

![Diagram](image)

**Fig. 22**

**DIP, OR HEIGHT OF EYE CORRECTION**

Parallax error caused by observations being made from earth's surface and not earth's centre.

To obtain the altitude of the sun's centre, 16\textdegree, the angular width of the sun's semi-diameter, was added or subtracted according to whether the lower or upper limb was observed.

**Fig. 23**

**PARALLAX AND SEMI-DIAMETER**

he declared. His table gave corrections for heights of from 5 to 90 feet involving corrections between 2 and 11 minutes—to be subtracted from the observed altitude after correction for 'ocular' parallax or eccentricity of the eye. Although the parallax of the sun—the error caused by observing
it from the surface of the earth and not from the earth’s centre—was small, Edward Wright included it because, as he put it, in the ‘groundes of Art . . . so much as is possible ought to be without all error’. He gave the correction as 2’ 58” at 0° diminishing to 0’ 14” at 85° altitude to be added to the observed altitude. Owing to their great distance, parallax for the stars was, he pointed out, negligible. On the other hand he had often observed refraction ‘to be something, especially when they [the stars] come neere the horizon’, but that it did not affect meridian altitude observations of the

![Diagram](image)

**Refraction:** Different corrections (erroneously) were given to sun and star observations.

**Fig. 24**

**REFRACTION**

sun ‘at London’. Wright realized that these errors were indiscernible at sea with the instruments in use, and recommended mariners not to be over-scrupulous about applying the corrections, as, indeed, few were. The real value of the corrections lay in the future when more accurate instruments of observation would be available.

Wright laid great emphasis upon the advantage of being able to take star sights. Indeed he gave more emphasis to star sights than to sights of the

1 See Figs. 22, 23 and 24. Inman’s *Nautical Tables* gives the following corrections for Refraction and Dip:

**Refraction.** The effect of refraction is to increase the altitude of a heavenly body, and the table gives the amount of arc to be subtracted from the apparent altitude in order to allow for this effect.

| o’  o’  | 35° 24’ |
| 5”  o’  | 9° 51” |
| 10” o’  | 5° 18” |
| 20” o’  | 2° 37” |

*Inman (1906)*  *Wright (1599)*

**Dip: Height of Eye**

| 10 ft. = 3’ 11” | 10 ft. = 3’ |
| 20 ft. = 4’ 4” | 20 ft. = 5’ |
| 30 ft. = 5’ 39” | 30 ft. = 6’ |
| 40 ft. = 6’ 22” | 40 ft. = 9’ |
| 50 ft. = 6’ 96” | 50 ft. = 8’ |

Minus to observed altitude
sun's meridian passage. He thought the latter a difficult and chancy observation; chancy, because the declination of the sun was 'only of good use for knowing the latitude at sea, when his meridian altitude might be observed', and because, although the sun shone clear and bright all day, a little cloud for a quarter of an hour at noon could make an observation impossible and so render the tables useless; difficult, because the sun's rapid change of altitude and declination made 'shooting the sun' a skilled job and involved calculation to correct for the observer's position east or west of the longitude of the place for which the declination tables were calculated. Besides this, whether the sun's declination was north or south had to be carefully checked. By comparison, he pointed out, the 'fixed stars' moved very slowly. As a result not only was shooting them easy but no interpolation was necessary to find their declination. Holding these views he had chosen for his tables more stars than usual close to the two poles, since they should be easy of observation in low latitudes, and in higher ones provide two opportunities of observing them, when they transited, at twelve-hour intervals, north and south. In winter in northern latitudes the same star could thus be observed at sunset and again at sunrise.

This large choice of stars was important. In practice the opportunities for taking star sights were limited, as they are today, to the twilight hours of dawn and dusk. Only then are the stars and the horizon both clearly discernible. Thus in those days, when only meridian transit sights could be taken profitably, the choice of star was limited to those transiting at dawn and dusk observable with a cross-staff; astrolabes, although they did not involve the use of the horizon, were too inexact for stellar sights at sea.

Included in _Certaine Errors_ was a chart of the Azores drawn on Wright's so-called 'Mercator' projection. This chart covers the eastern Atlantic and the Channel, from the southern coast of Ireland, the north-western and western coasts of France, the Bay of Biscay, and the western and southern coasts of Spain to the Azores. It shows the route followed by Cumberland's expedition of 1589, and illustrates the method of prick ing the chart. In the top left-hand corner is a description of the projection, of the longitude and latitude of the Azores, and of the various notations of the variation of the compass that the chart contains. That the westernmost part of Africa was taken for the prime meridian is explained at the foot of the chart. The chart provides a most interesting contrast to Thomas Hood's plane chart of 1592, which covers almost the same area.\(^1\)

Wright's Azores chart was undoubtedly far more important from a navigational point of view than the famous world chart which appeared on the

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1 See PIs. XLIX, L and LVIII. A MS. chart of the same area as Wright's, and on his projection, is at Hatfield House. It has been reproduced in E. M. Tenison's folio of charts of _Elizabethan England_, but its projection has been overlooked. This is probably the oldest chart on Wright's projection and may well have been a copy of the original of the engraved version. See Pl. LXI and Appendices 8 A and B.
same projection in 1600 in Hakluyt's new edition of the *Principal Voyages*. Like Mercator's of 1569, the world chart was on a scale too small for navigation; it, in effect, was a map. It was, of course, valuable as an accurate representation of the known world at the close of the sixteenth century. The Azores chart on the other hand was invaluable as an accurate navigational chart. It was indeed the first navigational chart ever printed on 'Mercator's projection'. It could actually be worked on.

Wright's interest in the problem of longitude was exemplified by his translation of a work by Simon Stevin, the distinguished Dutch mathematician, entitled *Hafenvinding*. It was published simultaneously in Dutch, French, Latin, and English, in 1599, the year *Certaine Errors* appeared, Wright's translation being called *The Haven-finding Art*.2

Edward Wright dedicated it to Charles, Lord Howard, now Earl of Nottingham, the Lord High Admiral, because of his 'singular affection for the advancement of knowledge and skill among our seamen'. He explained that he had brought the book out in the hope that it would assist masters engaged on long voyages to find their position by means only of their knowledge of their latitude and variation. He hoped too, he said, that such masters might through this work be able to turn their knowledge of dip to some similar practical use. To the Master, Richard Polter, and the Brethren of Trinity House, Wright added some sage remarks concerning the value of the knowledge and application of variation.

The Dutch original of *The Haven-finding Art* was the result of Prince Maurice of Nassau's deep interest in the use of variation made by the Portuguese for finding longitude. He had given orders that Dutch masters on voyages were to observe the variation carefully with proper instruments and, on their return, were to render certified reports of their observations to 'their companies or brotherhoods of the Admiralty'. The observations, being brought 'into good order', were then to be published for the common good. Pending the compilation of more records, Peter Plancius's geographical list was made use of. Places whose variation had been observed were grouped geographically, according to whether their variation was north-easterly or north-westerly, whether they lay north or south of one another, and whether the changes in variation experienced *en route* were 'decreasing' or 'increasing', that is to say, whether in the course of the voyage the

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1 Wright's world chart of 1600 has been reproduced by the Hakluyt Society: *Map of the World. A.D. 1600*.

2 THE HAVEN-FINDING ART, Or, THE WAY TO FIND any Hauen or place at sea, by the Latitude and variation. Lately published in the Dutch, French, and Latine tongues by commandement of the right honourable Count Mauritiz of Nassau, Lord high Admiral of the united Prouinces of the Low countries, enioyng all Seamen that take charge of ships vnder his iurisdiction, to make diligent obseruation, in all their voyages, according to the directions prescribed herein: *And now translated into English, for the common benefite of the Seamen of England*. Imprinted at London by G.B.R.N. and R.B. 1599.
variation was augmented or diminished. This had nothing to do with secular change of variation. 'That variation which before was found . . . is changed', was a phenomenon which it was still held 'reason will not suffer us to think.' As well as the variation, the tables included the latitude and longitude of the places named. With them navigators bound for, say, the island of St. Helena, an important watering place in the South Atlantic on the long homeward route between the East Indies and Europe, could decide 'assuredly whether they were more eastward or westward than that place', as Wright had expressed it in _Certaine Errors_. It was hoped that instead of guessing, as up till now those not in possession of the information had had to do, and often wrongly, 'I am east (or west) of St. Helena', English navigators knowing their variation when in the latitude of St. Helena would be able to say, like the Portuguese, 'I am east, or I am west, of St. Helena because my variation is less, or is more, than the variation at St. Helena.' They could, of course, find the variation of St. Helena from _The Haven-finding Art_. They could observe their own. On the magnetic data available the idea was good. It had been known to Robert Norman and, according to Edward Wright, had been put into practice by English navigators ten years before, which is interesting, for it will be recalled that it was in the early '80s, following on the occupation of Portugal by Philip II, that the English had obtained much nautical advice from Portuguese refugees. Don João de Castro, it will be recalled, observed variation on his voyage to the East Indies as early as 1538, and subsequent Portuguese navigators had continued the practice, embodying their observations in their rutters, not merely for the purpose of compass correction, but also for the determination of longitude.\(^1\) It was from them that the English in the '80s must have got the data necessary for relating longitude with change of variation. It was not from the Dutch, for at that time these were not yet experienced in oceanic navigation.

It was the decade following the defeat of the Spanish Armada by the English that witnessed the sudden and dramatic flowering of Dutch maritime activity. In the 1580s their activities, except for occasional Arctic voyages in the wake of the English Muscovy traders, were almost entirely confined to the waters of north-west Europe, but were growing in scale. The disasters that had befallen the southern provinces, since the ravages started by Alva in 1567, had resulted in a vast exodus of merchants and artisans. As many as four hundred thousand families are reputed to have been displaced. Many settled in England and Germany, but perhaps most settled in the seven northern provinces of the Low Countries which soon became the United Provinces. Before long Amsterdam had usurped the place of Antwerp as the premier port of Europe and, suddenly, in the 1590s, the Dutch seamen were active everywhere. For half a century they had

\(^1\) See, for instance, the Portuguese rutters embodied in Linschoten's _Discourse of Voyages . . ._ (Dutch original, 1596, English translation by W. Phillips, 1598) and in Hakluyt's _Principal Navigations_ (1598–1600).
been the supreme pilots of Europe. Dutch rutters, in the first half of the sixteenth century, had gradually supplanted the French as the best. In the '80s their 'waggoners' had become standard works in the chest of every ship-master with pretensions to some learning. The defeat of the Armada, at no cost to themselves at sea, had acted entirely in their favour. With the English preoccupied subsequently with sea-borne military operations, raiding cruises and letters of marque activities, and the continued threat of invasion, the opportunity had arisen for the Dutch to seize the coastal and short-sea carrying trade of Europe, and usurp the power of the Portuguese in the east. Excellent pilots in the treacherous waters of northwest Europe, and unsurpassed as hydrographers though the Dutch might be, and keen students of the Spanish art of navigation, they yet lacked that widespread knowledge and experience of oceanic navigation that would enable them to put their policy into effect. They were faced with the problem that had faced the English forty years before. Like the English then, they had merchants and mariners of experience, vigour, and imagination at the hub of affairs. Balthasar de Mucheron has been called the father of Dutch commerce, and rightly, for he was the driving force behind the earliest Dutch ventures—in the '80s—to the Arctic in search of trade with Russia. He it was who, now, in the mid '90s, sent two successive Dutch expeditions in search of Cathay via the north-east, and the first Dutch expedition to reach the East Indies via the Cape of Good Hope. But he was not alone. The names of Isaac and Jacob Le Maire, Cornelius Houtman, William Barents, Jacques Mahu, Jacques l'Hermitage, and William Usselinex— who first proposed, as early as 1591, that the Dutch should attack Spain in her colonies—and of Peter Plancius, the influential theorist whose contribution to Hafenvinding has already been discussed, stand almost as high in the list of men who raised Holland to the status of a first-class sea power.

The first Dutch expedition to the east via the Cape of Good Hope sailed in 1595. Between that date and 1601 no less than fifteen expeditions were sent out. These were all separate undertakings, competing the one against the other. In 1602 the folly of this in the face of Portuguese opposition was recognized, and the various companies were amalgamated into the Dutch United East India Company, with a joint stock of over half a million pounds. Thus was created the concern with the organization, accumulated knowledge, and capital sufficient for the usurpation of Portuguese power in the East. It may well be asked how, in view of the previous

1 Dutch rutters seem almost all to have been published in the northern provinces, even those brought out during the pre-eminence of Antwerp; see Gernez et Denucé, Le Livre de Mer, Antwerp. 1936.


See also Three voyages by the North-east Hak. Soc., Ser. 1, Vol. 13, and Early
limited Dutch experience of oceanic navigation, all this had been possible in the space of seven short years. The answer is, by assiduous study of the latest navigational methods—Plancius, for instance, set up a school of navigation at Enchuyzen—by obtaining possession of all the long-hidden secrets of the Portuguese navigators to the east, and by instruction and assistance in navigation from English mariners of skill and experience. Bourne's *Regiment for the Sea*, translated into Dutch in 1594, the year of the first Dutch expedition to the north-east and the year before the first Dutch oceanic expedition sailed, was an indispensable supplement to Spanish manuals, such as Medina's and Zamarano's, already translated into Dutch (Cortes's was never translated into Dutch), for it dealt at length with subjects skimmed over by the others. Moreover English navigators personally instructed the Dutch, and acted as pilots for them on many voyages. In 1598, for instance, three Dutch fleets sailed for the Indies, two via the Strait of Magellan, and one via the Cape of Good Hope. The Chief Pilot in each was an Englishman: Captain John Davis in Cornelius Houtman's fleet that sailed via the Cape; Captain Mellis (who had been on Cavendish's voyage of circumnavigation) in Oliver Noort's fleet, which completed the first Dutch and the fourth successful voyage around the world; and Captain William Adams in Jacques Mahu's fleet bound for the east via the Straits. These, 'and others afterwards', recorded Purchas in his *Pilgrimes* of 1625, were 'Guides and Pilots to the Hollanders in their Circumnavigations ... and ... first Indian Voyages', adding, truly, 'their exploits are honours to the English'. The popularity of Bourne's manual is evinced by the appearance of a second Dutch edition in 1599, and a third in 1611. Moreover, Hues's *Tractatus de Globis*, as we have seen, met with immediate recognition in Holland, being translated into Dutch as early as 1597. With their long background of mechanical and hydrographical skill it was the Dutch who, having taken whole-heartedly to oceanic navigation, became the leading nautical globe-makers of the world: though a second edition of the Molyneux globes came out in 1603, no subsequent English globes of the first half of the seventeenth century are known; but that there were English globe-makers we know from advertisements and remarks in journals, though their handiworks do not appear to have survived. In the seventeenth century it was Dutch globes, in the style of the Molyneux ones, that furnished the scholar's study and the sea-captain's cabin.

Although the Dutch developed a far eastern trade before the English, the latter had started organizing direct trade with the east via the Cape of


Barents who in 1597 perished, like Willoughby, by being trapped in the ice, took a Dutch translation of Medina's *Arte de Navegar* as a manual. His various instruments, like his copy of this book, were preserved in the ice and rediscovered in the nineteenth century.

See the Hakluyt Society's reprint of *Purchas his Pilgrimes*, Vol. II, for accounts of Dutch voyages made with English pilots.
LX. Mercator's Projection as described by Edward Wright, 1599.
Good Hope, and Magellan Strait, some years before them—in October 1589 to be exact.\(^1\) Sponsored by William Sanderson, John Davis had attempted a voyage by the Cape in 1590, but had been driven back by storms off the Canaries; the next year James Lancaster had made the attempt, also by the Cape of Good Hope, and Cavendish and Davis had made their attempted voyage to the east through the Strait of Magellan; both expeditions had eventually failed, though on his return trip Lancaster had reached the latitude of Bermuda with one ship before a hurricane, head winds, and lack of water had forced him back to the West Indies at the end of 1593. Here his ship had been wrecked. However, he had reached home the following year to report that the Portuguese 'have lately discovered the coast of China to the latitude of nine and fiftie degrees, finding the sea still open to the northward; giving great hope of the north-east or north-west passage'.\(^2\) Before this had been known, Richard Hawkins had set out, in 1593, and had passed the Strait of Magellan, but he had been captured off Peru: Robert Dudley's voyage to Trinidad in 1594 had originally been intended for the Indies, by the Strait of Magellan, but had been limited by the queen's command to one of a less hazardous nature. On his return in 1595 Dudley had set about organizing an expedition to the East Indies, and this had been dispatched in the following year, only to end in some unknown disaster in the China Seas.

The event that had fired these latest adventures had been the capture of the East Indian carrack, the Madre de Dios, in 1592, by Sir John Burrough, commanding a force fitted out by Sir Walter Raleigh. After a bloody fight she had been boarded and seized. Then had the Englishmen truly perceived

the true proportion of the vast body of this carak, which did ... justly provoke the admiration of all men not formerly acquainted with such a sight ... being in burden by the estimation of the wise and experienced no lesse then 1600 tunnes ...

Of its bulk 'full 900' were 'stowed with the grosse bulk of marchandise ...' and to their at first incredulous gaze it had transpired that besides jewels, which never came to light officially, it

consisted of spices, drugs, silks, calicos, quilts, carpets, and colours, etc. The spices were peppers, cloves, maces, nutmegs, cinnamon, greene ginger: the drugs were benjamin, frankincense, galingale, mirabolans, aloes, Zocotrina, camphire: the silks, damasks, taffatas, sarcenet, altobarsos, that is counterfeit cloth of gold, unwrought China silke, sheared silke, white twisted silke, curled cypresse. The calicos were book-calicos, calice-lawnes, broad white calicos, fine starched calicos, course white calicos, broune broad calicos, browne coarse calicos. There were also canopies, and course diaper-towels, quilts of course sarcenet and of calico, carpets like those of Turkey; whereunto are to

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\(^1\) Parks, G. B., *Richard Hakluyt and the English Voyages* (1928), p. 149. The start took the form of a memorial, addressed to the Privy Council by 'divers merchants'.


19—A.O.N.
be added the pearle, muske, civet and abmer-griecye. The rest of the wares were ... eliphants teeth, porcellan vessels of China, coco-nuts, hides, eben-wood as blacke as jet, bedsteads of the same, cloth of the rindes of trees very strange for the matter, and artificiall in workmanship.

Though they had the will and the navigational skill to get to the east via the Cape, the English were still handicapped by preoccupations with naval affairs—1596, for instance, was the year of Essex’s Cadiz operation, and another storm-shattered Spanish Armada. Despite Richard Hakluyt’s efforts they also lacked co-ordinated commercial effort in overseas enterprise and, perhaps most important of all, they lacked rutters of the route to the east. Individuals might possess these, but if they did they guarded them jealously. In this matter it was upon the Dutch that fortune had smiled. Indeed it was because a compatriot, John Huyghen van Linschoten, after years of wanderings in the east, had returned to Holland in 1593, armed with Portuguese and Spanish rutters and charts of the east, and of the West Indies, that the Dutch primed with the commercial lore of the Indies had been able to plunge headlong into successful navigation on a commercial scale. Linschoten possessed detailed records of many of the Portuguese trade routes. He knew from personal experience how the Portuguese lived and conducted themselves on their long and tedious voyages in their great carracks; what food they ate, where they watered; how long they voyaged; where they anchored in safety; where and how they traded; and he knew too the seasons of the year most healthful or profitable for trade at the various ports of call. Yet it is some indication of what such ventures involved that the Dutch, notwithstanding Linschoten’s knowledge of the Cape route, should have made their first attempt to reach the Indies, like the English before them, by way of a north-east passage. The voyage of 1594 to the north-east was undertaken with Linschoten sailing as supercargo to negotiate commercial treaties supposing the Orient was reached that way. It was not until the next year that the first Dutch Cape expedition had sailed.

It was in Holland in 1596 that Linschoten published his Voyages. On Hakluyt’s advice they were immediately taken in hand for translation and, two years later, an English edition appeared, with a dozen engraved charts and several harbour plans. Invaluable though such a work might be, what the English still lacked was the personal tuition Linschoten had been able to give to the Dutch. All the successful English navigators to the east were either busy like Lancaster on naval operations, or dead. However, as soon as the news came through at the end of 1597 of the triumphant return of the first Dutch expedition to the east, by way of the Cape, Essex, who for all his faults was a man of vision as well as of energy, got Captain John Davis—his pilot on the Azores expedition of that year—to sail in the next similar Dutch expedition as pilot. His especial task was to be the ‘discovering of these Easterne parts of the world, to the service of her
Majestie and the good of our Countrey . . .?; 'all which', wrote Davis on his return in the mid-summer of 1600, with a journal of the voyage, 'the Portugals with the lock of discretion have providently long concealed'. His action came to be regarded, in later years, as spying. But this was not the contemporary view. The triple alliance between England, France, and Holland had been signed in 1596. The Dutch were our allies, and as such had 'special assistance in their late navigations by the meanes of Master John Davis and other skilful Pylots of our nation', wrote William Walker to Sir Thomas Smith, and continued, 'and in return the Dutch . . . requite us; acquainting us with their voyages, discoveries and dangers . . .'.¹ So it was that in February 1601 there departed from Woolwich 'foure great ships . . . the Dragon, of the burthen of six hundred tunnes; the Hector, of the burthen of three hundred tunnes; the Ascension, of the burthen of two hundred and three score tunnes, and the Susan, of two hundred and forty tons'; accompanied by a victualler called the Guest; whose general was James Lancaster, and pilot-major, John Davis. Sailing in the flag-ship or 'Admiral' the Dragon, they were bound for the Far East, via the Cape of Good Hope, on a venture financed by the English East India Company. They almost certainly carried Linschoten's Discours of Voyages into Ye Easte & West Indies,² with its description of a Portuguese East Indiaman and of its routine; with its Portuguese rutter of

¹ Walker, W. (trans.) The Iournal, or Dayly Register, . . . of the voyage, accomplished by eight shippes of Amsterdam, . . . 1598. London, 1601. Translated to assist the first voyage of the East India Company 'being seconded by the persuasion of M. Richard Hackey, a man for his matchless industrie in collecting the English Voyages, most incomparably wel deserving of the state . . . For herein the Hollanders (who borrowed a great part of their light from vs, namely out of the famous Voyages of Sir Francis Drake, Master Thomas Candish, Master James Lancaster, Ralph Fitch, and Thomas Stephens, their fore-runners in those parts, and have had speciall assistance on their late Navigations by the meanes of Master John Davie, Master Timothie Shotton, and other skillfull Pylots of our Nation) doe in ample manner requite vs with the like. acquainting us with their Voyages, discoveries and dangers, both outward and homeward; with their negotiation and traffique . . . and the quantitie and value of Spices and other commodities which they brought home.'

² JOHN HVIGHEN VAN LINSCHOTEN: his Discours of Voyages into ye Easte & West Indies. Devided into Foure Bookes Printed at London by John Wolfe Printer to ye Honorable Cittie of LONDON
This is Phillip's's translation of the 1596 Dutch original, and was published in 1598. It is divided into four books, the second, third and fourth of which (though not the first) have separate title-pages, as follows:

THE SECOND BOOKE. The true and perfect description of the whole coast of Guinea, Manicongo, Angola, Monomotapa, and right over against them the Cape of S. Augustin in Brasilia, with the compass of the whole Ocean Seas, together with the Ilands, as S. Thomas, S. Helena, and the Ascension, with all their hauens, channels, depths, shallows, sands & grounds. Together also with
a voyage, of 1584, from Lisbon to the East Indies; its list of principal havens, rivers, and islands frequented by the Portuguese and Spaniards, with their latitudes; and finally the supplement to The Haven-finding Art.

Probably they also carried the first volume of Richard Hakluyt's new edition of The Principal Navigations, Voyages, Traffiques and Discoveries of the English Nation, with its description of voyages to the north-east and Cabot's ordinances, and the second volume which had come out in 1599, with its rutter giving 'the whole course of the Portugale Caracks from Lisbon to the barre of Goa in India'. The Principal Navigations was certainly used as a rutter on the third voyage, sent out in 1607, and 'saved the company, as Sir Thomas Smith affirmed to me', wrote Purchas, '£20,000', when the master, by its aid brought his storm-distressed ships in safety into Sierra Leone harbour.2

divers strange voyages made by the Hollanders: also the description of the inward partes of the same landes. Likewise a further Description of the Carde of Madagascar; otherwise called the Iland of S. Laurence, with a discovery of all the shallowes, cliffs, and numbers of Islands in the Indian seas, and the situation of the Coun- trey of the Cape de Bona Speranza, passing along to Monomotapa, Soffala, and Mosambique, and from thence to Quioqa, Gorga, Melinde, Amara, Baru, Magadoxo, Doara, &c. to the red sea: and what further wanteth for the description thereof, you shall find at large in John Hughen of Linschotens book: also the voyages that the Portingall Pilots have made into all places of the Indies, Extracted out of their sea Cardes, books, and notes of great experience. And translated into Dutch by I. Hughen van Linschoten. And now translated out of Dutch into English by W.P. London Imprinted by John Wolfe, 1598.

THE THIRDE BOOKE. The Navigation of the Portingales into the East Indies, containing their travels by Sea, into East India, and from the East Indies into Portingall, also from the Portingall Indies to Malacca, China, Japon, the Islands of Jaua and Sunda, both to and fro, and from China to the Spanish Indies, and from thence back againe to China, as also of all the coast of Brasilia, and the Hauens thereof.

With a description of the Firme land and the Islands of the Spanish Indies lying before it, called Antillas, together with the Navigation of Cabo de Lopo Gonsalues to Angola, in the coast of Ethiopia, with all the courses, Hauens Islands, Depths, Shallowes, Sands, Drougths, Riffles and Cliffs, with their situations, also the times of the yeares when the winds blow, with the true tokens and knowledge of the tides and the weather, water, and streams in all the Orientall coasts and Hauens as they are observed and set downe by the Kings Pilots, in their continual and dayly Viages.

Translated out of Dutch by W.P. London Printed by John Wolfe, 1598.

THE FOUVRTHE BOOKE. A most true and certaine Extract and Summarie of all the Rents, Demaines, Tolles, Taxes, Importes, Tributes, Tenthes, third-pennies, & incommings of the King of Spaine, throughout all his Kingdoms, lands, Provinces, and Lordships, as they are collected out of the originall Registers of his Chamber of accompts. Together with a briefe and cleere description of the government, power, and pedegree of the Kings of Portingall. Translated out of Spanish into Low-Dutch by John Hughen of Linshoten. And out of Dutch into English by W. P. LONDON Imprinted by John Wolfe, 1598

2 Parks, op. cit. p. 159. and,

THE PRINCIPAL NAVIGATIONS, VOIAGES, TRAFFIQUES AND DISCOVERIES of the English Nation, made by Sea or ouer-land, to the remote and farthest distant quarters of the Earth, at any time within the compass of these
The attempt embodied in *The Haven-finding Art* to systematize the observations of magnetic variation and to have them made on a world-wide scale was symptomatic of the scientific spirit now animating nautical affairs in north-west Europe. Another example was afforded by William Barentszoon’s ‘Waggoner’ for the Mediterranean, *Nieuwe beschryvinghe ende Caertboeck vande Midlandtsche Zee*, that had come out in 1595. Several of the charts, somewhat similar in treatment to Wagenaer's, contained a double network of rhumbs, one for use with Mediterraneanc, or meridional, compasses, the other with Dutch compasses, or ‘common sailing compasses’, with the wires offset three-quarters of a point to the

1500. yeeres: Deuided into three seuerall Volumes, according to the positions of the Regions, whereunto they were directed. This first Volume containing the woorthy Discoveries, &c. of the English toward the North and Northeast by sea, as of Lapland, Cirkillinia, Corelia, the Baie of S. Nicolas, the Isles of Colgoieue, Vaiqats, and Noua Zembla, toward the great riuer Ob, with the mighty Empire of Russia, the Caspian sea, Georgia, Armenia, Media, Persia, Bohgar in Bactria, and diuers kingdoms of Tartaria: Together with many notable monuments and testimonies of the ancient forren trades, and of the warrelie and other shipping of this realme of England in former ages. Whereunto is annexed also a breie Commentarie of the true state of Island, and of the Northren Seas and lands situate that way. And lasty, the memorabel defeate of the Spanish huge Armada, Anno 1588. and the famous victorie atchieued at the citie of Cadiz, 1596. are described By RICHARD HAKLTYT Master of Artes, and sometime Student of Christ-Church in Oxford. Imprinted at London by GEORGE BISHOP, RALPH NEWBERIE and ROBERT BARKER. 1598.

**THE SECOND VOLUME OF THE PRINCIPAL NAVIGATIONS, VOYAGES, TRAVFiques and Discoveries of the English Nation, made by Sea or ouer-land, to the South and South-east parts of the World, at any time within the compass of these 1600. yeeres: Diuided into two seuerall parts: Whereof the first containeth the personall travelus, &c. of the English, through and within the Streight of Giblaritar, to Alger, Tumis, and Tripol in Barbary, to Alexandria and Cairo in Algypt, to the Isles of Sicilia, Zante, Candia, Rhodes, Cyprus, and Chio, to the Citie of Constantinople, to diuers parts of Asia minor, to Syria and Armenia, to Ierusalem, and other places in Iudaea: As also to Arabia, downe the Riuier of Eufrates, to Babylon and Balsara, and so through the Persian gulf toOrmuz, Chaul, Goa, and to many Islands adioyning vpon the South parts of Asia; And likewise from Goa to Cambaia, and to all the dominions of Zelabim Echebar the great Mogor, to the mighty Riuier of Ganges, to Bengala, Aracan, Bacola, and Chonderi, to Pegu, Iamahai in the kingdom of Siam, and almost to the very frontiers of China.

The second comprehedeth the Voyages, Trafficks, &c. of the English Nation, made without the Streight of Giblaritar, to the Islands of the Açores, of Porto Santo, Madera, and the Canaries, to the kingdomes of Barbary, to the Isles of Cape Verde, to the Riuer of Senega, Gambia, Madrabumba, and Sierra Leone, to the coast of Guinea and Benin, to the Isles of S. Thomé and Santa Helena, to the parts about the Cape of Buona Esperanza, to Quitangone neere Mozambique, to the Isles of Comoro and Zanzibar, to the citie of Goa, beyond Cape Comori, to the Isles of Nicobar, Gomes Polo, and Pulo Pinaom, to the maine land of Malacca, and to the kingdom of Iunsalaon.

By RICHARD HAKLTYT Preacher, and sometime Student of Christ-Church in Oxford.

Imprinted at London by George Bishop, Ralph Newbery, and Robert Barker. NNO 1599.
east of north to allow for variation in home waters. These appear to be the first engraved charts to contain a form of double fly to clarify the amount of variation, if any, allowed for in their delineation. This waggoner also remained the only one of the Mediterranean until the middle of the seventeenth century and, either in its Dutch or French editions, must have been the standard pilot for English navigators in the Mediterranean sea.¹

That the labour of the preparation of The Haven-finding Art was in vain when it came to the precise determination of longitude was the result of the difficulty of determining variation accurately on board ship with the available instruments, and of the paucity of observations. What finally put an end to the scheme was the confirmation of the secular, or annual, change in variation by the Gresham College professor, Henry Gellibrand, in 1633, and the absence of any co-ordinating authority to issue the regular amendments necessary to keep the tables up-to-date. It was probably the Haven-finding scheme that the Spanish inventors, in search of Philip III's bounties for a means of longitude finding, were trying to exploit when they concentrated in the first part of the seventeenth century on producing 'a compass without variation'.² The difference between the reading of such

THE THIRD AND LAST VOLUME OF THE VOYAGES, NAVIGATIONS, TRAFfique, and Discoveries of the English Nation, and in some few places, where they have not been, of strangers, performed within and before the time of these hundred yeeres, to all parts of the Newfound world of America, or the West Indies, from 73. degrees of Northerly to 57. of Southerly latitude:

As namely to Engronland, Meta Incognita, Estotiland, Tierra de Labrador, Newfoundland, vp The grand bay, the gulf of S. Laurence, and the River of Canada to Hochelaga and Saguenay, along the coast of Arambec, to the shores and maines of Virginia and Florida, and on the West or backside of them both, to the rich and pleasant countries of Nueva Biscaya, Cibola, Tignex, Cicut, Queuira, to the 15. provinces of the Kingdom of New Mexico, to the bottome of the gulf of California, and vp the Rieur of Buena Guia:

And likewise to all the yses both small and great lying before the cape of Florida, The bay of Mexico, and Tierra firma, to the coasts and Inlands of Nueva Spaine, Tierra firma, and Guiana, vp the mighty Rivers of Orenoue, Dessekebe, and Maranon, to euery part of the coast of Brasil, to the Rieur of Plate, through the Streights of Magellan forward and backward, and to the South of the said Streights as farre as 57. degrees:

And from thence on the backside of America, along the coastes, harbours, and capes of Chili, Peru, Nicaragua, Nueva Espanna, Nueva Galicia, Culiacan, California, Nova Albion, and more Northerly as farre as 43. degrees:

Together with the two renowned, and prosperous voyages of Sir Francis Drake and M. Thomas Candish round about the circumference of the whole earth, and diuers other voyages intended and set forth for that course.

Collected by RICHARD HAKL VyT Preacher, and sometimes student of Christ-Church in Oxford.

Imprinted at London by George Bishop, Ralfe Newberie, and ROBERT BARKER. ANNO DOM. 1600.

¹ See Pl. LXII. The French edition was: Description de la Mer Méditerranée, Guillaume Bernard; [Amsterdam], 1608.

² Gould, R. T., The Marine Chronometer (1923), gives a summary of some of the schemes and inventions submitted and rewarded in the first quarter of the seventeenth century.
a compass and that of an ordinary mariner's compass would have given
the variation directly—nor is the attempt to be scoffed at; the gyro
compass is in effect just such 'a compass without variation'.

The instrument for finding variation advocated in *The Haven-finding Art*
consisted of a lead-weighted compass box, mounted in gimballs, marked off
in each quadrant from 0°–90°, and with a single arrow-like needle without
a fly. This was surmounted by a rotatable graduated quadrant set up in
the vertical plane, complete with a vertical sight bar, hinged at its lower
corner. With this the elevation and azimuth of the sun could be observed
simultaneously. Alternatively, since it was an expensive special instrument,
the navigator was advised to use a sea compass with a vertical style, or with
a plumb-bob, for casting a shadow on the fly in order to measure the
azimuth, while he observed the sun's altitude with a cross-staff or astro-
labe. This method, since it was the cheapest, was probably the one most
frequently used.

Hues, in his *Tractatus de globis*, had described the use of the ecliptic line
on the globe for finding the sun's declination, but had ended by saying
that the declination might be found much more accurately from 'those
tables which Mariners use, in which the Meridian Altitude, or Declination
of the Sunne for every day in the yeare, and the quality [whether North or
South] is expressed'. Bourne's *Almanac* of 1581 had become out of date in
1590. By then he had been dead seven years. Apparently no one saw fit to
bring this almanac up to date. The Digges' *Prognostication everlasting*, it is
true, was reprinted twice in the 1590s, but neither this, nor Moore's, nor, of
course, the annual common almanac, fully met the needs of the English
navigator. That he used and cherished his almanac is absolutely certain.
Bourne had made it clear in 1581 that common almanacs formed part of
the navigator's stock-in-trade. Hues felt it necessary to include in *Tractatus
de globis* the warning that only the latest almanacs should be used, 'for all
of them, after some certaine space of time, will have their errors'. It
was now, at the close of the old queen's reign, that John Tapp made his
most original contribution to the art of navigation: the nautical almanac
he compiled and published in 1602 under the title of *The Seamans Kalender*.1 Its popularity was immense. It was frequently brought up to
date. Indeed a fresh edition appeared roughly every three years. By 1615
it had gone through five editions, and had been enlarged. In 1631 the
tenth edition appeared. It was still being regularly published at the close
of the century, long after Tapp's death. Tapp called it *An Ephemerides*

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1 *THE SEAMANS KALENDER*, or *An Ephemerides* of the Sun, Moone,
and certaine of the most notable fixed Starres. Together with many most needfull
and necessary matters, to the behoofe and furtherance principally of Marriners
and Seamen: but generally profitable to all Traualiers, or such as delight in the
Mathematicall studies. The Tables being for the most part Calculated from the
yeere 1601. to the yeare 1624. By I.T. LONDON. Printed by E. Allde for John
Tapp, and are to be solde at his shop on Tower-Hill neere the Bulwarke gate.
1602.
of the Sun, Moone, and certaine of the most notable fixed Starres. Although Wright's amended declination tables had been out for three years Tapp did not use them; there are differences of about 5' between the two. On the other hand he used Wright's amended star declinations and star lists, but where Wright gave the names and data of thirty-two stars round the equinoctial, Tapp gave thirty-five. On the other hand Wright had given no less than thirty-two stars round the North Pole, an embarrassing number for a plain seaman; Tapp, familiar with the needs and capabilities of the men for whom he wrote, cut these stars down to seven, but gave, in addition, five round the South Pole.

Opening his text with certain definitions associated with the sphere, he followed with definitions and rules for finding the Golden Number and Epact, useful for calculating tidal data; a horizontal tide-table, on the lines of Bourne's; and a clear explanation of its use. He included the sage advice to the 'young scholler or apprentice in Navigation' that, 'first the 32 points [of the compass] must be perfectly learned without booke', and then went on to explain the relation between the 32 points of the mariner's compass and the 24 hours of the day. Boxing the compass, an expression not then in print (Captain Smith used the expression 'to say your compass'), is still one of the first things the young seaman learns to do perfectly. Tide-tables showing the establishment of places from Jutland to Cadiz, including the British Isles, and further tables showing the direction (but not strength) of tidal streams on the flood and on the ebb along the coasts accompanied the horizontal tide-table. Then came a calendar for determining the moon's age. A section on planets, which had no direct navigational value contained, however, the warning that the tide-tables were from a Dutch rutter and that their reliability could not be vouched for. The influence of Wagenaer had already become, as it was to remain for a hundred years, predominant in English pilotage. Tables of 'The Depths and Soundings near divers Provinces' succeeded the tide-tables but with no indication as to the state of the tide or datum level on which they were based. The directions for coming into the Soundings and proceeding up Channel were, as was usual in theutters, very detailed.

'The Almanacke or Ephemerides' was arranged in three parts. The first related to the moon, the second to the sun, and the third to the stars. It was comprehensive and covered a 24-year period. Why the sun's declination tables were not accurate for longer was explained. The effect of the precession of the equinoxes, though at first unappreciable, became evident over a period of years. The last column of the almanac consisted of the star lists in which stars were listed in Wright's eminently practical manner. They were shown according to their distance either from the equinoctial, or from the South Pole, or else from the North Pole. Thus the first thirty-five stars consisted of the most notable fixed stars of the 1st, 2nd, or 3rd magnitude at some distance from the poles. They had their declinations set down, that is, their distance from the equinoctial. The next seven stars were stars close to the South Pole, and so their polar distance was given, i.e.
their angular distance from the South Pole, while the last five stars being stars close to the North Pole had their polar distance given. This arrangement simplified the calculations involved in a star sight, and also the business of selecting and identifying a star suitable for observation. This task was further facilitated by marginal information on the time of each star’s meridian transit at night.

\[\text{Fig. 25}\]

'THE TYPE OF A TRAVERSE BOARD AND A PROTRACTOR'

(After the illustration in John Tapp's *The Seamen's Kalender*, 1602)

The earliest illustration of the method of plotting a ship's course on a Traverse or Plotting Board. It is interesting to find Tapp citing as an example a voyage to the island of Maida. This was a mythical island supposed to be south-west-by-westerly, distant some 299 leagues from Land's End. It will be found on many sixteenth-century charts, including Hood's chart of 1592.

The methods of working out sun and star sights were amongst the examples given of the use of the ephemerides. These were followed by examples, for the oceanic navigator, of how, knowing the longitude and latitude of two places, he could calculate mathematically the distance between
them. Since such a problem using the only known method, long division and multiplication, took up several pages, it can be appreciated why mathematical navigation was still rarely practised. Such workings also point to why Tapp's succeeding section was of much more practical value. In this he explained how, allowing for the convergence of the meridians by means of an accompanying table of 'Miles to a Degree of Latitude', the navigator could plot the track of his ship on a traverse board. This explanation he illustrated by a diagram of a plotting board, a protractor, and the track of a ship sailing from the Lizard (A) to 'an Iland in the Ocean Sea called Maida' (E) with a wind 'scant or contrary, so that you cannot saile a direct course'.¹ The prudent navigator, after the adverse wind, of course ran south so as to make his latitude short of the island, and then close it by sailing along the parallel in the right direction.

A geographical table of latitudes and longitudes completed the book. Tapp took Molyneux's prime meridian (evidence of the use of the globes), the westernmost part of St. Michael's in the Azores. London's longitude he recorded according to the five meridians in current use and in the customary eastwards direction. Tabulated, these were:

<table>
<thead>
<tr>
<th>Prime Meridian</th>
<th>London's Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Africa</td>
<td>10° 20' (E)</td>
</tr>
<tr>
<td>Canaries</td>
<td>18° 00'</td>
</tr>
<tr>
<td>Canaries more to westward</td>
<td>19° 30'</td>
</tr>
<tr>
<td>St. Michaels, westernmost part</td>
<td>25° 40'</td>
</tr>
<tr>
<td>Ile de Pico (Jodocus Hondius)</td>
<td>27° 40'</td>
</tr>
</tbody>
</table>

The chief purpose behind William Barlow's 'friendly Advertisement' of 1597 in The Navigators Supply had been to urge the study of mathematics and of navigation, under competent teachers, by all young men aspiring to go to sea in command of ships. To this end he desired, like Hakluyt, the creation of a chair of public lectureships in navigation, and of machinery for joint consultation between the teachers and theorists of navigation and the practical navigators. 'Except there be a uniting of knowledge with practise there can be nothing excellent', he wrote, and averred that a keen student could learn as much in a month under the system he advocated as an apprentice could during his seven years at sea. A strong plea for a lectureship in navigation, and for the examinations of masters and pilots for competency, along the lines of the Spanish system, was made by Hakluyt in two of the volumes of his revised Principal Navigations, which came out in 1598. So keenly did he feel on the subject that he drew the attention of the Lord High Admiral especially to the matter and later included a report of the Spanish form of examination.² From the

¹ See Fig. 25. ² See Appendix 19.
advocacy of these two authors at this time it would appear that Hood's public lectures had lapsed. If this was so, though one authority has it that Edward Wright succeeded Hood, then the keen student of navigation was entirely dependent for instruction upon the rapidly growing number of 'students of mathematics', professors of mathematics, chart and instrument sellers congregated round St. Paul's Churchyard and Wapping Steps, whose advertisements were now beginning to appear in text-books and almanacs. There was no organized instruction, unless apprenticeship to a master or service in the train of some gentleman adventurer could be counted as such. As things turned out, neither Barlow's nor Hakluyt's schemes were taken up by the Government, for in this very year, 1598, the provisions of a will made twenty-three years previously by a far-sighted financier, Sir Thomas Gresham, founder and builder of the Royal Exchange, were put into effect, and a college was opened where navigation was one of the subjects publicly taught. This was Gresham College.

It was Sir Humphrey Gilbert who had first put forward a clear-cut scheme of higher education based in principle upon the application of science to daily activities. This had been in about 1572. He had visualized a 'Queen Elizabeth's Academy' where matters of 'action' were to be studied by selected youths. While this in itself struck a new note in higher education, his proposals for the teaching staff were even more unorthodox. Two professors, one of arithmetic and one of geometry, were to teach, the one military subjects, the other 'cosmography and astronomy, with navigation', and how 'to draw maps, sea charts, and perspective'. Gilbert's scheme came to nothing, but three years later its essential features were embodied in the will of Sir Thomas Gresham, which contained the statutes of, and the provision for, a college to be founded in London after his death and that of his wife. When this occurred seven professors were to be lodged in his mansion, and were to receive from the revenue of the Royal Exchange an income of fifty pounds a year each for lecturing respectively on law, rhetoric, divinity, music, physic, geometry, and astronomy. Sir Thomas died in 1579, Lady Gresham not until December 1596. Then the Corporation of London and the Mercers Company, to whom the running of the college was to be entrusted, could at last take action. So it was that 1598 saw the college opened and the first professors appointed. The first Professor of Geometry was the brilliant mathematician, Henry Briggs.

The foundation of Gresham College was one of the most significant

1 That Edward Wright succeeded Hood as lecturer in navigation in Sir Thomas Smith's house in Philpot Lane until 1614, when he was appointed hydrographer to the East India Company, is stated in the article by Parsons, E. J. S. and Morris, W. F., 'Edward Wright and his Work', Imago Mundi, Vol. 3. The lectureship must have lapsed, (see Wright's dedication of The Haven-finding Art, 1599), but Tapp states in his dedication to Sir Thomas Smyth of The Pathway to Knowledge, of 1613, that there had been such a lectureship for some time, so it had evidently been revived.

events not merely in English educational and navigational history but in the general history of the development of science. Gresham College brought mathematics, the language of science, within reach of common men and harnessed it to their service, and formed a nodal point for the collection, discussion, and systematic examination of scientific problems. Its establishment confirmed that in England the scientific era had begun. At the universities, at Oxford and Cambridge, although in the sixteenth century the quadrivium included arithmetic, music, geometry, and astronomy, instruction was perfunctory. Cambridge did not emulate the mid-century enthusiasm of John Dee and William Cuningham for mathematics. At Oxford in the latter part of the century Sir Henry Savile, it is true, taught astronomy, but until he founded the Chairs of Astronomy and of Geometry, in 1619, the university evinced remarkably little interest in the subject. The fact is, the higher studies of Tudor mathematicians were made after leaving the universities, on their own initiative. Robert Recorde, the most influential of the pre-Elizabethan Tudor mathematicians, the father of English mathematics, won his mathematical reputation not as an academician, though he was a graduate of Cambridge, but when he was a physician. The same is true of William Cuningham, of John Dee, except that he was an astrologer and not a physician, and of Thomas Hood, to name only the most notable. Nor is this surprising. Until the middle of the century the universities were primarily ecclesiastical in purpose and outlook. Elizabeth’s accession to the throne confirmed, however, not only the Reformation in England but also the revolution, the secular changes involved in the Reformation, the creation of new estates, new money, new families, the cultivation of the new learning. It was inevitable that the universities should be slow in adjusting themselves to the heightened tempo and wider outlook on life ushered in with the expansion of English maritime commerce, and to the new type of young man to be educated.

In the first half of the century the cultivated man, Erasmus considered, needed no more than ‘a smattering of Arithmetic’. The year 1570 that saw Billingsley’s *Euclid* and Dee’s challenging *Preface*, found Roger Ascham, Elizabeth’s one-time tutor, condemning, in *The Scholemaster*, mathematicians as solitary and ‘unapt to serve the world’. Eleven years later, it is true, Mulcaster was advocating the teaching of mathematics as a training for the mind, but he was years ahead of his time.

In the grammar schools, where from the middle of the sixteenth century elementary education was conducted, it was exceptional for even arithmetic to feature in the curriculum. At the higher grammar schools it was never taught. At the lower ones, when it was, it was taught only to those ‘best fitted for the trades’, or ‘dul at learning’. Even then there were two sorts of arithmetic, mechanical or the ‘casting of accounts’ by the manipulation of a mechanical calculating aid, the *abacus*, and ‘cyphering’ or ‘arithmetic with the pen’. Although ‘algorisms’, the arabic numerals, had been introduced into Europe in the twelfth century, their use had spread extremely slowly. For example, the accounts of all
the Tudors were kept in Roman numerals. In the middle of the sixteenth century the first English navigators also used Roman numerals, as we have seen. Although, thanks to Recorde, Billingsley, Dee, the Digges, father and son, Bourne, Hood, and Blundeville, a growing number of educated men were beginning to recognize in the last quarter of Elizabeth’s reign the utilitarian value of geometry and arithmetic in accountancy, surveying, siegecraft, and, above all, navigation, the popular, ill-informed view, lasting well into the seventeenth century—for there was little change in grammar school education—was as often as not that the student of mathematics was ‘smutted with the black art’, and that his subject smelled of the Devil and his machinations. The consequence was that to most men mathematics was an unknown art, ‘cyphering’ an unusual accomplishment, and mathematical calculation, however simple, a remarkable feat. Indeed it was far from easy, as the signs of addition (+), subtraction (−), and of equality (=) were not in universal use until the seventeenth century, so that one man’s arithmetic might be as incomprehensible as today one man’s short-hand is to another; logarithms were still unknown and division was not done by the present simple method.1

In stipulating as early as 1575 that the geometry professor of his college was ‘to lecture for one term on arithmetic, the next on theoretical geometry, and the third on practical geometry’, Sir Thomas Gresham was clearly ahead of his time. In directing that the astronomy professor was to read ‘the principles of the Sphere and the theoriques of the planets, and to explain the use of common instruments for the capacity of mariners’, and to apply ‘these things’ to use by reading geography and the art of navigation, he was again prescient, for he was catering for the greatest need in English navigation at the end of the century, practical and theoretical instruction and research by educated men. He showed his wisdom in another way too. He insisted upon instruction in English, in the vulgar tongue, reminding his professors that their hearers would be ‘merchants and other citizens’, and directing that they were not to read their lectures, as at the universities, in Latin, but were to tune them to ‘the pitch and capacity’ of their audience. This in the 1570s was revolutionary.

In practice the professors gave their lectures in Latin as well as in English—for the benefit of foreigners—but they gave them in public. This was important. What was equally important was that, being housed in the greatest port and in the commercial centre of England, hard by the principal naval bases and the seat of government, the professors of geometry and of astronomy were in a position to keep in constant touch with the practical needs of the practical men who, by their efforts at sea, had raised England into the front line of nations. Further, the fact that the income and thus the position of these lecturers were assured gave a sense of permanence and of continuity to their work hitherto lacking in such lecturerships as Hood’s. In the middle of the seventeenth century, out of

1 Plus and minus signs were first devised by John Widman in 1489, the sign of equality by Robert Recorde, in 1540.
the informal gatherings customary in the rooms of the Gresham professors of astronomy and geometry after their lectures, was developed the first scientific society in the English-speaking world—the Royal Society.¹

It was not long before the first results of Gresham College were seen. But first we must go back to the early 1580s. A year after the publication, in 1581, of Robert Norman’s *The Neve Attractive* and William Borough’s *A Discours of the Variation of the cumpas* a certain William Gilbert of Norwich, in due course one of Queen Elizabeth I’s physicians, started studying methodically the nature and properties of the lodestone and of magnetism. There is little doubt that these two navigational works of Norman and of Borough inspired Gilbert’s researches. It would seem that he and William Barlow, who was similarly engaged, exchanged views and information. Edward Wright was closely associated with Gilbert’s work. Thomas Blundeville, besides being a personal friend of Gilbert’s, was a keen follower of his investigations. In 1600 Gilbert published the fruits of his researches in what is generally acclaimed as the first truly scientific English treatise. It will be recalled, though, that Norman’s work is more deserving of that fame. Gilbert’s work was the famous *De Magnete*. Although the major part of *De Magnete* was devoted to the problem of the nature of electricity and magnetism, its later chapters dealt with the practical application of Gilbert’s conclusions to the problems of navigation. In this it promised to be of considerable value to mariners. Gilbert’s theory of variation, for instance, was of interest. He rejected the current theory that the magnetic poles were situated some 20° distant from the geographical poles, at determinable points, and that this was the cause of variation. He postulated the idea that variation was caused by the proximity of land masses, and by the varying depths of the ocean. While this idea cleverly accounted for the now generally acknowledged irregularity of the distribution of variation, which he held to be unchangeable at any given place, it damped yet more the spirits of those hoping to be able to use the asymmetric theory of the magnetic poles as an aid to longitude finding. Nevertheless, by paying special attention to magnetic dip he raised the hopes of those who saw in this the means of determining latitude independently of dead reckoning and

¹ The importance of Gresham College as a centre of scientific research, particularly in connexion with the mathematical solution of navigational and astronomical problems is ably discussed in ‘Gresham College, Precursor of the Royal Society’, by Johnson, F. R., *Journal of the History of Ideas*, Vol. 1. The same author’s *Astronomical Thought in Renaissance England* (Baltimore, 1937) deals in a masterly way with astronomical thought in England and the writings and activities of English astronomers in the sixteenth and early seventeenth centuries. It is particularly valuable for showing their relation to the current navigational problems. It contains an admirable bibliography.

The functions of Gresham College are also clearly outlined in Foster Watson’s *The Beginning of the Teaching of Modern Subjects in England* (1909). It also contains valuable chapters on the teaching and growth of mathematics in sixteenth and seventeenth century England, and of popular interest (or the lack of it) in mathematics.

See also Appendix 17.
of celestial observations. The reason why they were anxious to find such a means was the perennial one of the seaman—the desirability of being able to fix his ship’s position accurately at all times; not merely in mid-ocean but especially in coastal waters when fog, rain, mist, or falling snow blots out the seascape and shrouds from view the dangers of a treacherous lee-shore. Gilbert took up Norman’s discovery of dip. Norman, it will be recalled, had devised a dip-needle mounted in a brass ring mounted on a pedestal. William Barlow modified this instrument for use at sea by fitting it with a suspensory thumb ring and by enclosing the sides of the dip-needle case, which measured about 5¾ inches in diameter and 1¼ in breadth, with discs of unbacked Venetian mirror glass. Thus modified, the dip-needle could be used easily at sea. Suspended in the cock-pit, where it was out of the wind, and aligned north and south, the dip needle could be read quite accurately. Gilbert’s contribution was to add an horizon line of brass and to incorporate the description of the instrument in his work. He also invented a second instrument to be used in conjunction with the dip needle. This was a disc of brass, or of pasteboard, on which were engraved a ‘spiral’ dip line and parallels of latitude. By means of this instrument, and a ruler, the latitude of a place could be determined mechanically it was hoped, by reference to its dip. It was one thing for a scientist to describe in Latin the making of such instruments, quite another to get untutored mariners to use them. It was the business of Gresham College to bring the two together. However, the dip-dial was not easy to construct; its engraving alone was a skilled job. Edward Wright, we have seen, was an enthusiastic improver of navigational aids and methods, particularly of magnetic ones, and he was keen to get the Gilbert-Barlow dip instruments before the seafaring public. Equally so was Gilbert. Thomas Blundeville, no less enthusiastic for the cause, being a friend of Gilbert’s, was easily persuaded to add, as an appendix to a book he was bringing out on the planets, the requisite brief treatise, written ‘at the motion of Dr. Gilbert by Edward Wright’. Blundeville also included a table, compiled by Henry Briggs, the Gresham Professor of Geometry, which did away with the need for Gilbert’s brass disc. Thus it was that in 1602, the year that The Seamans Kalender was first published, there appeared The Theoriques of the Seven Planets . . . a Booke most necessarie . . . for all Pilots and Sea-men, or any others that love to serve the Prince on the Sea . . .’, by Thomas Blundeville with, appended to it, The Making, Description, and Use, of two most ingenious and necessarie Instruments for Sea-men, to find out thereby the latitude of any place upon the Sea or Land, in the darkest night that is, without the helpe of Sunne, Moone, or Starre. . . .

1 See Pl. LXIII. ‘I was the first’, claimed William Barlow in his Magneticall Advertisements of 1616, ‘that made the inclinatory instrument transparent, to be used pendant, with a glass on both sides, and a ring on the top . . . and moreover I hanged him in a compass box, where with two ounces weight he will fit for use at sea.’ This last was evidently a later refinement.

2 THE Theoriques of the seven Planets, shewing all their diverse motions, and all other Accidents, called Passions, thereunto belonging. Now more plainly
Blundeville’s work on the planets, an illustrated book of some bulk, showing their motions, was undoubtedly erudite, but its practical value must really have been small. The most important part was the appendix, and of that the most valuable was the final sheet of paper. This embodied the results of Briggs’s laborious calculations, doing away with the need for a dip-dial. Four columns of figures contained the angle of dip calculated for every degree of latitude between $1^\circ$ and $90^\circ$. Thus the co-ordinated efforts of four men of science resulted in their devising, out of a complexity of research and calculation, the simplest and most necessary aids for seamen. Although the data on which they had based their work was to prove inadequate and their labours to be in vain, yet it was their pioneer efforts and the institution of Gresham College that made possible the progress towards modern aids to navigation.

The powers given by the Act of 1565 concerning Sea marks and Mariners’ to the Trinity House of Deptford Strand will be recalled. The Master and Wardens had interpreted the Act as empowering them to set up sea-marks on banks dry at any time as well as on the seashore itself and also, as ‘the placing and laying out of buoys in convenient places of the sea and channel, for passing into and out of havens and rivers is a thing more necessary to forewarn, shun and prevent the peril and danger of those places,’ to lay out buoys in channels. In doing this they were exposing themselves to the charge of infringing the rights of the Lord High Admiral. For long he had been responsible to the Crown for discharging the offices of buoyage and beaconage, and had been allowed to levy on this account both buoyage and beaconage on ships entering or leaving

set forth in our mother tongue by M. Blundeule, than euer they haue been heretofore in any other tongue whatsoeuer, and that with such pleasant demonstrative figures, as euyer man that hath any skill in Arithmetick, may easilie vnderstand the same. A Booke most necessarie for all Gentlemen that are desirous to be skilfull in Astronomic, and for all Pilots and Sea-men, or any others that loue to serve the Prince on the Sea, or by the Sea to trauell into foraine Countries.

Whereunto is added by the said Master Blundeule, a briefe Extract by him made, of Maginus his Theoriques, for the better understanding of the Prutenicall Tables, to calculate thereby the diuerse motions of the seuen Planets. There is also hereto added, The making, description, and vse, of two most ingenious and necessarie Instruments for Sea-men, to find out thereby the latitude of any Place upon the Sea or Land, in the darkest night that is, without the helpe of Sunne, Moone, or Starre. First inuented by M. Doctor Gilbert, a most excellent Philosopher, and one of the ordinarie Physicians to her Maiestie: and now here plainly set downe in our mother tongue by Master Blundeule. London, Printed by Adam Islip. 1602.

The second part, in the same volume, has this title page: THE MAKING, DESCRIPTION, AND VSE, OF TWO MOST INGENIOVS AND necessarie Instruments for Sea-men, to find out thereby the latitude of any place upon the Sea or Land, in the darkest night that is, without the helpe of Sunne, Moone, or Starre. First inuented by my good friend, Master Doctor Gilbert, a most excellent Philosopher, and one of the ordinarie Physicians to her Maiestie: and now here plainly set downe in our mother tongue by Master Blundeule. London, Printed by Adam Islip. 1602.

1 See Pl. LXIV.
LXII. PRINTED CHART OF THE STRAIT OF GIBRALTAR, 1595.
LXIII. 12" Dip Ring of the Seventeenth Century.
ports. In practice the Lord High Admiral was extremely unlikely to object to Trinity House discharging his offices of buoyage and beaconage for, so long as the Master and Wardens did not interfere with its perquisites, he could only benefit from their activities. The Act of 1565 had not empowered Trinity House to levy any additional dues to defray the expenses incurred by their increased responsibilities, and by the 1590s a situation had arisen whereby Trinity House was maintaining important and expensive fairway beacons and buoys out of its ordinary revenue while the Lord High Admiral, nominally at least, was receiving the buoyage and beaconage which should have defrayed the cost of their laying out or setting up and maintenance. The trouble was that the Lord High Admiral leased out the buoyage and beaconage of the various ports to deputies, primarily no doubt for their personal benefit, in return for services rendered to him or the Crown directly. Inevitably the provision of as few beacons and buoys as possible and the collection of as much buoyage and beaconage as possible became the main concern of the lessors. Other important perquisites of the Lord High Admiral had for long been lastage and ballastage, dues levied on ships according to their lading and for ballasting with stones and shingles dredged from the harbour-beds. These too the Lord High Admiral farmed out. One consequence was that ballast was not necessarily obtained from those channels which it was in the best interests of the ports to deepen and widen by dredging. By now London was the greatest port in the realm. With the steady improvement in ship design and the improved arrangements for pilotage initiated early in the century, ships which had hitherto loaded or discharged at the channel ports between Southampton and Dover in order to avoid the hazardous and often protracted doubling of the North Foreland, the variable winds and strong tidal streams in the Strait of Dover, and the intricacies of the Thames estuary, now made the port of London itself their destination and their port of departure. As a consequence the overland carriage of cargoes between the south-eastern ports and London had dwindled, the trade of these ports had declined, while that of London had increased correspondingly. Moreover, as a result of the expanding overseas trade, it had developed still further. The problem of the buoying, beaconing, and dredging of the Thames channels had thus grown to be one of national importance.1 Trinity House had to choose between infringing the Lord High Admiral’s rights by levying dues to meet its rising costs, or curtailing—with disastrous effects upon shipping using the Thames—its beaconing and buoying activities. In the event the Lord High Admiral, Lord Howard of Effingham, rose to the occasion with the same statesmanlike ability that he had displayed during the Armada campaign. In 1593 he relinquished to the Crown the offices and dues of lastage, ballastage, beaconage, and buoyage in the Thames that the Crown might grant them—which it did—to the Master, Wardens, and Assistants of the Trinity House of Deptford Strand. The

1 See Pl. LXIV.

20—A.O.N.
Crown on the same date—6 June 1594—confirmed that Trinity House was entitled to have set up or to have laid out, and to set up or to lay out in the future beacons and buoys ‘in or upon the sea, and places navigable’, as well as on the ‘sea shores, coasts near the sea, or uplands or forelands’, of England. Thus the means as well as the powers of Trinity House to ensure the safety of shipping in English waters of pilotage were greatly increased and an anomalous situation concerning the chief port of the realm was removed. In other ports the Lord High Admiral still retained his rights, but at Hull, from 1594, the local Trinity House became responsible for the buoying of the Humber—and a great trouble and expense they found it to involve during the winter months, what with hiring boats and boats’ crews to recover the buoy when it broke adrift, purchasing new moorings and sinkers, and re-laying the buoy.

The Trinity House of Deptford, like that of Hull, did not maintain a staff to lay out or set up and maintain its navigational aids, but leased the work out to contractors for an annual rental. For instance, in 1605, a certain Ponny, of Stroud (Strood on the Medway), was commissioned by the Deptford Trinity House ‘to keep, repair, maintain, and uphold 8 buoys and 3 beacons, or 6 buoys and 5 beacons’, the buoys with their dimensions being specified, the beacons to be erected at the Whitaker, the Shoe, the Last, and the Nore, for a payment of £70 a year during his life. Seven years later he undertook the same task for £80 a year.

The effect of granting the office, rights, and emoluments of ballastage in the Thames to Trinity House was of no less importance than the grants of beaconage and buoys, for it meant that henceforth those most interested in the facilities of the port of London would be able to ensure that ballast was removed from the river-bed and beaches in such a manner that the existing channels would be progressively widened and deepened by dredging and kept scoured by tidal action. The records show that this was in fact what happened. The dredgers—lighters manned by teams of men armed with long poles, termed spoons, with an iron framework and a leather bag attached and held by a rope leading to one end of the lighter—commenced working at half ebb and continued until the flood lifted them too high, when they proceeded to the ships requiring ballast, into which it was thrown before the ebb recommenced and carried them back to their appointed stations.  

Thus by the close of Elizabeth’s long reign not only were her men of science and her navigators tackling the problem of improving the knowledge, skill, and aids of those who occupied their business in great waters, but Trinity House was taking practical measures to ensure the greater safety of the channellers, and of all shipping passing into and out of the havens and rivers of the realm.

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1 The chief sources on navigational aids and Trinity House are:

Whormby, J., *An Account of Trinity House and of Sea Marks* (1746), Alton, J., *Memoir of Trinity House* (1831) in which the relevant acts, grants, and charters are reproduced in full or in part.
Chapter Three

SEAMEN AND SCIENTISTS
IN PEACE
1603–1622

‘the Sea yeelds ... the World to the World ... by this Art of arts, Navi-
gation.’

Purchas his Pilgrimes, 1625.

‘... in our time the whole Art of Navigation is grovne to much greater
perfection, then ... ever it had in any former ages.’


In many ways the reign of James I, who succeeded Elizabeth in March
1603, makes sorry reading. In maritime affairs it is customary to lay
the emphasis upon the sudden, prolonged and almost total eclipse of
the Royal Navy as an efficient fighting force, and upon the scandalous
corruption prevalent in high places, upon the callous neglect and cruel
treatment of the seamen serving in the royal ships, and upon the humiliat-
ing failure of the only naval operation of note in the reign—the futile
Algiers expedition of 1620–21. In matters of commerce the growing
ascendancy of the Dutch in the home carrying trade, and their supremacy
in the East Indies are stressed, while political and religious conflicts colour
the whole panorama of the years. Yet there are other aspects that are apt
to be overlooked; the reign of James saw the development on a com-
mmercial scale of the telescope, and the discovery of new worlds beyond the
known world. In mathematics and navigation they witnessed one of the
most useful developments of modern times, the invention of logarithms.
The journals of English mariners of this reign increasingly record success
in the establishment of colonies which gave rise to new trades across the
western ocean.

One of James’s first actions on succeeding to the English throne had
been to declare hostilities with Spain at an end, and to negotiate a peace
treaty. This had been signed in 1604, and, resolving none of the underlying
economic and colonial issues of the war, left Englishmen for years with the
conception of Spain as the arch-enemy. As until 1608 the United Provinces
continued a Spanish war, Hollanders were looked upon favourably, and
in the opening years of the reign continued to be freely served. The
Dutch, for their part, continued to reciprocate the Englishmen’s friendly
feelings. It paid them to do so. But with the signing in 1609 of the nine-
year Truce of Antwerp their attitude changed. They now regarded the

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English first and foremost as trade rivals in a world of limited markets. They grew almost openly hostile. Indeed in the East Indies, despite a treaty of friendship with Britain, their hostility eventually culminated in the atrocious massacre of Amboyna in February 1623. From then on Anglo-Dutch relations grew increasingly embittered. Though they were not yet, to use a nautical expression, to part brass-rags, the Dutch and English went different ways in the East. The English abandoned the Indies to the Dutch, and concentrated upon the Indian peninsular trade. The Dutch, having evicted the Portuguese from all their important trading-posts, monopolized the archipelago. Having mastered, by the help of the English, the art of navigation, they felt competent to find their own way over the oceans.

In other regions the Dutch were already asserting their independence. Once again they had been given the lead by Englishmen. The survivors of Barents's third voyage to the north-east had returned in 1597 with reports of whaling prospects in the waters around Spitzbergen. The Muscovy Company had at once claimed it as their preserve. With the help of skilled Spanish whalers from Biscaya they had started a whale-fishery. In 1612 they obtained a charter from James I giving them the monopoly of the fishery. Unfortunately this was the very year that the Dutch, reaping the benefit of the Truce of 1609, felt the time opportune to participate also in the Spitzbergen whale industry;

The Hollanders [ran one account] to keep their wont in following of the English steps came to Greenland [Spitzbergen] with one ship, being brought thither by an Englishman, Allen Sallowes, a man employed by the Muscovia Companie in the Northerne Seas for the Space of twenty yeers before; who leaving his country for debt, was entertained by the Hollanders and employed by them to bring them to Greenland for their Pylot ... there was also a Spanish ship from San Sebastian, brought thither by one Nicholas Woodcock this yeare, a man formerly employed by the said Companie.¹

Henry Hudson was serving the Dutch East India Company in 1609, when, failing to find a North-East Passage to Cathay, he doubled back, crossed the Atlantic, and explored the river named after him, hoping it was the North-West Passage. British mariners extended their services to other countries also; thus, Scots and English mariners led the Danish expeditions of 1605, 1606, and 1607 to West Greenland in search of the ancient Norse settlements, and John Adams, reaching Japan in 1612, initiated the Japanese into the arts of western navigation and shipbuilding. Others rendered less creditable service, turning to piracy. Captain Smith

in his *True Travels* gives an account of some of these, from whom the Barbary pirates learnt their navigation.\(^1\)

Ward, a poore English sailor, and Dansker a Dutchman, made first here their marts, when the Moores scarce knew how to saile a ship; Bishop was Ancient, and did little hurt, but Easton got so much, as made himselfe a Marquessa in Savoy; and Ward lived like a Bashaw in Barbary; those were the first that taught the Moores to be men of warre, Jennings, Harris, Thompson, and divers others, were taken . . . Hewes, Bough, Smith, Walsingham, Ellis, Collins, Sawkwell, wolleston, Barrow, Wilson, Sayres, and divers others, all these were Captaines amongst the Pirats, whom King James mercifully perdoned.

Many quarrelled so amongst themselves 'till they became so disjoynted, disordered, debawched, and miserable, that the Turks, and Moores beganne to command them as slaves, and force them to instruct them in their best skill which many an accused runnagado or Christian turned Turke, did'. Thus it was that men like Thomas Ward, mentioned by Smith, and Sir Francis Verney and Sir Henry Mainwaring, mention of whom he tactfully omitted, whose careers read like improbable romances, taught the Barbary pirates the art of oceanic navigation. The result was that in the first half of the seventeenth century these pirates scourged the seas of north-west Europe and terrorized the inhabitants in the coastal regions. Between 1609 and 1616 alone they captured four hundred and sixty-six British vessels, many of them in English waters.

Whilst these Barbary pirates were the most renowned, they were by no means the only ones. Many Englishmen—and Frenchmen—operated from bases nearer home. Piracy was a real threat. Working from creeks and havens in the rugged coasts of Brittany, Devon, and Cornwall, where the isolation of the hamlets and villages cloaked the lawless activities of many poverty-stricken and brutal men, small craft would scud out to surround and loot a merchantman becalmed off shore. On dark and windy

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\(^1\) THE TRUE TRAVELS, ADVENTVRES, AND OBSERVATIONS of Captaine IOHN SMITH, in Europe, Asia, Affrica, and America, from Anno Domini 1593 to 1629. His Accidents and Sea-fights in the Straights; his Service and Stratagems of warre in Hungaria, Transilvania, WALLACHIA, and Moldavia, against the Turks, and Tartars; his three single combats betwixt the Christian Armie and the Turkes. After how he was taken prisoner by the Turks, sold for a Slave, sent into Tartaria; his description of the Tartars, their strange manners and customs of Religions, Diets, Buildings, Warres, Feasts, Ceremonies, and Living; how hee slew the Bashaw of Nalbrits in Cambria, and escaped from the Turkes and Tartars. Together with a continuation of his generall History of Virginia, Summer-Iles, New England, and their proceedings, since 1624. to this present 1629; as also of the new Plantations of the great River of the Amazons, and Barbados in the West Indies. All written by actuall Authours, whose names you shall finde along the History.

LONDON, Printed by J.H. for Thomas Slater, and are to bee sold at the Blew Bible in Greene Arbour, 1630.
nights a donkey with a lantern tied to its head to simulate a ship's lantern rising and falling with the send of the sea, would be driven along the shore to lure the hesitant sail sighted at dusk on the horizon to its doom upon the unexpected reefs running out from the shore, or upon the bar across the river's mouth. Ireland was a favourite advance base for the better organized and better found pirates. The loughs and havens of southern Ireland afforded innumerable isolated hiding-places where loot could be sorted and shared and where the vessels could be careened or breamed on friendly beaches to free them of the weed and barnacles that could prove fatal in the event of pursuit by men of war. By 1611 the Dutch had got thoroughly exasperated by the activities of both the Barbary and Irish-based pirates. In that year, in an endeavour to put an end to both, the Dutch States-General issued a stern decree forbidding intercourse with the pirates under threat of severe penalties, and fitted out a fleet of seventeen ships under the command of the Zealant Vice-Admiral Houl- tain, who had orders to capture every ship 'that had no letters of marque from the Prince or Government, whatever nation it might belong to'. Some of Houtain's fleet sailed in October, the rest in November 1611, and the journal which he ordered to be kept records that, on receiving news from French merchantmen of a fleet of sixteen pirate ships at sea off Cape St. Vincent, the force proceeded to the coast of Spain. For four months—while the winter storms to the north cleared the seas of lawful shipping and of pirates alike—Houtain's fleet cruised in the waters off Spain, Portugal, Morocco and around the Canaries, according to information received. About mid-April, 1612, having already sent some ships on ahead, Houtain decided to proceed with the rest to the coast of south- west Ireland. After cleaning his ships there of barnacles and weeds, his intention was to surprise and capture the pirates who, with the returning warmth of spring, would, like flies, be stirring to be about their pestilential work. He arrived at Crookhaven on 28th April, and having put his ships into better trim for successful pursuit, he spent eight days scrutinizing the south-west coast of Ireland with every available ship and boat. But his luck was out. Not a pirate was to be found, and, early in May, he left the coast and proceeded home to Flushing. While there was nothing remarkable in Houtain's failure to find pirates' craft, for they were as elusive to his ships as is the U-boat to the modern ship of war, his cruise is of particular interest because it reveals the reliance of the Dutch upon English pilots. Houtain took one with him, John Hunte of Plymouth. Hunte had compiled a rutter and prepared a chart of the S.W. coast of Ireland. Another English pilot, Levy of Wexford, had provided him with additional data for the rutter, and one Dirck Gerritz had drawn two charts of the east coast for him. Hunte had taken further information from Wagenaer's Thresoor der Zeevaerdit of 1596 and Enchuser Zeevaerditboeck of 1598. The resultant rutter, primarily Hunte's work, had been translated into Dutch and the charts had been engraved and printed by the well-known Dutch publisher, Hessel Gerritz, for use by the fleet. Hessel Gerritz was commissioned
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by order of the High Noble Lords of the Admiralty residing within Amsterdam to publish the charts and rutter. This he did, with the addition of a general chart of Ireland and the Irish Sea, being paid thirty 'pounds Flemish' on 12 November 1612 for doing so. Such is the origin of Hessel Gerritsz's rare Beschrijvinghe vande Zeecusten ende Havenen van Yerland.

Despite the losses from pirates English ships were in demand as much for their fighting qualities and seaworthiness as for the navigational skill of their masters. 'I have engaged five most capital vessels . . .', wrote the Venetian Ambassador in England to the Doge and Senate in 1618. 'Some Flemish ships were offered me at a much cheaper rate, and also of much heavier tonnage; but the English being held in infinitely greater account by reason of the strength of their build, the quality of their guns, and their crews, which yet more excel all other nations in battle, I did not choose to part with them.' The fact is, although the Royal Navy, through graft and nepotism, was in a decadent state, the Jacobean seaman, like the seaman of later Elizabethan days, was an expert in gunnery. Lucar's 1588 Appendix to and translation of Tartaglia's The Arte of Shooting,

1 Cannenburg, W. V., 'An Unknown "Pilot" by Hessel Gerritsz, dating from 1612', Imago Mundi Vol. 1. (1935). The title-page and four charts are reproduced.
3 THREE BOOKES OF COLLOQUIES CONCERNING THE ARTE OF SHOOTING IN GREAT AND SMALL PEECES OF ARTILLERIE, VARIABLE randages, measure, and weight of leaden, yron, and marble stone pellets, minerall saltepeeter, gunpowder of diuers sortes, and the cause why some sortes of gunpowder are corned, and some sortes of gunpowder are not corned: Written in Italian, and dedicated by Nicholas Tartaglia vnto the Royall Prince of most famous memorie HENRIE the eight, late King of England, Fraunce, and Ireland, defender of the faith &c. And now translated into English by CYPRIAN LVCAR Gent. who hath also augmented the volume of the saide Colloquies with the contents of every Colloquie, and with all the Corollaries and Tables, that are in the same volume. Also the saide CYPRIAN LVCAR hath annexed vnto the same three bookes of Colloques a Treatise named LVCAR APPENDIX collected by him out of diuers Authors in diuers languages, to shew vnto the Reader the properties, office, and dutie of a Gunner, and to teach him to make and refine artificial saltpeeter, to sublume brimstone for gunpowder, to make coles for gunpowder, to make gunpowder of diuers sortes and of diuers colours, to make gunmatches, touchwood, and fire stones, to know the weight and measure of any pellet, to make carriages, ladies, rammers, scouers, and cartedges for any great piece of artillerie, to know the proportioned length, due thickness and weight of euery great piece of artillerie, to know what number of men, horses, or Oxen wil drawe any great piece of artillerie, to make platformes for great ordinance, to make gabbidons of earth for the defence of gunners in time of seruice, to charge euery great piece of artillerie with his due charge in serpentine gunpowder, and also in corne gunpowder, to shoote well at any marke within point blanke, to shoote well at any marke upon a hill or in a valley without poynct blanke, to shoote well at a marke in any darke night, to mount morter peeces to strike any appointed marke, to tell whether a thing scene farre of doth stand still, come towards him, or goe from him, to make and vse diuers Trunkes, and many sortes of fire workes, to make mynes, to measure altitudes, longitudes, latitudes, and profundities, to draw the true plat of any place, and to do other
and Thomas Smith's *The Art of Gunnery* of 1600 had served to maintain the high standard of Elizabethan gunnery initiated by Bourne's work of 1578. They also served the Jacobeans well for the first quarter of the seventeenth century. It should be explained that the losses that the Jacobeans suffered at the hands of the Barbary pirates were not so much the fault of their gunnery as the result of the small size and slow speed of the vessels attacked, of the pirates' pack-tactics, executed with small, especially speedy and therefore elusive craft, and of the abandonment by the Government of convoy. The ships of the Chartered Companies, well armed and sailing in company for mutual support, did not fall victims to the pirates.

It was in the service of the Chartered Companies, of the Muscovy, Levant, and East India Companies, of the Virginia Company of 1606, of the later Newfoundland Company, and the short-lived North-West Passage Company of 1612, that the English navigators chiefly maintained their reputation for skill and sound seamanship. Nevertheless, from the opening of the century far larger numbers of them than were ever employed by the Companies had been engaged in individual and clandestine trading along the Spanish main. It was with the ending of hostilities that they increased and improved the organization of their activities across the ocean. Indeed, while peace was still in the air in 1602, the East India Company, anxious to find if possible a shorter route to the East than that by the Cape of Good Hope and still ignorant of the outcome of their first commendable things which not onelie in time of warre, but also in time of peace may to a good end be practised.

*La possessione delle ricchezze non è sicura, se la non si salua con la difensione delle armi.*

[PRINTED AT LONDON FOR (J)ohn Harrison. 1588.]

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1 THE COMPLETE SOULDIER. Containing the whole Art of GVNNERY, with certaine new and rare Additions concerning FIRE-WORKS. Wherein is exactly layd open a great number of serviceable and practicall Conclusions, belonging to Militarie Profession. As also certaine new deuices of sundry experienced Fireworks, verie necessary to be vset both for Sea and Land-services. Set forth for the benefite of this Kingdome in these troublesome times of Warre. The second edition, newly perused and amended. By THOMAS SMITH Souldier. LONDON. Printed for R. DAWLMAN, at the Brazen Serpent in S. Pauls Church-yard, 1628.

This is followed immediately by this title-page:

THE ART OF GVNNERY. Wherein is set forth a number of serviceable secrets, and practicall conclusions, belonging to the Art of Gunnerie, by Arithmetick skill to be accomplished: both practic, pleasant, and profitable for all such as are professors of the same facultie.

Compiled by THOMAS SMITH of Barwicke vpon Tweed Souldier. LONDON, Printed for WILLIAM PONSONBY, 1600.

Text of the *Art of Gunnery* follows, when another title-page appears, namely:

CERTAIN ADDITIONS TO THE BOOKE OF GVNNERY, with a supply of Fire-Workes. All done by the former Author Thomas Smith Souldier of Barwicke vpon Tweede, Both pleasant and profitable. LONDON, Printed by H. L. and are to be sold by R. Dawlman, in Fleet-street neere the great Conduit. 1627.
voyage by that route, dispatched Captain Waymouth in the Discovery—a name now immortal in the annals of English voyages—with the Godspeed, to find the North-West Passage so assiduously sought by their Pilot-Major, John Davis. Waymouth retraced Frobisher’s and Davis’s explorations, and then penetrated Frobisher’s ‘mistaken strait’, Davis’s ‘furious overfall’—soon to be known as Hudson’s Strait—before disaffection amongst the crew forced his return. This same year, 1602, Captain Gosnold crossed the Atlantic by way of the Azores, thus following a more northerly route than usual, and landed on the sands of New England, then called Norumbega, giving its name to Cape Cod.¹

The next year, 1603, Captain Bartholomew Gilbert made a voyage to Virginia in a bark of 50 tons, the Elizabeth of London. Sailing from Plymouth on 10th May, by the 26th they were in latitude 32° N hoping to see Madeira. Missing the island they ‘haled over to the West Indies’ on 1st June, and fifteen days later saw land which they took to be the Bermudas. However, on landing they found the island was St. Lucia in the West Indies, a discovery, since St. Lucia is some 15° south of Bermuda, that does scant credit to their navigational skill, and speaks volumes for

¹ A Briefe and true Relation of the Discouerie of the North part of Virginia; being a most pleasant, fruitfull and commodious soile: Made this present yeere 1602, by Captaine Bartholomew Gosnold, Captaine Bartholowmew Gilbert, and divers other gentlemen their associates, by the permission of the honourable knight, Sir WALTER RALEGH, &c. Written by M. John Brereton one of the voyage. Whereunto is annexed a Treatise, containing important inducements for the planting in those parts, and finding a passage that way to the South Sea, and China. Written by M. Edward Hayes, a gentleman long since imploied in the like action. LONDINI, Impensis Geor. Bisho. 1602.

An account of the first English attempt to settle in the land since called New England. The earliest English publication relating to its history. Despite its title, the voyage was not made with Raleigh’s permission. Instead of making the circuitous route via the Canaries, Gosnold sailed past St. Mary’s in the Azores, and was apparently the first to accomplish this direct course to America, saving the better part of ‘500 leagues’. Further experience showed, however, that owing to the prevailing winds ‘the longest way round was the shortest way home’. He made the voyage between March and July, outward in six and a half weeks, homeward in five weeks.

The voyagers made the headland, which they named Cape Cod, and went ashore to tread on the ‘white sandie and very bolde shore’—the first spot in New England trodden by English feet. Eighteen years later, the Pilgrim Fathers, after a nine and a half weeks’ voyage on the same route, from Dartmouth, were to make the same landfall.

Gosnold, it is interesting to remark, noticed the approach towards land by observing the change in the colour of the water, sounding ‘with thirte fadome line’, observing the flight of birds, the presence of ‘sculls of fish in great numbers’, and the ‘smelling of the shoare, such as from the Southern Cape and Andulazia in Spaine’. See the account in Purchas his Pilgrimes, Hak. Soc., Extra Ser., Vol. 18.

Martin Pring, who voyaged to Virginia in 1603, followed Gosnold’s route. See the account in Purchas above.

For Waymouth’s voyage see: Stevens, H., Court Minutes of the E.I. Company, 1599–1603 (1886).
their courageous ignorance. That Captain Waymouth was no such rash adventurer is suggested by his compilation in 1604 of *The Jewell of Artes*, a valuable manuscript treatise on ship-building and navigation, and by his voyage to Virginia in 1605. This he made in the *Archangel*, being sent forth by Henry, Earl of Southampton, and the Lord Thomas Arundel. Purchas records it, as he does Gilbert's voyage mentioned above. Sailing from the Downs on the last day of March, Waymouth sighted no land until 14th May, when he was in latitude 41° 30' N. Joseph Rosier recounted how, 'Thursday the sixteenth day of May, we stood directly in with the Land, and we much marvelled that we descried it not: wherein we found our Sea-Charts very false laying out Land where none was, for though we bare in directly with it according to them: yet in almost fifty leagues running we found none...'. Later he described how, coming to anchor in a harbour, 'Our Captaine upon the Rocke in the midst of the Harbour made his certain observation by the Sunne, of the height, latitude, and variation exactly upon all his instruments: 1. Astrolabe, 2. Semsphere, 3. Ring-instrument, 4. Cross staffe, 5. And an excellent Compas, made for the variation. The latitude he found to be 43. degrees 20. minutes, North. The variation, 11. degrees 15. minutes, viz. one point of the compass Westward. And,' Rosier added, quoting Borough's observation in his *Discours of the Variation*, 'it is so much in England at Limehouse by London, Eastward...'.

Setting sail on Sunday, 16th June, a month later, on 'Sunday the fourteenth of July about six a clocke at night we were come into sounding in our Channell', recounted Rosier, 'but for want of sight of the Sunne and Starre, to make a true observation: and with contrary winds we were constrained to beate up and down till Tuesday the sixteenth of July, when by five a clocke in the morning wee made Sylly...'. Waymouth was what he advised every seaman to be, a prudent navigator.

Whereas Waymouth's voyage of 1602 marked the resumption of the quest for the North-West Passage, these later voyages to Norumbega and Virginia were chiefly in the nature of reconnaissance sorties in preparation for serious attempts at colonization. But in 1606 Captain Knight, lately

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1 The account of Gilbert's voyage of 1603 is in *Purchas his Pilgrimes*, Hak. Soc., Extra Ser., Vol. 18, pp. 329–35.
2 'The Jewell of Artes', in seven books: describing the ancient instruments of navigation; the manner of building ships by geometrical proportion; with numerous pen-and-ink drawings, partly coloured. By George Waymouth. Dedicated to King James I. (1604). (B.M. Add. Ms. 19,889)
3 This MS. work is particularly valuable as it shows the method of graduating various forms of back-staff, quadrant, cross-staff and astrolabe, including Davis's original staff and the final style incorporating two arcs. This appears to be the earliest representation of this type.
4 There is another MS., probably the earlier version, in the library of Mr. Henry C. Taylor, of New York.
one of the English pilots serving the Danes, was dispatched by the East India Company on yet another search for the North-West Passage. This voyage was inspired by Lancaster's report, rendered late in 1603, on the return of the first successful English voyage to the East by the Cape, that: 'The passage to the East India lieth in 62½ degrees by the north-west on the America side'—an obvious reference to the Bering Strait. But Knight died, and the voyage was curtailed. However, the following year, 1607, saw the dispatch of expeditions by the two Virginia Companies chartered in 1606, to settle Virginia and to seek for the North-West Passage in those regions. One settlement survived, Jamestown, on the James River. The ships these settlers sailed in were the Susan Constant, the Godspeed and the Discovery.

Meanwhile the East India Company resumed the search for the North-East Passage, employing Henry Hudson in 1607. Though his voyage failed, he discovered Jan Mayen Island, and the next year repeated the attempt via Novaya Zemlya. As he was again frustrated by ice the Muscovy Company finally abandoned all hope of a passage that way. English maritime activities now became focused upon three regions—the North-West Atlantic, in search of the North-West Passage; the American Atlantic seaboard and islands, in order to colonize them, and to control the sea-traffic between them and Europe; and the Indian Ocean. Robert Harcourt tried to settle Guiana in order to flank the Spanish sea-route to Mexico and the Main. This was in 1609, the year in which Sir George Somers, taking a more northerly route to Virginia than usual by skirting instead of calling at the Antilles, was wrecked in the Bermudas, an adventure that led to its colonization and fortification. Hudson's voyage of 1610, financed by Sir Dudley Digges, Sir Thomas Smith and Sir John Wolstenholme, the leading spirits behind the Jacobean maritime ventures, ended with the return of the mutineers in 1611; but their reports of a passage to the north-west gave rise to the most sanguine hopes of success, and to the dispatch of Captain Button in the following year to Hudson's Bay. Hull merchants sent Captain Hall and William Baffin to search for minerals in West Greenland this same year of 1612. Button's return in 1613 led to Gibbons's attempt to find the Passage in 1614—he had been on Button's expedition. His failure was followed by Bylot's searches of 1615 and 1616, the latter ending in the discovery of Baffin Bay. Meanwhile Captain John Smith had surveyed the coasts of Maine from 'Cape James' as he called Cape Cod, to 'Pembrocks Bay, calling the land New England, for at that time [1614] the Coast was yet still but even as a Coast unknoune and undiscovered. I have had six or seven several plots of those Northerne parts', he wrote in his Generall Historie of Virginia, New England, & The Summer Isles, 'so unlike each to other, or resemblance of the Country, as they did me no more good then so much waste paper, though they cost me more, it may bee it was not my chance to see the best; but lest others may be

deceived as I was, or through dangerous ignorance hazard themselves as I did, I have draun a Map from point to point, Ile to Ile, and Harbour to Harbour, with the Soundings, Sounds, Rocks, and Land-Markes as I passed close aboard the shore in a little Boat... it will serve to direct any that shall goe that waies to safe Harbours and the Salvages habita-
tions...'; and indeed it is a very fair outline, complete with a scale of leagues, latitude and longitude scales and a network of rhumbs.1

Captain Smith's subsequent attempt at colonization here in 1615 had been frustrated by his capture by French privateers, 'so did they rob and pillage twentie saile of English men more, besides them I knew not of the same yeere', he recorded. Nevertheless, the English continued their activi-
ties by sea undaunted. Raleigh made his fateful voyage to Guiana in 1617, and Robert North settled the land two years later, when Munk, in Danish service, made a belated search for the North-West Passage and William Baffin sailed as pilot in an East Indiaman to tackle, if possible, the North-West Passage from the Pacific side. His death at Ormuz, at the mouth of the Persian Gulf, three years later, deprived England of a navigator of exceptional originality and skill. By then the Pilgrim Fathers had been settled at New Plymouth in New England for two years. They had chosen this spot by accident of weather and ignorance of the Atlantic passage, and not by design. Sailing in Mayflower by the northern route to the new world they had met the prevailing head-winds, and as the season for successful settling threatened to be spent before they reached a southern haven, they had anchored in the lee of Cape Cod and settled there. In little more than a decade Captain John Smith's gage about ship-building would be taken up. 'I dare ingage my head (having but men skilfull to worke the Simples there growing) to have all things belonging to the building and rigging of ships of any proportion and good Merchandise for their fraught', he had written, in his Generalle Historie, of 'the Coast of the Massachusetts'.

Like many another account of those times that of the Pilgrim Fathers' voyage was published.2 Other voyagers told their stories to Samuel Purchas, the successor of Richard Hakluyt, who had died in 1616, as historiog-
rapher of the English seamen. These narratives, with many a journal, Pur-
chas collected into voluminous books which, though more substantial than Hakluyt's, lack his inspired touch in the editing. Nevertheless, they hold many a stirring tale of bravery at sea, ice under a midnight sun in Arctic seas or, far away south, under a tropic moon or brazen noontide sun. They tell of parching thirst, and freezing cold, of chill winds that searched men to the bone, and of the hot breath of desert sands that scorched their

1 From the most recent reprinting of the work:

2 A Relation or Iournall of a Plantation settled at Plimoth in New England... Abbreviated in Purchas his Pilgrimes, Pt. 4 (1625) from Mourt's Relation of 1622.
flesh and drove them crazed to death. Some tales were never told, some were never published. Others were recorded officially, after careful perusal and docketing, and filed carefully away in manuscript amongst the archives of the East India Company.

How did these Jacobean seamen cross and recross the ocean? Mention has already been made in the preceding chapters of the clockwise circulation of the winds and currents in the North Atlantic, and of the counter-clockwise system in the South Atlantic. Examining these a little more closely, we find that the N.E. trades blow steadily from the vicinity of Portugal across the eastern Atlantic islands—the Madeiras, the Canaries, the Cape Verdes—and along the northern tropic to the Antilles, where they sweep northward, curving round as they approach the coast of North America to constitute the broad and often stormy belt of the westerlies which reaches to the British Isles. With sailing ships capable of sailing to within only six or seven points of the wind the longest way round was the shortest way home. As we have seen, the earliest English colonists of North America—the Elizabethans—followed the track first defined by Columbus and the Spanish pioneers—out, by way of the Atlantic islands, to the Antilles and northward, by way of the Mona Passage, to the coasts of Virginia, then homeward by way of the Newfoundland Banks and the Azores to the European coast. This circuitous route by way of the Antilles and not the more direct route past the Azores, was the usual outward route followed by the first colonial adventurers to Virginia. The reason was, as a glance at the wind-chart will show, that a quicker and more comfortable passage could be made by the longer route, with the aid of the following winds, than by the shorter route with its head-winds and contrary currents. Within a few years, however, of the ending of hostilities with Spain, as already mentioned, a shorter but still circuitous route had been discovered. The Antilles were now skirted to the northward, and a passage south of the Bermudas was followed until a northerly course brought the ships straight to Virginia. With settlements in Guiana and the Bermudas the Jacobeans soon felt—as the lesser Antilles were inhabited only by natives—that they held and denied to Spain the key-outposts to Virginia and to a possible North-West Passage. The northern route to America, the modern great-circle steamship route, was rarely attempted. When it was, the experience of the Pilgrim Fathers was typical. Of the route farther north the ordinary experience of the Newfoundland Banks fisherman, wrote John Davis, in 1595, was that they met such great quantities of ice that 'they are so noysomely pestered, as that in many weeks they have not beene able to recover the shore, yea and many times recover it not untill the season of fishing be over. This . . . in the septentrionall latitude of 46, 47, and 48 degrees. . . .'

Until Richard Hakluyt published his third volume of the Principal Navigations in 1600, the English had no printed runters of the North

Atlantic. John Frampton’s 1578 translation of Enciso’s work of 1519 had been confined to the West Indian section, and, as remarked in a previous chapter, had evidently left much to be desired as a rutter. We know from Hakluyt that the English had such rutters—filched from the Spaniards—but they must have been treasured, well-thumbed, manuscript compilations, rated amongst their most precious possessions by the masters owning them. Working knowledge of the consistencies and vagaries of the dominant winds and currents of the ocean was to all intents and purposes confined to what each pilot could glean from acquaintances and learn by his own limited personal observations, or had acquired as an apprentice, from his master. Thus until 1600 it had been personal experience that counted. Hakluyt changed this by placing upon the market, and thus making accessible to every English shipmaster, the hard-won fruits of the experience of generations of Spanish pilots. For by printing two Spanish rutters in his *Principal Navigations* he laid bare their jealously guarded secrets, and made their knowledge common to all English mariners. If he had done nothing else Hakluyt would have deserved fame for this, for the essential prerequisite to the successful founding of English transatlantic colonies was a set of sailing directions easily accessible to all ocean seamen, and such were his alone. Though embedded unobtrusively in his *Principal Navigations*, his two rutters played an important part in the inauguration of transatlantic trade when peace set Englishmen’s energies free. They were one of the factors that made possible its rapid growth after the establishment of the colonies, for they removed the difficulties—ignorance of winds and courses, landmarks, and safe anchorages—that prevented free and expeditious traffic between the homeland and the colonies. Generations of Englishmen followed Hakluyt’s sailing directions. Nelson, in his pursuit of Villeneuve to the West Indies in 1805, before the battle of Trafalgar, followed the route Hakluyt had had printed more than two centuries before, and he did so with the assurance that he was on Villeneuve’s track, not from knowledge of Villeneuve’s plans, but because, thanks to Hakluyt, he knew that the season was unpropitious for transatlantic voyages elsewhere.

The first of the rutters was *an excellent rutter for the Islands of the West Indies, and for Tierra firma, and Nueva Espanna*; and the second, *A principal rutter containing most particular directions to saile from S. Lucar in Andaluzia by the Isles of the Canaries, the small Isles called Las Antillas, along the South parts of the Isles of S. Juan de Puerto rico, Hispaniola and Cuba: and from Cabo de Corrientes, or Cabo de S. Anton without and within the little Isles called Los Alacranes, to the port of S. Juan de Ullua in Nueva Espanna: and the course from thence backe againe by Havana, and through the Chanell of Bahama to Spaine: together with the speciall markes of all the Capes, Islands, and other places by the way; and a brief declaration of their latitudes and longitudes.*

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1 From Hakluyt’s *Principal Navigations*, Hak. Soc., Extra Ser., Vol. 10.
TWO NORTH ATLANTIC RUTTERS

They are typical of the sailing directions of the master in Jacobean days. The second of these rutters commences: 'If you depart from the barre of S. Lucar de Barameda towards the West Indies in the summer time, you must stirre away Southwest untill you come to the head-land called Punta de Naga upon the Isle of Tenerif. But if your departure be from the sayd barre in the Winter, you must stirre away Southwest and by South, untill you come to the height of Cape Cantin on the coast of Barbarie.'

The first rutter explains that in winter you kept 'along the coast, because if thou goe farre from the coast, thou shalt meete with the wind off the sea until thou be as high shot as Cape Cantin, which is a low flat cape with the sea'.

The second rutter is more explicit about the cape, explaining that it is a lowe Cape and small to the seaward, and maketh a snowt like the nose of a galley, and hath upon the top of the poyn a Heath or shrubby place, and on the toppe thereof stand two homocks, that to the sea-ward being higher then the other; but that on the Souther side sheweth like a tower: and his Cape is in 32. degrees and ½.

'And', it continues,

he that wil seeke from this Cape to discover Punta de Naga aforesayd, must stirre away Southwest and by West, untill he bring himselfe Northeast and Southwest with the same point, and then he must stirre away South to fetch the said point . . .

which

Head-land is an high point of Land, and plaine upon the toppe like a table, and without it there are two little rockie Islands; and upon the North side of the said point is another point called Punta de hidalgo, and upon the top thereof are 2. picked rockes like unto the eares of a Hare.

'If you set saile from any of the Islands of the Canaries for the West Indias', the second rutter continues, 'you must stirre away 30. or 40. leagues due South, to the end you may avoid the calmes of the Island of Fierro: and being so farre distant from the said Island, then you must stirre away West Southwest, untill you finde your selfe in 20. degrees.'

The first rutter explains how if, after 'thou art shot fifty leagues on thy way' you are met by head winds, you can return and find a safe anchorage in 'the bay of Cadiz' in approaching which,

if thou be in thirtie or forty fadomes, thou shalt have ooze; but if thou bee in lesse than thirtie fadomes, thou shalt have other sounding, which if it chance, then thou art against S. Pedro. And if it bee by day thou shalt see the Ermitage of Saint Sebastian, which seemeth to be a shippe under sayle . . . And if thou chance to bee benighted when thou fallest with the bay, and wouldest goe into the bay, thou shalt carie thy lead
in thy hand, and be sounding: and finding thy selfe in rockie ground, thou shalt steere North . . .

On the other hand if after leaving the Canaries you experience favourable winds the second rutter advises you to

sail West and by South until you come to 15. degrees and \( \frac{1}{2} \). And from thence stirre away West and by North; and so you shall make a West way by reason of the Northwesting of the Compasse: which West will bring you to the Island of Deseada . . . having no trees upon it and . . . proportioned like a galley . . . in 15. degrees and \( \frac{1}{2} \).

Thus it will be seen that the route to the West Indies swept down the eastern edge of the North Atlantic to the Canaries, and then curved across the tropical belt to the northernmost of the lesser Antilles. In fact it followed the trade winds.¹ From Deseada the various courses led to the Caribbean islands, and to the ports of Mexico and the Spanish Main, each island, headland, and cape being described in apt terms.

The directions for ships returning to Spain commenced from Havana, the customary port of departure. The mariners were instructed to steer away north-east from here till they came to the Martires, the small islands lying off the Cape of Florida 'in 24. degrees and a halfe'. When these were reached the hazardous task of passing through the Florida Strait into the ocean sea had to be tackled.

. . . if the wind be large, thou mayest go East and by South [the first rutter directed] until thou seest the coast to lye Northeast and South-west: and, if the wind be scant, then go turning up: and take good heed that every evening at Sunne going doun e thou have sight of the land, and so thou must do being in the chanell, until thou bring thy selfe into the middest of the chanell: and thou must lye off from the going doun e of the sunne, until the ende of the first watch with thy courses alone, without any more sayle: and from midnight forwards cast about, and lye the other way with the like sayle untill day . . . untill thou bring thy selfe into the chanel . . . And if being in the Chanel thou meete with the wind at North, then thou must turne with a little saile 4. glasses one way, and 4. another, as thou thinkest good. And if thou canst not beare sayle, then thou mayest goe with all thy sayles doune, except when thou wouldest cast about, thou mayest loose some small sayle to winde thy ship.

¹ And being in 28. degrees and a halfe, you shall be shot out of the chanel', the second rutter stated with a brevity that by its very terseness conjures up as graphic a picture of the passage as any more highly coloured one. 'If in Winter you should passe through the chanel of Bahama for Spaine, stirre away the first . . . course Eastnortheast', the rutter advised,

¹ See Pl. LXXV.
WINDS & CURRENTS
of the ATLANTIC

LXV. THE WINDS AND CURRENTS OF THE ATLANTIC. (SEE APPENDIX 26).
‘and after East and by North, and so shall you passe by the South side of Bermuda: and you must take heede that you goe these four hundred or five hundred leagues, because you shall not come neere the said Isle of Bermuda’, a hazard whereon, explained the first rutter, ‘many have bene lost . . . because of their negligence.’ The course, E.N.E. was to be continued until ‘thou be in 30. degrees rather lesse than more’, and then altered to ‘East and by North because of the variation of the Compass’. When ‘thou art sure thou art past this island, then goe East Northeast’, continued the instructions, ‘until thou be in the height of the seven and thirtie degrees: which is in the height of the Island of Saint Marie’ in the Azores. On ‘cumming out from Faial, and leaving all the Islandes . . . goe East and by South untill thou bring thyselfe in 37. degrees, which’, explained the rutter, ‘is the height of Cape Saint Vincent: and then goe East and thou shalt see the Cape.’ So ran the directions, adding,

if thou stand in feare of men of warre about the Cape [a favourite haunt of English letters of marque men—and of pirates], I advise thee then goe in 36 degrees 4. And finding thyselfe within the Cape, if thou see many signes of greene weedes, then cast about to the North Northeast, and by this way finding land, and the same shewing white, be sure it is the castle of Aimonte.

In summer the route from the Bahamas lay north of Bermuda. The course was the same, E.N.E., but it was held, according to the second rutter, until ‘you have brought your selfe in 35. degrees’; according to the first rutter, ‘39. degrees and ¼, which is the height of Flores’ in the Azores. Indeed the second rutter advised, ‘if thou thinke good to go in more degrees, [in a higher latitude] to have the seawinds, thou shalt goe by the same height . . .’. On the other hand ‘if thou shalt finde the winde off the sea [the westerly wind] thou hast no neede to go in more heights: and from thence thou shalt goe East and by South, and . . . find the Isles of Flores and Cuervo, which stand in 39. degrees ½, and in 40 large . . .’.

These sailing directions make two things abundantly clear, the clockwise circulation of shipping in the North Atlantic, on account of the winds and currents, and the fact that the displacement of the wind system with the seasons—northerly in summer, southerly in winter, following the sun—was well known to the Spanish navigators, and hence to the Jacobians.

While Bourne as early as 1578 had recognized three sorts of currents, no man yet knew their strength or their cause. The ocean currents were still not generally associated with the winds, which were spoken of as exhalations of the earth. The influence of the moon and the conformation of the continents were still considered to be the prime causes of ocean currents. It was for this reason that in the searches for the North-West Passage so much stress was laid upon the identification of currents and the

21*—A.O.N.
measurement of tides. The impracticability of measuring longitude accurately made the formulation of any reliable estimate of the strength of the currents still quite impossible. The only estimates that could be made were in a North-South direction, when the day's run could be checked by the noon sights. But as a ship's speed was still estimated or else was measured by an inaccurate log-line, and as the average navigator could get his observed latitude only to within half a degree, such estimates were only approximate. Sir Richard Hawkins in his Observations, which, though published in 1622, were written twenty years earlier, sums up contemporary knowledge of the main ocean currents, and illustrates the dangers and errors that arose from ignorance of them. ¹ Writing of his voyage of 1593 to the Pacific, he describes how after leaving the Cape Verde Islands

'with a faire and large winde, we continued our course, till we came within five degrees of the equinoctiall lyne, where the winde took us contrary by the south-west ... and to advantage ourselves what wee might, wee stode to the eastwards ... The next day about nine of the clocke, my companie being gathered together to serve God, which we were accustomed to do every morning and evening, it seemed unto me that the colour of the sea was different to that of the daies past ... the capitaine and master of my ship ... made answere, that all the lynes in our shippes could not fetch ground: for wee could not be lesse than three-score and tenne leagues [210 miles] off the coast, which all that kept reckoning in the ship agreed upon, and my selfe was of the same opinion. And so wee applied ourselves to serve God, but all the time that the service endured, my heart could not be at rest ... Our prayers ended, I commanded a lead and lyne to be brought, and heaving the lead in fourteene fathoms, wee had ground, which put us all into a maze, and sending men into the toppe, presently discovered the land of Guynne [Guinea] some five luges from us ... Here is to be noted, [Sir Richard observed] that the error which we fell into in our accomplis, was such as all men fall into where are currents that set east or west, and are not knoune, for that there is no certaine rule yet practised for triall of the longitude ... God Almightye dealt ... mercifully with us,' he added, 'in shewing us our error in the day; and in time that wee might remedie it ...'.

He had of course got into the Doldrums, and there encountered the powerful east-flowing counter-equatorial and Guinea currents. He described them in these terms: 'This current from the line equinoctiall to twentie

¹ THE OBSERVATIONS OF SIR RICHARD HAWKINS KNIGHT, IN HIS VOYAGE INTO THE South Sea. Anno Domini 1593. Per varios Casus, Artem Experientia fecit, Exemplo monstrante viam.—Manil. li. LONDON Printed by I.D. for IJOHN IAGGARD, and are to be sold at his shop at the Hand and Starre in Fleece-streete, neere the Temple Gate. 1622.

The extracts are from The Hawkins Voyages, Hak. Soc., Ser. 1, Vol. 57.
degrees northerly, hath great force, and setteth next of anything east, directly upon the shore.' The inadequacy of the description—the omission of speed and of east-west limits—is illuminating.

The currant that setteth betwixt New-found-land and Spaine, runneth [Hawkins commented] also east and west, and long deceived many, and made some to count the way longer, and others shorter, according as the passage was speedie or slowe; not knowing that the furtherance or hindrance of the current was cause of the speeding or flowing of the way. And in sea cardes I have seene difference of about thirtie leagues betwixt the iland Tercera and the mayne. And others have recounted unto me, that comming from the Indies, and looking out for the ilands of Azores, they have had sight of Spaine. And some have looked out for Spaine, and have discovered the islands . . .

'In Brasill and the South sea', Hawkins noted that the current likewise was changeable, but that it ran 'ever alongst the coast, accompanying the winde . . .', an observation that nearly but not quite connected wind and current together. 'In the West Indies onely the current runneth continually one way', he stated, 'and setteth alongst the coast from the equinocitial lyne towards the north . . .', also accompanying the wind, of course, but this phenomenon escaped him. 'No man hath yet found that these currants . . . run . . . as doth the course of ebbing and flowing . . . only, neere the shore', he correctly observed, 'they have small force. When the currant runneth north or south, it is easily discovered', he explained, 'by augmenting or diminishing the height', (finding the latitude by observation) 'but how to know the setting of the current from east to west in the mayne sea' was, he confessed, 'difficult'; adding, 'as yet I have not knoune any man, or read any author, that hath prescribed any certaine meane or way to discover it; and therefore the best and safest rule to prevent the danger (which the uncertainty and ignorance heerof may cause)', he advised, 'was carefull and continuall watch by day and night, and upon the east and west course ever to bee before the shipp, and to use the meanes possible to know the errour, by the rules which newe authors might teach; beating off and on, sometimes to the eastwards, sometimes to the eastwards, with a fayre gale of winde.'

In the Soundings, the western approaches of the English Channel, such precautions were peculiarly necessary. The usual landfalls, Ushant and the Lizard, were time-tested as well as time-honoured. From long experience Land's End and the Scillies were given a wide berth. Nevertheless, despite allowing ample reckoning before his ship, and despite setting a course to pass well to the south'ard of Land's End and the Scillies, many a prudent navigator had been and for centuries would continue to be wrecked on the Scillies in thick weather or at night, or would find himself embayed in the Bristol Channel, there to be dashed upon the granite rocks of Lundy or North Cornwall, or flung upon the sand dunes of North Devon. For generations these unaccountable disasters occurred.
It was not until the chronometer began to come into general use in the best-found merchant ships at the end of the eighteenth century that it became possible to measure the velocity of ocean currents. Then in 1793 Rennell, a scientist, by comparing the logs and workings of some East Indiamen’s masters in the Soundings identified the dreaded current now called after him. This, it appeared, was the hitherto unknown terror of the deep that had caused so many fine ships to be cast away. Rennell ascertained that for days, sometimes for many days, after westerly or south-westerly gales in the Bay of Biscay, the mass of waters piled up by the wind against the western bosom of France, and clasped between the outstretched arms of Finisterre and Ushant, escaped back into the Atlantic by way of Ushant. The contour of the coast makes it at once clear that the escaping water must flow north-westward across the Soundings, carrying incoming shipping to the north, and sweeping it back into the Atlantic, thus setting at nought the ‘reckoning before the ship’, and in thick or misty weather causing the navigator to believe, on sighting land, that he had made his intended landfall of Ushant, when in fact it was the Scillies or Cornwall. Thus, it will be recalled, Edward Fenton in 1583 identified his landfall as the Seams off Ushant and later found it to be the Bishop Rock off Scilly! He was fortunate in making his landfall in fine weather, and had been prudent in not proceeding on his way at nightfall while he was uncertain of his precise position. The snares that lay in the way of the homecoming navigator in the Soundings explain why so much attention was given in every rutter and waggoner to the nature of the sea-bed, where the recognition of a grain of sand could turn the scales between life and death.

Despite Richard Hawkins’s assertion to the contrary it was not always easy to identify a north-south current, particularly in the regions where exploration was most hazardous, the N.W. Atlantic. For instance Frobisher in his first voyage in search of a North-West Passage, in 1576, had identified the North-East Drift Current, well known to the Spanish navigators farther south, between England and Greenland. But both he, and later Davis, had been much troubled by the diversity of northward and southward flowing currents in the vicinity of Greenland, Labrador, and Newfoundland. Similarly Christopher Hall, in his first voyage to the west coast of Greenland in 1605, had found that the current on the east coast set to the south (East Greenland Current) but that on the west coast it set to the north (West Greenland Current). On the other hand on the 10th July, while in the Davis Strait ‘he found much drift ice with a high sea, which he thought to be a current setting through Davis Strait to the southward, as by experience he proved; for by observation at noone he was in latitude 62. deg. 40 m., whereas, the day before he was in latitude 66

1 Rennell, J., ‘Observations on a current that often prevails to the westward of Scilly, endangering the safety of ships that approach the British Channel’. From Phil. Trans., London, 1793. ‘Some further observations on the current that often prevails to the westward of the Scilly islands’ are to be found in a pamphlet in the Admiralty Library, Whitehall.
deg. 10 min., having made by account a S. by W. way, about 10 leagues. This current he found to set along the coast of Greenland, South by East. It was in fact the start of the Labrador Current which sweeps over to the west and runs along the coast of Labrador to Newfoundland where it divides, entering the Gulf of St. Lawrence and re-emerging through the Belle Isle Strait to join the Cabot Current, another part passing round the eastern shores of Newfoundland as the Cabot Current, and yet another surging on to the southward to mingle with the Gulf Stream and North Atlantic Drift.

While the identification of the Labrador Current was not difficult, on the next voyage, made in 1606, Hall, after clearing the Shetlands, reckoned himself to be in latitude 58° 10' N on the 14th June, having steered west, with a S.E. wind, in thick weather. However, on getting a sight he found he had made, contrary to his expectation, a way of twenty-two leagues West by South. He also found that the compass varied one point westward. On 1st July he sighted land which he took to be Busse Is. This island, like Maida and Brendon, was one of those imaginary islands that arose from ignorance of longitude at sea, lack of telescopes for certain identification of objects at a distance, and a readiness to record a supposed hazard without risking certain proof of its existence. In Frobisher's fleet of 1578 had been a certain buss—a small, strongly built, two-masted, fishing-boat—of Bridgewater, called the Emanuel. She 'comming home, found an Iland in 57° and a halfe, sailed a long [it] 3 dayes, and said it was a fruitful, Champion country, and woody'. Since then this mythical island had been placed on many charts, and called Busse Island. Hall reckoned Busse Island must lie farther west than it was charted. Steering away W. by N. he found himself in a great current setting S.S.W., so he steered W.N.W.—he had of course sighted Greenland—but on 6th July, when nearing the American shores

he found himselfe to be in 58 deg. 50 min., whereby, contrary to his expectation, he did plainly see the Southerne current to be the cause. This Evening, he found the Compasse to be varied 12 deg. 5 min. Westward . . .

July 8. He was in 59 deg. 30 min. and finds still the Current and variation to carry him to the South-ward of West.

July 10. He sees the Coast of America in Latt. 60 deg. 16 min., about 9 leagues off, and finds the needle varied 23 deg. W.

Thus Captain Luke Foxe summarized in the 1630s the experiences of Hall, who had got into the East Greenland Current and then into the Labrador Current, but being unable to determine the width of either—since they ran North and South—had thought them one and the same. Hall's experience contains another clue to the peculiar complexities of north-western naviga-

1 For the mythical islands of the Atlantic see: Babcock, W. H., Legendary Islands of the Atlantic (1922).
tion—the rapid changes in the variation as well as the conflicting currents. Unless the navigator frequently found his variation and corrected his course to allow for it as he steered west, he actually steered more and more south of west, of true west, for increasing westerly variation swung his compass needle, unknown to him, farther and farther west of north. But in thick weather he could not find his variation, and so was ever liable to go astray, however wary he might be. Then he blamed unknown currents.

Captain John Knight, who had been with Hall on the voyage of 1605, in this year 1606 was also employed in these waters, as already noted, but by the East India Company, in a renewed attempt to find the North-West Passage. His journal records how he found the variation:

From fryday at noone tyll 2 o'clock the next morninge. It was calme then it blewe an esy gale at est southeast being sattorday the 31st of May. The O beinge 50 deg. above the horizont I found it to be 27 deg. to the estward of the southe. Agayne in the after noone the sonn being 50 deg. high he was distant from the south to the westward. 51 deg. At noone he was 55 deg. 6 m.: hight of the pole 58 deg. 3 min.: varyatyon 24 deg. our waye this 24 howers not above 6 leagues west, being little wind for the most part. [The fly was off-set one point to the east of the wires].

As Borough had explained in his work of 1581, the principle underlying the equal altitude method of finding variation was that if the sun were observed at the same altitude before and after noon it would be on the

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1 From Foxe's précis of the voyage in: NORTH-WEST, FOX, or, FOX from the North-west passage. BEGINNING With King ARTHVR, MALGA, OCTHVR, the two ZENI'S of Iseland, Estotiland, and Dorgia; Following with briefc Abstracts of the Voyages of Cabot, Froibisher, Davis, Waymounth, Knight, Hudson, Button, Gibbons, Bylot, Baffin, Haweridge: Together with the Courses, Distance, Latitudes, Longitudes, Variations, Depths of Seas, Sets of Tydes, Currents, Races, and over-Falls; with other Observations, Accidents and remarkable things, as our Miseries and sufferings.

Mr. IAMES HALL'S three Voyages to Groynland, with a Topographical description of the Countries, the Salvages lives and Treacheries, how our Men have beene slayne by them there, with the Commodities of all those parts; whereby the Marchant may have Trade, and the Mariner Employment. Demonstrated in a Polar Card, whereunto are all the Maines, Seas, and Ilands, herein mentioned.

With the Author his owne Voyage, being the XVIth with the opinions and Collections of the most famous Mathematicians, and Cosmographers; with a Probabilitie to prove the same by Marine Remonstrations, compared by the Ebbing and Flowing of the Sea, experimented with places of our owne Coast. By Captaine LVKE FOXE of Kingstone uppon Hull, Capt. and Pylot for the Voyage, in his Majesties Pinnacle the CHARLES. Printed by his Majesties Command. LONDON, Printed by B. ALSOP and THO. FAWCET, dwelling in Grub-street. 1635.

2 Oliver Brumel's Postscript to the Journal of The Voyage of Captain John Knight to seek the North-West Passage, 1606, in Hak. Soc., Ser. 1, Vol. 56.
meridian at the mean time between the two observations. Then the difference between the sun's azimuth at each observation and the meridian would disclose the compass error, i.e. the variation.

The journals of Henry Hudson afford a good insight into the navigational practice of the Jacobins. He steps across the threshold of history from obscurity in 1607, when he appears as a captain in the service of the Muscovy Company keeping, in accordance with the seventh of Sebastian Cabot's Ordinances for that Company's servants, an admirable journal. He recorded not only the variation, but also the dip.

On Tuesday, the sixe and twentith day [of May], in the morning, we made the Iles of Shetland, and at noon we were in 60 degrees 12 minutes, and sixe leagues to the eastward of them: the compass had no variation. We had sixty-four fathomes at our sounding, blacke, ozie, sandie, with some yellow shels. Our ship made more way than we did suppose. On Saturday, the thirtith of May, by our observation we were in 61 degrees 11 minutes. This day I found the needle to incline 79 degrees under the horizon . . .

With what care he made his observations is exemplified by this extract from his entry for 14th July:

This night proved cleere, and we had the sunne on the meridian, on the north and by east part of the compass; from the upper edge of the horizon—with the crosse-staff, we found his height 10 degrees 40 minutes, without allowing anything for the semi-diameter of the sunne, or the distance off the end of the staffe from the centre of the eye. From a north sunne [midnight] to an east sunne [6 a.m.], we sayled betwene north and north-east, eight leagues.

On another night he recorded a successful Pole Star observation for latitude.

In Hudson's journal of the second voyage to the north-east, in 1608, we frequently find full details of land fixes and celestial observations; for example:

The first of June, a hard gale at east north-east, with snow . . . the Third, in the morning we had sight of the North Cape [of Norway]; and at a west and by north sunne [6.45 p.m.], the Cape bore off us south-west, halfe a point southerly, beeing from us 8 leagues: and observing the variation, I found it to the westward 11 degrees: and having a smooth sea, the needle inclined under the horizon 84 degrees and a halfe, the nearest I could finde. We had the wind at south-west, and wee stood away north-east and by east. It was cleere weather, and we saw Norway fishermen at sea.

The seven and twentith all the forenoone it was almost calme . . . The sunne was on the meridian on the north north-east, halfe a point

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1 Henry Hudson the Navigator, Hak. Soc., Ser. 1, Vol. 27, p. 2.
easterly, before it began to fall. The sunnes height was 4 degrees, 45 minutes; inclination [declination], 22 degrees, 33 minutes [N.] which makes the latitude 72 degrees, 12 minutes. There is disagreement betweene this and the last observation [taken the previous noon]; but by means of the clearenness of the sunne, the smoothnesse of the sea, and the neernesse of the lande, wee could not bee deceived, and care was taken in it.

At the end he records

voide of hope of a north-east passage . . . I resolved to use all means I could to sayle to the north-west, . . . to make triall of that place called Lumley's Inlet, and the furious over-fall by Captain Davis, hoping to runne into it an hundred leagues, and to returne as God should enable me.

It was from this intended voyage, undertaken in 1610, that he never returned. Entering the strait now called after him, and discovering the bay also called by his name, he wintered there, and in the next midsummer was set adrift in the ship's shallop, with his son and seven men. As for the mutineers in the ship, when 'it was said that the shallop was come within sight, they let fall the main sayle, and out with their top-sayles, and fled as from an enemy . . .'.

Robert Juet, Hudson's mate on this as on other voyages, and one of the ringleaders of the mutineers, though 'an ancient man', on the return voyage met his deserts for he 'dyed miserably for meere want'. Nevertheless his journal of the third, 1609, voyage to the north-east and later to Hudson's River is packed with fascinating entries, and we learn amongst other things that on the 1st June, when passing the Faroes on the way to America, 'this night we lighted candles in the bittackle again'. The continual daylight had rendered them unnecessary in the higher latitudes whence they came.

The greatest of the Jacobean navigators, William Baffin, also gained his fame initially in northern navigations. He accompanied Hall as his mate on his voyage of 1612 to Greenland, and made the first recorded observation for longitude by an English navigator. A fragment of his journal in Purchas opens with 'Wednesday, the eighth of July, 1612 . . . I purposed to finde out the longitude . . . by the moones coming to the meridian . . .'. He then explains how he laid out a meridian line on shore and the next day

very early in the morning . . . observed till the moone came iust upon the meridian. At which very instant I observed the sunne's height, and found it 8° 51' north; in the elevation of the pole 65° 20'. By the which, working by the doctrine of sphericall triangles, having the three sides

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LUNAR OBSERVATIONS FOR LONGITUDE

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given... to find out the quantitie of the angle of the pole... Which, when I had done, I found by mine ephemerides... the difference of longitude betwixt the meridian of London (for which the ephemerides was made) and the meridian passing by this place in Groenland... to wit, 60 degrees, 30 minutes, or neere there about... to the westward of London.

Baffin gave the working of the problem and confessed that it was 'somewhat difficult and troublesome', and might after all be erroneous; as indeed it was, for Cockin Sound, on the west coast of Greenland where he took his sight, is in longitude $52^\circ 50'$ W. As he pointed out, the accuracy of the ephemerides used largely determined the accuracy of the solution and, since the moon's motions are very complex, it was not until the latter part of the eighteenth century that prolonged and systematic observations of the moon's motions enabled lunar tables, sufficiently accurate for constant use, to be published. Baffin claimed that the taking of lunars for longitude-finding by mariners, although beyond the capabilities of most, could be done by 'some of the better sort, which are able to work other like propositions exactly'. Nor was it now difficult for English seamen to learn the propositions Blundeville had outlined.\textsuperscript{1} In 1604 the versatile Robert Norton had published A Mathematicall Appendix devoted primarily to the various celestial methods of longitude-finding, with accompanying geometrical diagrams attached.\textsuperscript{2} Lack of knowledge of the means of

\textsuperscript{1} The use of trigonometrical or geometrical tables, and the purpose and use of trigonometrical functions, will be examined in the next chapter.

\textsuperscript{2} (i) A MATHEMATICAL APENDIX, CONTAINING MANY PROPOSITIONS AND CONCLUSIONS mathematicall:

with necessary observations both for Mariners at Sea, and for Cheronographer and Surveyors of Land; TOGETHER WITH AN EASIE perspective mechanical way, to Delineat Sunne dyalls vpon any Wall or Plaine giuen, be it direct, inclyning, declyning, or rectlyning, from the Horizon, or Meridian, in any Region or Place of knowne Latitude.

With other things pleasant and profitable for the weale publick, not heretofore extant in our vulgar: Partly collected out of Foreigne moderne writers, and partlie inuented and practised by the Author. Written by R. N. Gent.

LONDON, Printed by R.B. for Roger Iackson, and are to be sold at his shoppes in Fleet-street [sic], ne [corner cut off page] duit, 1604.

This is a treatise 'chiefly composed' for the solution of the problem of finding longitude. It includes the suggestion of a distance meter (mechanical log) made of a wooden wheel rotated in a wooden trough by the passage of the vessel through the water.

(ii) In corroboration of Baffin's statement that many navigators knew how to find longitude, is this entry in the Court Minutes of the East India Company for 9th September 1614:

Letter in behalf of Edward Jyles, who offers his services for the East Indies; he is experienced in knowing the latitude and longitude by observation of the sun or any star; was with Sir Francis Drake in his voyages; has been four times in the West Indies, with my lord of Cumberland, and in many other sea voyages...

*Calm S.P. Colonial Series, East Indies, No. 765.*
finding longitude he considered to be 'the greatest imperfection in the Art of Navigation'. Norton's work, Baffin's observations, and his remarks on longitude-finding exemplify the change that had come over the bulk of English navigators, but not all, in the last fifty years, in the scientific trend of their thought and practice. Although Dr. John Dee, who had died in 1608, had been largely responsible for this change, he had been in many respects, as we have seen, a man of his times, in that he was much influenced by astrology. In the 1570s he had claimed a mysterious method of finding longitude. Twenty years later, when Simon Forman had succeeded to Dee's position as the leading astrologer of the day, he had made a similar claim. His astrological manuscript of 1604, To know in what state a ship is that is at sea, is in strong contrast to Norton's scientific treatise, and shows that science and astrology were still often bedfellows, to the confusion of the honest seaman.¹ The confusion had doubtless been further deepened by the publication in 1609 of Anthony Linton's Newes of the Complement of the Art of Navigation.² He was parson of the little Sussex village of Worth, and wrote a curious little treatise on the importance of navigation to England, of ways and means of finding a passage 'to Cathay', and of navigational problems. If he was a charlatan there is at least a sincerity of expression in many parts of his book that shows that he did have the country's nautical interests at heart, as well as his own. After citing the criticisms of the art of navigation of Humphrey Gilbert, Thomas Digges, William Borough, Richard Polter, and Edward Wright, whose chart he praised, he pointed out that in navigation position-finding was still imperfect. Having made this unimpeachable statement he then claimed that any navigator could 'make his conclusions of Latitude, Longitude, and Variation', as accurately 'as is possible to be done in any other Mathematicall practise in use amongst us' by 'continued observation', and by exploiting the existence of the two magnetic poles. By the use of certain globes and charts of his devising, obtainable at a price, and 'in six other ways', the navigator, knowing 'the variation of the Compass and the

(iii) Button, in this very year in which Baffin was writing, 1612, was searching for the N.W. Passage through Hudson's Bay with instructions, if he had time enough, to observe 'the beginning and ending of the Eclipse that will happen on the 20th of Maye next. Especiallie, if you should winter, let there be carefull and painefull watching to observe the instant of the conjunctions of anie fixed starre or starres of note."


¹ Forman was also the author of another treatise on longitude:

The Groundes of Longitude: with an admonition to all those that are incredulous and believe not the truth of the same. (1591).

² NEWES OF THE COMPLEMENT OF THE ART OF NAVIGATION:
AND OF THE MIGHTIE Empire of Cataia. TOGETHER WITH THE Straits of Anian.
By A.L.
The principall Contents whereof follow in the next page.
AT LONDON, Imprinted by FELIX KYNGSTON, 1609.
Latitude of the place', would 'find out by Arithmeticall calculation the true longitude of the same place'. However, for the satisfactory working of this admirable but obscurely worded system there appeared to be one serious drawback only, namely, that it required 'professors of greater skill and practise in the Mathematics, then are now commonly to be found'. Perhaps Linton was serious after all, and merely distressed that practical seamen should have turned his scheme down. Perhaps he had taken it over from John Dee. It is possible he was merely stealing the ideas and labours of a French scholar, Guillaume de Nautonier, who had published a work on magnetism and longitude-finding, the *Mecometrie de Leymant*, between 1602 and 1604. His purpose had been to facilitate the determination of longitude by variation. The relevant portion he had written in the Scots tongue; it contained tables giving the calculated variation at every degree of latitude and longitude on the old assumption that a complete and symmetrical network of magnetic meridians and parallels, to which the compass needle conformed, could be identified on the globe. The theory had been refuted in 1610 by the inclusion of an appendix in the second edition of Wright's *Certaine Errors* listing the observed variation in many places. Wright's object was to demonstrate that there was no such simple system of magnetic co-ordinates as Nautonier and others still supposed; the result of this scientific controversy must have bewildered many an honest navigator. As we shall see, the controversy was to continue for another decade. Incidentally, Wright's appendix was inaccurate, as the variations listed had been made at different dates, and were not corrected for the secular, or annual, change of declination, for this phenomenon was still unknown. Meanwhile let us return from the study to the sea.

1 MECOMETRIE DE LEYMANT CEST A DIRE LA MANIERE DE MESVRE les longitudes par le moyen de l'eymant. Par laquelle est enseigné, vn trescertain moyen, au paravant inconnu, de trouver les longitudes Geographiques de tous lieux, aussi facilement comme la latitude. /[ornament]/ Dauantage, y est monstree la declinaison de la guide ymant [sic], pour tous lieux. /[ornament]/ OEUVRE NECESSAIRE AVX ADMIRAVX, Cosmographes, Astrologues, Geographes, Pilotes, Geometriens, Ingenieux, Mestres des mines, Architectes, et Quadraniers. /[ornament]/ DE LINVENTION DE GVILLAVME de Nautonier Sieur de Castelfranc en Languedoc /[ornament]/ DEDIE AV ROY

IMPRIME A VENES CHES
L'auteur
M D C III.
Auec privilege du Roy,
Pour dix ans.

2 CERTAINE ERRORS IN NAVIGATION, Detected and Corrected by Edw: Wright. With Many additions that were not in the former edition as appeareth in the next pages. Printed by Felix Kingslo at London 1610. It begins with an 'Epistle Dedicatorie' to THE HIGH AND MIGHTIE PRINCE HENRY, eldest Son to our soueraigne Lord King Iames: Prince of Wales, Duke of Cornwall, Earle of Chester, &c.
From Baffin’s journal of 1613, when he was engaged in a whaling expedition and voyage of discovery in the North-East for the Muscovy Company, we learn that the ‘common sayling compasse’ was still ‘touched five degrees and a halfe to the eastward’. How inconvenient this could be is shown by his having to explain on one occasion that, although he found the variation to be 12° 14’ W ‘by our common sayling compass’, owing to the off-setting of the needles, ‘it is 17°’. For such observations he used a four-foot quadrant, set up on land of course. By these means he could confidently observe to within minutes of arc.

It was on this voyage that Baffin demonstrated his originality as a navigator by taking a solar observation ‘to finde the sunnes refraction’. It will be recalled that Edward Wright had first discussed the effect of refraction upon celestial observations in his Certaine Errors of 1599. Baffin’s method was ingenious, being based upon the accurate observation of the latitude of the place of observation, the accurate calculation of the sun’s declination, and its diameter, measured in minutes of arc. As a result of his observations and calculations—which he recorded fully—he found the refraction to be 26’, adding judiciously, ‘I suppose the refraction is more or less according as the ayre is thicke or clear, which I leave for better schollers to discourse: but this I thought good to note, for the better helpe of such as doe professe this studie.’

Baffin’s latitude was then 79° N, and in fact a recent naval navigation manual observes, ‘In polar regions refraction varies over much wider limits than in lower latitudes ... Refraction is known to vary with temperature and barometer pressure, but there are other factors which are imperfectly known.’ Baffin’s ‘schollers’ are still discussing polar refraction!

Another voyage by Baffin to the Spitzbergen region in 1614 was followed by an invitation to him in 1615 to sail as pilot to Robert Bylot in the voyage in search of the North-West Passage. It has already been remarked that the return of Hudson’s mutineers in 1611 had ‘gained more hope of the discovery of the South Sea by a northerly Passage than ever before’. Prince Henry himself, the heir apparent, and Edward Wright his tutor had drawn up the instructions for Captain Button, who had been dispatched in April 1612. ‘You will not returne, without either the good newes of a passage or sufficient assurance of an impossibility ... spend as little time as maie bee in ... search, saving of the Passage, til ... your Entrie into the South Sea ...’ ran his orders, and in July ‘The Company of the Merchants of London Discoverers of the North-West Passage’ had received its charter on the confident grounds that its subscribers were ‘the first adventurers and discoverers of the North-West Passage’.

Button’s failure to return in 1612 had led to the belief that nothing would

1 Baffin’s journal is reproduced in Hak. Soc., Ser. 1, Vol. 63 and in Purchas his Pilgrimes (Part III) Bk. IV, cap. V., pp. 716–720.
2 Purchas his Pilgrimage, 1613, p. 624.
be heard of his vessels 'before they return to England from East India or China and Japan'. When he had returned in 1613, having wintered at Fort Nelson on the south side of Hudson's Bay, it had been a cruel check. Nevertheless hope had remained, and had continued after Gibbons had got embayed in Labrador the following year. This was why Robert Bylot, who had been on Hudson's ill-fated, Button's disappointing, and Gibbons's frustrating expeditions, had now been selected to lead a further survey of Hudson's Strait, and to follow up, in particular, what were believed to be good tidal indications of a strait.

On their return Baffin forwarded to the Company a covering letter, a 'brief journal' and 'A True Relatyon of such things as happened ...', for his task had been to guide the expedition and execute the survey. His track and his survey work in the strait are preserved on the large chart he prepared—on a circumpolar projection—while his report is a model of scientific observation. Purchas called Baffin 'that learned un-learned mariner and mathematician'. His antecedents cannot be ascertained, but as he had served in the Muscovy Company his schooling had been thorough, and one is tempted to believe that he may have been one of the unlearned mariners who benefited by the Gresham lectures.

In his covering letter Baffin observed that

... seinge I have been impoyed, and have reaped some profit from your purses ... I have endeavoured to set done our proceedinges in so short a methode as conueniately I could, referringe our pertyculer courses, latytudes, longitudes, windes, leagues we run, and varietyon of the compas to the breffe table or Jurnall ... where every of these is set in their seuerall collombe with theytles at the heade.

In the column entitled Trucourse, he remarked that there would often be found 'a number betweene the letters, as on the last day of April, is N. 20 E.'. This, he explained, signified 'north 20 degrees eastward, or almost north north east'. It is of interest, for it is apparently the earliest example of courses being recorded in degrees and not in the rhumbs of the winds. The term 'Trucourse' signified the course made good, or 'the tru waye that the shipp had room that 24 houers, the varietyon of the compas, and other accidents alowed'.

We have seen that Hakluyt printed one of Davis's journals containing a longitude column, and that this is the earliest example of a journal with such a column. Baffin's journal also included one, although it was still, according to him 'not usual in Jarnaales'. Its advantage was, as he explained, 'that theareby ech seuerall varietyon of the compas, and any other accidente may be the more redylie found without protractinge all or parts of the voyage'. In other words, in order to find the position in which an incident recorded occurred or where a particular variation was experienced, if the longitude had been omitted from the journal it was necessary to replot the ship's position from the point and date of departure until the date of the particular entry. This might well involve plotting several
weeks' voyaging. A moment's reflection upon the work involved in all this
plotting will convey the important forward step in the art of navigation
represented by the recording of the daily longitude as well as of the daily
latitude of the ship's position, the course made good, and the distance
run. Now all that was necessary was to look up the latitude and longitude
on the given day and, with two pairs of dividers, prick the position straight
off from the latitude and longitude scales on the chart—the chart of course
being either on a circumpolar projection or on Wright's Mercator's pro-
dection. The real advance that the longitude column in ships' journals of
this time indicates is the introduction and widespread use of circumpolar
charts and Mercator's charts. It is an indication also that the master used
charts on one or other of these projections. Incidentally, Baffin's use of the
expression 'protracting' is indicative of a more general use of protractors
at sea; so is his recording of courses by degrees, for no network of rhumbs
would enable him to read off a course such as N. 20° E.

In order that the Company might 'more redclyie see and perseue howe
far we haue beeene', Baffin marked in his chart all the land sighted west of
the entrance to Hudson's Strait—Resolution Island—in green, and pricked
out the ship's track in red, marking with a red cross every point where
they went ashore 'to make tryall of the tyde'. He also tabulated the result
of the ten tidal observations made, on the following lines, though his columns
were without headings: Typical entries ran:

<table>
<thead>
<tr>
<th>Place Name</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Establishment Rhumb</th>
<th>Time of High Water on the change day</th>
<th>Distance from Resolution Is.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution Island</td>
<td>66°.26'</td>
<td>61°.31'</td>
<td>E.S.E.</td>
<td>7½ legues</td>
<td></td>
</tr>
<tr>
<td>At Cape Comfort</td>
<td>84°.22'</td>
<td>65°.00'</td>
<td>S.5.W.</td>
<td>11½</td>
<td>180</td>
</tr>
</tbody>
</table>

Typical extracts from 'The Breese Iournall' which was written up daily,
read as follows:

<table>
<thead>
<tr>
<th>Days</th>
<th>The Tru Course</th>
<th>Leagues</th>
<th>Windes by the compas</th>
<th>Latitude</th>
<th>Longitude from London</th>
<th>Variatyon</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>19</td>
<td>...</td>
<td>...</td>
<td>S.E.</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>20</td>
<td>W.4N.</td>
<td>41</td>
<td>E.S.E.</td>
<td>50.38</td>
<td>10.15</td>
<td>...</td>
</tr>
<tr>
<td>21</td>
<td>W. by N.4N.</td>
<td>37</td>
<td>E.S.E.</td>
<td>51.12</td>
<td>13.00</td>
<td>6.50[E.]</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

This morning we sett sayle from Padstowe.
<table>
<thead>
<tr>
<th>Dayes</th>
<th>The Tru Course</th>
<th>Leagues</th>
<th>Windes by the Compas</th>
<th>Latitude</th>
<th>Longitude from London</th>
<th>Variatyon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maye 1</td>
<td>N. by W.</td>
<td>17½</td>
<td>W.N.W.</td>
<td>59.50</td>
<td>29.26</td>
<td>1.30W.</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>10</td>
<td>W. 15 N.</td>
<td>15</td>
<td>N.E.</td>
<td>58.40</td>
<td>47.30</td>
<td>...</td>
</tr>
</tbody>
</table>

*Cape Farewell bore north 15 deg. east at noone. [C. Farewell lies in lat. 59° 45' N, long. 43° 50' W]*

*Variation had been found and logged on the 9th.

It will be noticed that Baffin used the modern notation of variation, the deflection of the north end of the needle, so many degrees and minutes east or west. The Elizabethans had been less clear. Davis's journals for instance—and those of others—often recorded variation in terms of the amount the south end of the needle was deflected east or west—no doubt because, with instruments such as Borough's, it was the easiest entry to make when finding the variation by the noon shadow of the sun. To be of use such entries had to be reinterpreted in terms of the deflection of the north end of the needle from the true meridian. Thus although it was the easiest way to record the results of observations for variation, it was not the easiest way to use them. The Jacobean method thus represented yet one more advance in the art of navigation.

From Baffin's *Tru Relation* we learn amongst other things that the *Discovery* was a vessel of 55 tons, and in addition to Bylot, the master, and Baffin 'his mate and associate', was manned by fourteen men and two boys. This gives a crew of three men to each ton displaced, a figure consonant with contemporary naval manning establishments.

Ten days after sighting Cape Farewell, *Discovery* had 'sayled through many great ilands of ice, some of them 200 foot high'. In fact Baffin had measured one which he 'found to be, 240 foote high above water'. This berg he calculated to be '1680 foote, from the top to the bottome', reckoning 'that there was but a seventh part of it above water'. The next day they sighted Resolution Island and moored the ship to a piece of ice. Here their observations of a westward flowing current bolstered up their hopes of a passage to the Pacific. They saw the point of the south shore bearing south from them by compass, 'which', Baffin pointed out, 'is indeed south-south-east, somewhat eastward, because here the compas is varied to the west 24 degrees'. The next day, anchoring off

1 A similar inflow is experienced in the Strait of Gibraltar. The Atlantic water flows into the Mediterranean in a top layer about 150 feet deep, the denser Mediterranean water flows out beneath it.
the west side of Resolution Island—named by Button on his voyage of 1612, in all probability after his flagship Resolution—they 'made tryall of the tyde' finding that it was high water there on days of full and change at 'an east south-east moone . . . or halfe an houer past seven . . . ' and that the tide rose and fell 'about 22 or 23 foote'. Baffin reckoned this place to be 'west from London 66 degrees 35', the latytude of the north ende of the iland . . . 61 . . . 36'; and the latytude of the south end . . . 61 . . . 26'. Modern charts show the northern end of Resolution Island as uncharted, the southernmost part as lying in latitude 61° 20' N, and the longitude of the bay where they anchored (probably) as 65° 00' West. Thus in his latitude observation that can be checked Baffin was only 6' in error. Others of his observations show him to have been in error generally only between 5' and 10' on latitude—a remarkable feat when it is remembered that all his observations were made with the naked eye, with astrolabe, cross-staff, quadrant or back-staff, fitted at best with open slit or pinhole sights, and most probably plain sight or shadow vanes without any such refinements. Resolution Island actually lies between longitude 64° 15' W and 65° 30' W; Baffin in his reckoning placed his position about 1° 30' too far to the west. When the unknown currents, the adverse winds, the icebergs, the sudden changes in variation, the gales and fog-bound days, and storm-torn seas, are recalled, it is remarkable that his longitude error should have been so small.

Baffin mostly passes over the difficulties of navigation amongst ice, because as he put it: 'to Wright of our offten mooringe to ice, takeinge in sayles, and fast inclosing, would proove but tedious to the reader, as it was troublesome to us'. But all was not tedium. In the latter part of June they had extraordinary weather, 'so faire, cleare, and calme' was it. Fast closed though they often were in ice they saw to it that they kept their bodies healthy and their spirits keen. 'Some days', said Baffin, 'we shott at butts with bowe and arrows, at other times at stoole ball [a game still played in Sussex villages], and some tymes at foote ball.' Baffin exercised his intellect as well as his body, for one day seeing 'the sonn and moone very cleare', he set up his instruments upon the ice and took a sight of the sun's and the moon's altitude and azimuth, in order to work out his longitude.¹ Actually he never worked this problem out for he took a better sight next day. The 'morne being fayre and cleare, and almost as stedy as on shore', he waited with his 'instrument of variation . . . to take the time of moone's comming to the meridian', and with his quadrant of two foot radius to take the sun's altitude. Having frequently found the variation to be 28° 30' W he knew the precise direction of the meridian, and so the moment when the moon transited. At the instant that the moon crossed the meridian he took the height of the sun. Then working with an English almanac, Searle's Ephemerides of 1609, which he had probably used in 1612 also, he calculated his longitude to be 74° 05' W from London. Using Origanus's Ephemerides, of 1599, he found it to be 91° 35' W of

¹ By lunar culmination as before.
LXVI. Champlain’s Illustration of the Log, Log-line, Log-board, etc., 1632.
LXVII. A MODEL LOG OF THE EARLY SEVENTEENTH CENTURY (1615). (SEE APPENDIX 21).
<table>
<thead>
<tr>
<th>Day</th>
<th>Hour Course</th>
<th>SW E</th>
<th>Length</th>
<th>Winds</th>
<th>Course</th>
<th>Sound</th>
<th>Caps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov 27</td>
<td>2 1/2</td>
<td>3.6</td>
<td>7.6</td>
<td>E</td>
<td>10 1/2</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>Nov 28</td>
<td>2 1/2</td>
<td>5 1/2</td>
<td>10</td>
<td>S</td>
<td>2 1/2</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>Nov 29</td>
<td>2 1/2</td>
<td>4 1/2</td>
<td>9 1/2</td>
<td>N</td>
<td>10 1/2</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Nov 30</td>
<td>2 1/2</td>
<td>5 1/2</td>
<td>10</td>
<td>N</td>
<td>10 1/2</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Dec 1</td>
<td>2 1/2</td>
<td>5 1/2</td>
<td>10</td>
<td>N</td>
<td>10 1/2</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Dec 2</td>
<td>2 1/2</td>
<td>5 1/2</td>
<td>10</td>
<td>N</td>
<td>10 1/2</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Dec 3</td>
<td>2 1/2</td>
<td>5 1/2</td>
<td>10</td>
<td>N</td>
<td>10 1/2</td>
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LXVIII. A Model Journal of the Early Seventeenth Century (1615). (See Appendix 21).
LXIX. FOUR SEA ASTROLABES.

(1) Probably Portuguese, dated 1555. Brass; diameter 8”; weight 6 lb. 6 ozs. On the back an owner’s mark, Andrew Smyton, 1688. (By courtesy of the Curator of the Albert Institute, Dundee.)

(2) Probably Spanish, c. 1585, brass; diam. 7”, weight 5 lb. 8 ozs. Found in Valencia, Co. Kerry, Ireland. Probably a relic of the Armada. (By courtesy of the Trustees of the National Maritime Museum, Greenwich.)

(3) Iberian(?), c. 1600. Bronze; diam. 7 1/2”, weight 4 lb. 2½ ozs. The alidade is modern. Dugged up from a wreck in Vera Cruz Harbour, Mexico. (By courtesy of the Curator of the Museum of the History of Science, Oxford.)

(4) By Elias Allen, London, 1616. Brass; diam. 1 3/4”, weight 17 lb. 8 ozs. Apparently taken to Scotland by Prof. James Gregory in 1673. (By courtesy of the Department of Natural Philosophy of the University of St. Andrews.)
Wittenberg. 1 ‘Nether of them is much different from my supposed longitude according to my iurnall which was 74° ... 30°’, he noted. In 1821 Captain Parry reported that ‘the long. 74° 05' ... is not a degree to the westward of the truth’, a remarkable tribute to Baffin’s observational and mathematical skill. His keenness is further exemplified by the fact that he records having taken a longitude sight ‘at sea the twenty six of April’, by another method, that of an occultation of a star by the moon. By this means he could obtain ‘the houre of tyme’, and hence the longitude, a method taught him by ‘Master Rudston’, a mathematician and almanac writer. Baffin was thus the first English navigator to record taking an observation at sea for longitude whilst under way. 2

In the middle of July Bylot and Baffin found a place where the six men they set on shore to observe the tide affirmed that the flood came from the northward. If this were so it was indicative of a passage that way, so they named the cape where the observation was made ‘Cape Comfort’, and pushed on north. But a few days later they found, clear for all to see, that ‘the tyde of floud did come from the south east, and the ebb from the north west ... playnlie perceiuing the sett of the ships riding at anchor, and also by the settinge of the ice’. For their better assurance Bylot went on shore himself to observe the rise and fall. The false hopes at Cape Comfort had been caused by an indraft of the bay, and, disappointed, they turned back.

When in September Baffin reached Plymouth Sound, with only three or four men sick, who soon recovered, and without the loss of one man—a fine feat—he reported that in his opinion the North-West Passage did not lie through Hudson’s Strait, and further, that if there were such a passage it lay through Davis Strait. Accordingly in March 1616, he was

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1 AN EPHEMERIS. FOR THE YEARE OF GRACE. 1609. [ ... 1617]
BEING THE FIRST FROM BISSEXtile.
The Common Notes and moueable FEASTS, according to the

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<th>Old Accompt</th>
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<tr>
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<td>The GOLDEN Number</td>
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<td>22</td>
<td>The CYCLE of the Sunne.</td>
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<td>The ROMANE Indiction</td>
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<td>The DOMINICALL Letter</td>
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<td>26 Of Febrarrie</td>
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<td>1 of March</td>
<td>ASHWENSDAY</td>
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<td>26 of April</td>
<td>EASTER Day</td>
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<td>21 of May</td>
<td>ROGATION Sunday</td>
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<td>25 of May</td>
<td>Ascension Day</td>
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<td>4 of June</td>
<td>WHITSVNDAY</td>
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<td>15 of June</td>
<td>CORPVS CHRISTI Day</td>
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<td>3 of December</td>
<td>ADVENT Sunday</td>
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Each year has a separate title-page, with those items which change each year being adjusted accordingly.


2 The title-page of an almanac for 1606 by Rudston is preserved in B.M. Harl. 5937. No. 133.  
22*—A.O.N.
sent forth once again in the *Discovery*, and again as pilot to Bylot. The outcome of this voyage was the discovery of Baffin Bay, and of the greatest variation in the world—in Sir Thomas Smith's Sound in latitude 78° N. 'I found it to be above five points or fifty-six degrees varied to the westward', reported Baffin, 'so that north-east and by east is true north . . . which', he observed, 'may make questionable D. Gilberts rule, tom. I, l.2 c.i, that where more earth is more attraction of the compasse happeneth by variation toward it . . . for 'the known continents of Asia, etc., must be unspeakably more than here there can be, and yet here is more variation then about Japan, or Brasil, Peru, etc.' They are the words of a scientific seaman. As for the passage, Baffin had to report that Davis had been justified in raising hopes of one beyond Hope Sanderson, 'for to that place which is in 72° 12' [N] the sea is open, and of an unsearchable depth, and of a good colour' and 'the ebb is stronger than the fluid'. But he had also to report that in latitude 74° 34' N the sea was pestered with ice, there was a tidal rise and fall of but five or six foot, and the cause of the ebb stream's being appreciable, while the flood was small, lay not in the existence of a passage, but in the 'melting snow from off the mountains'. He was forced therefore to conclude that there was no 'hope of passage in the North of Davis Straights'.

If he had found no passage and had crushed all reasonable hopes of one, Baffin had at least brought evidence to shake Gilbert's theory of the cause of variation. Just as on his previous voyage he had first recorded the size of icebergs, so on this latest one he had solved a mystery of the sea that had long vexed men with scientific minds, the origin of icebergs. It was, he pointed out, the combination of the strong ebb stream, caused by the melting snows of Greenland and these northern lands, and the prevalence of a wind from the north in 'the fore part of the yeere' that cause 'the great iles of ice' to be set to the southward, 'som into Fretum Hudson, and others into Newfoundland'.

Baffin's practice of keeping a 'Breese Journall' and a 'Tru Relatyon' was by now general. The records the navigator kept had various names, but brief journal, traverse book, and log-book were, to begin with, much the same in content, and contained the entries of each day's sailing necessary for its accurate plotting. The 'True Relation' or journal contained a précis of the foregoing with the addition of reflections and observations by the master on navigational and ship-board matters, generally in narrative form. The earliest form of journal would appear to have been written up in this manner, the journals of 1553 of Sir Hugh Willoughby, and of 1578 of Hall being good examples.1 When long voyages became more frequent as they did from the 1570s, the log and log-line was adopted, and a wider appreciation of the need for accuracy in oceanic navigation was developed. As a result, more systematic and more detailed records of the courses sailed and natural phenomena experienced were called for. The 'Traverse Book', of which John Davis's examples in *The Seamans Secrets*

1 See Pls. XXIX and XXXVII.
and in Hakluyt's *Principal Voyages* appear to be the prototypes, was evolved.\(^1\) As Baffin explained, the traverse book enabled the course made good, the distance run, and observations of latitude, to be accurately plotted on a chart. With the growing use of the log, and of circumpolar charts for navigation in the higher latitudes and especially of Mercator charts for oceanic voyaging in the middle and lower latitudes, the log-book with its longitude column came into use. It enabled the various traverses made during the day to be recorded for finding the resultant daily position by mathematical workings in the traverse book. This was at the close of the sixteenth century. The essential difference between the earlier traverse book and the later log-book was the inclusion in the latter of a longitude column. As already pointed out, whereas with the early traverse book the daily traverses could be plotted only consecutively from day to day, from the recordings in the log-book not only the daily traverses, but also the estimated daily geographical positions could be ascertained quickly and as quickly plotted. The log-book was the essential complement of the 'paradoxal' and 'Mercator's' charts. With the plane chart a longitude column signified nothing.

Since the development of charts upon which it was possible to record accurately the ship's position, and in the continued absence of an accurate timekeeper for finding longitude, the means of measuring accurately the distance run by a ship had become of increasing importance. While many mariners continued to estimate their speed by eye and rote many masters, as we shall see in the next chapter, threw the log every two hours. Some even threw it every hour. The log was generally timed over the half minute, and the actual log-line, was, as will be recalled, wound round a log-reel and paid out from this.\(^2\) The log-reel was held horizontally in both hands over the transom by a seaman and, being greased with tallow, rotated freely. The reading was 'logged' on the log-board, and transferred later to the log-book. We are indebted to Champlain for a description of the log-board used by English navigators. It measured, he stated, 3 feet high by 15 inches wide, and was ruled into four columns and thirteen lines. The top line contained the column headings—Hours—Knots—Fathoms—Courses & Rhumbs. The twelve lines in the Hours column were numbered at 2-hourly intervals from 2 to 12, and again from 2 to 12 to cover the 24 hours of the day. In the succeeding columns were entered the knots and fathoms logged every two hours and the mean course steered.\(^3\) Every 24 hours the knots and fathoms were added up, doubled to produce the sum of the hourly distance sailed, and converted into leagues sailed in the 24 hours, on the basis that a knot equalled a mile, and three miles a league. This distance was then transferred to the log-book. Here, besides the entries already referred to were logged the wind, the allowances for leeway,

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1 See Pls. XLVI and LI.
2 The use of the log-reel is mentioned in the Dutch mathematician Snell's *Tiphys Batavus* of 1624.
3 See Pl. LXVI.
the variation and dip observed, the soundings made, and landfalls. The log-book was likened by one teacher of navigation to the 'waste book' in accountancy. Daily the traverse from the previous noon position was worked out in the traverse book and, after the difference of latitude and the departure—movement east or west—had been plotted and corrected by the noon observation for latitude, if one had been made, the position was entered up in the journal. This was likened to the ledger or fair book in account-keeping. The narrative part of the journal was akin to the minutes of board meetings or to a report of proceedings.

To turn now to the problems of oceanic voyages to the East we find that by the time of Baffin's death at Ormuz in 1622 'as he was trying his mathematicall projects and conclusions' for siting the siege cannon, the East India Company's voyages had become routine. Skirmishes, scurvy, tropical diseases, and occasional treachery of natives were now the chief hazards, and took their annual toll of merchants, factors, and seamen. Save that departure and return were made in the Soundings the route followed was that first blazed by the Portuguese pioneers. The outward one was via the Madeiras, Canaries, and Cape Verde Islands, and thence across the line to the coast of Brazil, if possible at Cape St. Augustine, in the vicinity of modern Pernambuco. Failure to weather this cape could enforce a return to Sierra Leone on the West African coast, for fresh water and provisions. A glance at the chart of winds and currents of the Atlantic will make clear why this particular route was followed and why Cape St. Augustine was so important a landfall.¹

In the South Atlantic the most favourable winds for a passage to the Cape were to be found in the tropics off the Brazilian coast. A landfall on this coast was desirable in order to check the longitude after the slow and often alarming 'middle passage' through the doldrums and over the line at the mercy of sudden squalls and of the as yet imperfectly identified eastward flowing Guinea and Equatorial Counter Currents, and the westward flowing North and South Equatorial Currents. A late start from England, or a slow equatorial passage often resulted in head winds being met south of the Line, the S.E. Trades being encountered in latitude 5° S, and in their being experienced as far as 20° S. In such circumstances if Cape St. Augustine had not been weathered, it was generally impossible to make sufficient headway to the south and east to pick up favourable winds before disease, starvation or lack of water threatened disaster. Indeed, if Cape St. Augustine had not been weathered it was almost certain that the ship would be borne steadily westward, by the South Equatorial Current. In this event shipwreck upon the coast of northern Brazil could hardly be escaped if a south-west course were persisted in. The ideal was to reach the Brazilian coast in the southern summer before the S.E. Trades had followed the sun to the north, or to pass or to call at the island of Fernando de Noronha for water. Then a southerly course—passing well to the seaward of the dreaded Abrolhos Shoals—could be followed broad

¹ See Pl. LXV.
on the S.E. Trades and with the Abrolhos Current. As the parallels were raised and the wind crept round to the east, north-east, north, then north-west, the course was progressively brought round more and more to the east until in the latitude of the Cape of Good Hope the eternal westerlies were reached, and the ships were bowling crisply along steadily reeling off the leagues as they ran down their eastering. In the first decade of the seventeenth century the ships had invariably anchored at the Cape in stormy Saldanha Bay for water, rest, and fresh food, though they had generally reached it in midwinter. On the East India Company's first voyage Lancaster had left Tor Bay on the 20th April, 1601, and as a consequence had got caught in 'the calmes and contrarie winds' prevalent off Guinea in early summer, together with the 'many sudden gusts of wind, stormes, thunder, and lightening, very fearefull to be seene and dangerous to the shippes, unless a diligent care be had that all sayles be strucken doune upon the suddn ... '. He had spent a month in the doldrums and not 'doubled the line', or lost sight of the Pole Star until the end of June. This had meant that he had reached the Brazilian coast in midwinter. Although he did succeed in doubling Cape St. Augustine he could not circumvent the S.E. Trades. As a result he had a most tedious passage to the Cape, and many men fell sick. On arrival, in all save his own ship the men had become so enfeebled after four and a half months at sea without anti-scorbutics that the crews 'could hardly handle the sayles to bring the ships to anchor; it was only Lancaster who had brought to sea with him certain bottles of the juice of lemons, of which, it was reported, he had given to each of his crew as long as it had lasted, 'three spoonfuls every morning ...'.

On his homeward voyage Lancaster had sighted the Cape of Good Hope on 3rd February 1603 and, proceeding via St. Helena and the Azores so as to gain the fullest advantage of the prevailing winds and currents, had sighted the Lizard three months later. While Lancaster's outward passage of four and a half months to the Cape was unduly lengthy, it

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1 Winds off West Africa: Between June and September, because the area of low pressure over Africa extends to the N.W., the West African Monsoon, permanent south and south-west winds, extends over the Atlantic between the equatorial limits of the N.E. and S.E. trades about 5° N to 10° N as far as 32° W. Consequently on a voyage to Guinea at this season the navigator would meet consistent head winds from about Cape Verde. On a voyage to the Southern Hemisphere he would also experience head winds at this season in the vicinity of the Cape Verde Islands before entering the Doldrums. This part of the passage to the East Indies was therefore best made if it was timed to cross the equatorial belt between November and April. An additional reason was that during this latter period North-East winds (the N.E. Monsoon) would be experienced off the coast of South America between Cape St. Augustine and the Tropic of Capricorn. This would speed the passage through the southern tropics where otherwise, between April and October, the contrary S.E. trades would be met off the Brazilian coast.

was short compared with that of the fleet that sailed in 1607 under Captain William Hawkins. Like Lancaster he left England late, in mid-April, but unlike him he failed to double Cape St. Augustine, and had to put back to Sierra Leone. Ironically enough Lancaster had been asked to give advice for this fourth voyage of the Company, and had advised reaching the Cape of Good Hope by June at the latest and, to ensure this, that the departure should be made early in the year. Lancaster also advised the Company that its ships should no longer attempt to water at the Cape, since in June, being midwinter there, the storms were at their worst and most dangerous, but that instead the ships should go on to St. Augustine Bay on the south-west coast of Madagascar and water there. This became the practice for ships proceeding from Madagascar to the Red Sea or to peninsular India.

In the Atlantic it was the winds off N.E. Brazil in particular which determined the time of departure from England, while it was the regular trade winds and westerlies that dictated the route followed. Once around the Cape of Good Hope and in the Indian Ocean, it was the monsoons which controlled the movements of shipping. ‘Aboute Aprill the west and nor west wyndes beginnyng to blowe’ in the Arabian Sea, ‘thinke not to touch upon the coast’ of peninsular India, Lancaster had warned, ‘for yt is exceeding daungerous at that tyme of the yeare . . . till August . . . fowle weather and verie thicke and stormy . . . and the wyndes’—the S.W. monsoon—‘sett right upon the coaste, May, June, and Julie’. If the S.W. monsoon prevented passages to India in the summer it expedited those of ships proceeding to the Company’s factory at Bantam on the N.W. coast of Java. Provided they did not take too southerly a course it gave them an easy passage on a soldier’s wind.¹

Sailing directions such as Lancaster’s were invaluable. They summarized not only his own experience but also the Portuguese, in a manner to be

¹ There are two main seasons in the Indian Ocean, the season of the South-West Monsoon, May to October, and of the North-East Monsoon, November to April. There are three main weather belts in the Indian Ocean between May and October, the S.W. Monsoon period, these are:

1. The S.W. Monsoon Belt. Although just north of the Equator the S.W. Monsoon sets in during May, it does not prevail over the Arabian Sea and Bay of Bengal until June. Once established it persists until the end of September. In October it begins to retreat southward, and the winds become light and variable, but towards the end of the month are mainly from North and N.E. as the season of the N.E. Monsoon approaches—November to April.

2. The Trades Belt. The Trade wind belt lies between the Equator and about latitude 25°–30°S. Southerly and S.E. winds prevail throughout the belt.

3. The Unsettled Weather Belt. This lies southward of latitude 35° S.

The coastal winds off the South and S.E. coasts of South Africa are variable, but westerly winds predominate and may reach gale force at times. Off the southern part of Madagascar winds are usually between N.E. and S.E.; from the Mozambique Channel to the Equator they are light to moderate, between E.S.E. and South, between May and August, in September and October calm and light winds occur.
found nowhere else, not even in Hakluyt's, nor yet in Linschoten's works, of which John Saris wrote, when reporting on his return voyage from Japan in 1613, 'Wee found Jan Huijghen van Linschoten's booke very true, for thereby we directed our selves from our setting forth from Firando.'

The fifty years' experience of the Muscovy Company of making its servants observe old Sebastian Cabot's ordinances had by now permeated all English mercantile ventures. Baffin's journals had but contained the information demanded in detail of Captain Button by the Company of the Merchants Discoverers of the North-West Passage. Indeed the value of such records was so well appreciated that we find the East India Company ordering its servants to keep 'a journal . . . of each day's navigation and of all circumstances that may occur, such journals to be kept by the lieutenant, merchant, purser, pilots and master's mates, who are from time to time to compare their notes'. In 1614 the Company received a letter from one of their ship's captains, 'Captain Downton, in behalf of Mr. Wright, the mathematician, who has gathered great knowledge in the Universities, and effected many worthy works in rectifying errors formerly smothered'; on the strength of which it 'resolved that for his courses of lectures hitherto paid for by Sir Thos. Smythe and Mr. Wolstenholme, the Company would allow him 50 l. per annum; he to examine their journals and mariners and perfect their plott'. In July of the same year 'sundry journals and letters of intelligence, necessary for instruction, both for the places and commodities fit for trade in the Indies' were minuted as having to be examined 'by Mr. Wright' for reduction 'to heads to be readily found upon occasion offered'. The English were establishing their eastern trade no longer accidentally, but methodically.1

Between November and April, in the period of the N.E. Monsoon, there are four main weather belts:

1. *The N.E. Monsoon Belt.* This prevails throughout the Indian Ocean north of latitude 3°-4° N throughout the months November-March. During April the N.E. Monsoon retreats northwards. Strong squalls with thunderstorms occur this month.

2. *The Doldrums.* These are south of the Equator from December to the end of February, and to the north of it in March, April, and November. The width averages 400 miles.

3. *The Trades.* The Trade Wind belt lies approximately between latitudes 10° S and 30° S, and southerly and S.E. winds prevail. The winds are usually light to moderate, but cyclones occur in the S. Indian Ocean.

4. *The Unsettled Weather Belt* south of latitude 40° S.

1 (i). The East India Company's instructions are in *Voyages of Sir James Lancaster*, Hak. Soc., Ser. 1, Vol. 56. The 8th Article of 'the Commission issued to Sir Henry Middleton and others for the sixth voyage to the East Indies', [1610].


(iii). The Court Minutes of the East India Company are quoted from *Cal. S.P. Colonial Series, East Indies*, Nos. 702 and 744.
We have seen that in their North-West voyagings the English had found the vagaries of variation an unmitigated curse. On their oceanic voyages to the East they found it, on the contrary, a valuable check to their estimated longitude. Thus John Floris on his outward voyage, made in 1611, noted in his journal for 1st April, 'Wee were in the heighte of 2 degrees 40 minutes by S. of the lyne, . . . and had 4½ degrees variation, so that wee were well aboute [towards] E., setting our course S.S.W. and S. by W. to passe the Abrollos.'

Captain Best noted, on approaching the Cape of Good Hope in 1612, your variation is a sure rule to knowe when you come within some faire distance of the shore; for if you be 40 legues of[f], you shall have one degree 40’ [East] or neare thereaboutes; and so proportion your distance by your variation, allowing 30 legues to a degree of variation (I mean 30 legues east),

for the variation at the Cape was 'some 30 or 40 minutes' East, and east of the Cape it became West. 2

Sir Thomas Roe, who sailed in 1615 as the first English Ambassador to the Great Mogul, was a competent, though amateur, navigator, who had already voyaged to Guiana. Being blessed with a superior intellect, an inquiring mind, and a good education, this brilliant courtier and diplomat entertained himself on the voyage out by keeping a log and a journal, and by making his own observations and deductions. He made two references to a chart of the Atlantic on Mercator's projection, and reckoned, correctly, that Cape Bojador was plotted too far to the east. 3 On the other hand he reckoned the Cape of Good Hope to be correctly charted for longitude when it was shown in a position 5° too far to the west. Nevertheless by his reckoning he expected to see the Cape during the first watch—between 8 p.m. and midnight—on the 4th June, and, much to the chagrin of the various masters in the fleet, he proved right. They had made the error of relying too much upon the evidence of variation for determining their longitude. They had made sure to see the Cape 'within 12 howers after the variation was lessened to one degree', explained Sir Thomas, adding 'but this . . . is an error', for 'variation be an excellent evidence in the . . . course of

(iv). Voyages of Sir James Lancaster, Hak. Soc., Ser. i, Vol. 56 gives on p. xvi a list of the ships' journals of voyages to the East Indies from which Purchas gives extracts in his Pilgrimes, and on pp. 263-277 'A Calendar of the Ships' Journals', written within the seventeenth century, preserved in the India Office. There are no less than 52 which fall within the period of the present study.

They are all MS. The first log with a printed form and headings is No. 130, the voyage of the Samuel and Anna, Captain Redell, 1702-03.

nearing land but delivereth no other certainty but warninge to looke out'. He reckoned that 'the Magneticall amplitude being so difficult to observe truly, by the shippes Motion and the Needles quickness that a degree is scarce an error', and that consequently it was impossible to fix a ship's position to within even sixty miles, by means of observation of the variation.

That Best was a careful and capable navigator is proved by the fair copy of his journal, extracts from which have already been cited. This shows that as far as Maio Island in the Cape Verde group he logged his course and distance run from noon to noon. From the Canaries onward he also entered the observed latitude. After leaving the Cape Verdes Best logged the course steered, distance run, and longitude from Maio Island, almost daily, and every two or three days the latitude observed. 'The morning variation' and 'evening variation' in accordance with the best practice, were logged daily, except when cloud evidently prevented observation of the sun's amplitude.

On sighting Trinidad Island, some seven hundred miles east of Brazil, Best logged its latitude, correctly, as 20° 30' S. Its longitude, however, he made to be 1° 50' E of Maio Island. In this he was some 8° 24' in error to the east, for Maio Island is 23° 16' W of Greenwich and Trinidad Island is 29° 50' W of the same meridian. This error was not exceptional. John Davis of Limehouse, not to be confused with John Davis of Sandridge, the author of the Seamans Secrets, was also a navigator of repute. He had made four voyages to the East and was actually Chief Pilot of the fleet in which Captain Best was sailing. He placed Trinidad Island in longitude 16° 42' W of London and thus was 13° in error. The Cape he placed '28 degrees in longitude from the meridian of the Lizard' being 4½° in error for it actually lies 23° 37' E of it. These extracts exemplify the practice of reckoning longitude, not from a fixed prime meridian, but from the meridian of the last point of departure. As we shall see again, the Lizard was a particular favourite of English seamen.

1 Purchas his Pilgrimes (1625). Part I. Bk. IV. p. 444. A Ruter, or breife direction for readie sayling into the East-India, digested into a plaine method by Master IOHN DAVIS of Limehouse, upon experience of his fiue Voyages thither, and home againe. Davis's rutter is of particular interest, for it is filled with detailed directions on variation for longitude determination. For instance:

Between the Coast of Brasil and this Roade, [Saldanha Bay, Cape of Good Hope] the Compass hath twenty degrees variation, and more or lesse as you are to the Northward or South. For the more you are to the Southward, the more you haue, and to the Northward the lesse. But in thirtie three degrees thirty minutes, you haue the highest variation twenty one degrees from North to East, & longitude from the Lizard seuen deg. thirtie minutes, or from the Cape of Good Hope, thirtie five deg. thirtie minutes West: Now when you come in eleuen degrees no minutes of variation, you may assure your self, if your variation bee good, you are three hundred and thirtie leagues short: and it will keepe a good method in decreasing after the rate of thirtie or eight and twentieth leagues to a degree: for when you are in two degrees of variation, you shall bee eight and fortie or fiftie leagues short: and when you have fortie minutes, and cannot see the land, you are but ten leagues off.
On his return voyage Best fell in with Flores and Corvo in the Azores when he expected to be much farther to the east. This was almost certainly caused by the westward-flowing South and North Equatorial and Canary Currents under whose influence he must have made much of his Atlantic passage. Indeed, though he did not name these currents he made mention of their effect, noting in his journal that from the equator it (he recognized only one current) 'hath put us more westerly than our judgemente, by some 40 or 50 leagues'. By the 1st June Best reckoned he was approaching the Soundings, being then in latitude 48° 00' N, the variation being 8° E, and the course north-east. Two days later, having run a further 34 leagues, Best logged his position as latitude 48° 55' N, and longitude from the meridian of the Cape of Good Hope, 28° 32' West. A comfortable S.W. breeze was bearing them steadily homeward when they sounded. … 78 fathom, white sand (2 or 3 sharkes teeth), right Ushant soundinge'. Best logged, 'it being east-southerly from us some 16 or 18 leagues. Note', he added, 'that yesternight wee sounded at 7 of the clocke, and coulde not have gronde with a 150 fathom, soundinge right upp and with our pynnace (both then and also nowe). From the former soundinge we rann N.E. by N. 11 or 12 leagues, then sounded at 7 of the clocke, and had 62 or 63 fathom, fine peppery sand. Our latitude at this tyme, 49° 30'. From this last soundinge', Best logged later, 'we rann N.E. 15 leagues. Then at 5 in the morning wee sounded, and had 52 fathom, faire brandy sand, fishinge gronde. And at 9 of the clocke this morninge wee saw the Lyzard north from us, some 4 or 5 leagues of[f] …'.

It was a prosperous landfall, yet, though they had quitted St. Helena but two months and nine days since, 'one half or more of our company are laide upp of the Scurbate', noted Best, 'and two dead of it'. There is, significantly, no mention of any issue of lime juice or lemons.

Although Best's, and the others', errors in longitude sound formidable when their positions are expressed in degrees and minutes, and are compared with similar positions on modern charts, they were not always so in reality. The errors in longitude of their geographical positions arose to a considerable extent from ignorance of the length of a degree. Thus, although Best placed the Lizard 5° 38' W of its true geographical position, that is 217 miles west of it, he actually reached the Soundings within 18 hours of the time he expected to. Assuming he was making good 5 knots, which is about what he was logging, he was not more than 90 miles out. In practice this is not being fair to him, for as a prudent navigator he would have sounded at least 12 hours before he reckoned to cross the 100-fathom line—the most valuable check for longitude possible for inward bound shipping—so that he was probably not more than about 30 miles out.

Sir Thomas Roe, from whose journal we have already quoted, found the ordinary masters in the East India Company's service ignorant fellows. He criticized adversely their conservatism, and had much dispute with

1 '… so that the difference of longitude betweene the Cape of Good Hope and the Lyzard is 29° 20', or very neere thereabouts …', he logged. It is in fact 23° 42'.
them over the correct track from Brazil to the Cape, holding, with some justification, that a more direct one than they favoured would also be a quicker one. According to him they blindly followed former practice, running far south before running down their easting. He seems to have deduced the anti-clockwise wind system in the South Atlantic which made practical his scheme of a more direct route.

At that time there was no variation at the Cape; to-day it is about $23^\circ$ W, but to the west and to the east of it, as already indicated, there were respectively increasing easterly and westerly variations.\footnote{See Pls. LXVII and LXVIII. The journal of Sir Thomas Roe commences with 'Observations according to the Table of Course.' Unfortunately the editor of his voyages for the Hakluyt Society considered that it contained 'nothing of general importance', and so omitted it. In fact, from a navigational point of view, this abstract of the journal is of very real importance for showing 'in tabular form the course, variation, latitude, longitude, leagues run etc., from the 6th March to 17th September [1615].' It provides an admirable example of a ship's log of the early years of the seventeenth century and the means of plotting the track of the fleet by contemporary methods. Many extracts from contemporary journals are contained in Purchas his Pilgrimes (1625), and these frequently illustrate the use made of variation for finding longitude. As an example may be cited this extract from Vol. 4, pp. 280 et seq. in the Hak. Soc., Extr. Ser.}

Memorials of a Voyage, wherein were employed three shippes . . . 1614. Written by John Wilward Merchant, . . .

The twentieth of December, the generall caused the Masters and Masters-mates to come aboard supposing that we were shot one hundred and fiftie leagues more then reckoning to the East, in eightene degrees fortie minutes. The nine and twentieth we discryed land, but knew not well in what height we were, resolved that it was Java, but knew not what part of it . . . the plats make it to be betwixt eleven and twelve degrees, and our latitude at that time, was but eight degrees forty minutes; yet it is questionable whether it hath been discovered. But howsoever, or wheresoeuer we were, it is certaine that we were fallen to Leeward of the straits of Sunda, by two or three degrees, and unto the North-West Monsors, which blow thereabouts from September to the last of March. All the Masters were of opinion, to goe backe into thirteene or fourteene degrees South-ward, to fetch the South-east wind, which is a Trade wind betwenee twentie eight and eleven degrees, and so to shape our course more northerly . . . The next day noone, we had a good observation in the latitude of eight degrees thirty-five minutes . . . On the eighteenth [January, 1615], we had land in seven degrees tenne minutes, being by likelihood not farre West from our first land, notwithstanding that we had runne from it by our course, neere one hundred leagues to the West, by reason of a violent current to the East . . . The second of February, we were in tenne degrees twelve minutes . . . The fourth at Sun-setting, we had three degrees tenne minutes to the West variation. It is an infallible rule, that from the Cape of Good Hope to Java, the variation increaseth to the West, the further East we runne, till it come to about seventene degrees, and then as we runne to the East decreaseith, till we come to the Straits of Sunda, where it is three degrees and a halfe variation, and is holden the best guide for Easting and Westing, though not observing exact proportion. On the fifth, we had nine degrees sixteen minutes, and three degrees forty-eight degrees variation West. The declination of the Crosiers in twenty eight degrees and a halfe. On the thirteenth, we were in the straights of Sunda.
lay in the Mayne', that is the mainland. Thus while Baffin was refuting with his observations Gilbert's theory of the cause of variation, Sir Thomas was apparently substantiating it.

After leaving Table Bay Sir Thomas noted the effect of the Agulhas Current. It 'kept us', he noted, 'both from raysing and Eastering, so that notwithstanding the ships way by the passing of the water gave so many leagues as the table of Course mentions', that is 'the Rule to raise or lay a degree', now frequently given in tabular form, 'yet the error was great, for at fower in the afternoone the 25th day'—they had weighed and proceeded on the 20th June—'we sawe land bearing from W. to N.E. by E. all along, wheras by rekoning I was more than 40 leaugs off'. Two errors were hereby observed, he noted, namely, that the trend of the coast was incorrectly charted on 'the Cardes', and 'that wee were kept back by the Current in this Course 50 leaugs at least, wherybe we dayly mistooke our longitude, Judging it only by our Easterly way . . .'.

It is clear that up till then the existence of the powerful Agulhas Current, which flows down the East African coast from the Mozambique Channel, had been unknown to English navigators. Counting now on this current as they made their way north-eastward to St. Augustine's Bay for water they soon found that they 'raysed more then course and variation did bring out by 4, 5 and 6 leaugs in 24 howers, right before the wind'; so that now, contrary to their expectation they experienced 'another current setting . . . to the North . . .'.

By the 8th July, by Roe's reckoning, the ships were hard and fast ashore on Madagascar, but in fact they had failed to make any landfall and did not make one until they had sailed 10° farther to the north, when they made it on the Comoro Group at the northern exit from the Mozambique Channel.

'Caution—The great strength, variety of direction, and general uncertainty of the currents in all parts of the Mozambique channel, render it necessary for a vessel's position to be constantly verified . . .', warns the *Admiralty Pilot* for those waters.1 Without means of checking longitude, navigators like Sir Thomas Roe needed great faith in the mercy of God, and iron nerves.

Sir Thomas observed that he 'always made two or 3° more variation then all the fleete' as it was his practice to touch his compass needle afresh 'once in 10 dayes'. As the needles he touched for others showed the same difference he concluded correctly that the cause of the difference lay in these needles being 'more animated and fixed then those that being long touched must daylie somewhat weaken'.

It is to the credit of the East India Company that it attempted to tackle the problem of preserving the health of its crews. It strictly enjoined cleanliness, and provided good rations, surgeons, and special stores for the sick. In 1614, Dr. John Woodall, a surgeon of long standing and high

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1 The Admiralty Pilot referred to is: *Africa Pilot Part III* (1939).
repute, was appointed by the Company to be Surgeon-General, with the task of seeing to the selection of suitable ship's surgeons and the supervision of their medical stores and instruments. In 1617 'being wearied with writing for every shippe the same instructions a new', Woodall put them into print under the title of The S urgions Mate.¹ In this exhaustive treatise, the first of its kind, surgery, medicine and hygiene at sea, were dealt with thoroughly. Particular attention was given to scurvy, its probable causes, and its prevention. 'How excellent hath it been approved', wrote Woodall of lime juice as an anti-scorbutic. By doing so he perhaps perpetuated the fallacy that it was the best preventative. Actually the vitamin C content of limes is much lower than that of oranges and of lemons, which are therefore better anti-scorbutics. Unfortunately Woodall recommended that lime juice should be administered on reaching shore, and said nothing about its issue at sea. Although lime juice was frequently issued to East Indiamen from the time of the first voyages scurvy continued to take terrible toll of the crews. Lancaster could have taught Woodall more about anti-scorbutics, but no doubt professional teaching and etiquette ruled out his successful empiricism. It was a tragedy for generations of seamen. Until dietetics and general hygiene became better understood and the latter enforced, and until cheap cotton clothes permitting of easy washing and frequent changing became procurable in the eighteenth century, even lemon and orange juice would not have prevented scurvy entirely. They would have made it rarer and its attacks less terrible. In this matter of clothes the Royal Navy started on the right lines in 1623 by commencing the issue of 'purser's slops'. These were clothes for the seamen procurable on board ship from the purser. The arrangement enabled the men to buy, if not a change, which they could probably not afford, at least a sound set of clothing with which to cover themselves. This was a great advance. In the year of the Armada, for instance, Howard had reported that many of the men in the fleet were in rags and suffering from the cold, to the detriment of their health.

Besides attending to the physical welfare of its servants the Company was not unmindful of their spiritual well-being. The True Honor of Navigation and Navigators: or, Holy Meditations for Sea-men was written by John Wood in 1618, with an especial eye to the needs of the men of the

¹ THE SURGIONS MATE, or A TREATISE DISCOuering faithfully and plainly the due contents of the SVRGIONS Chest, the use of the Instruments, the vertues and operations of the Medicines, the cures of the most frequent diseases at SEA: Namely Wounds, Apostumes, Vlcers, Fistulaes, Fractures, Dislocations, With the true maner of Amputation, the cure of the Scurue, the Fluxes of the belly, of the Collica and Illiacca Passio, Tenasmus; and exitus Ani, the Callenture; WITH A BRIEFE EXPLANATION of Sal, Sulphur, and Mercury; with certaine Characters, and termees of Arte.

Published chiefly for the benefit of young Sea-Surgions, employed in the East-India Companies affaires. By John Woodall Mr. in Chirurgery.

LONDON Printed by EDWARD GRIFFIN for Laurence Lisle, at the Tygershead in Pauls Church-yard. 1617.
East India Company, to whose sagacious and now venerable Governor, Sir Thomas Smith, he dedicated it. It contains the elements of later and more famous prayers for use at sea, and is notable for being in all probability the earliest printed seaman's prayer-book; it was no doubt thankfully received by the captains of those ships of the Company's fleet which did not carry chaplains.

Study of the charts and journals of the navigators of the chartered companies of the Jacobean era reveals that the chart projections they used were generally scientifically accurate ones, either circumpolar charts or charts on Mercator’s projection. Except in waters of pilotage they seem to have discarded plane charts. As early as 1606, it would appear, James Hall had drawn and used a chart of the seas between Scotland, Iceland, Greenland and Newfoundland, between the latitudes of 44° N and 72° N on Mercator’s projection for his voyages to Greenland. Hudson on his voyage of 1610-11 drew his chart of the seas and coasts between England and the Bay named after him on Mercator’s projection, and by 1615 John Daniel had drawn a chart on Mercator’s projection of the whole Atlantic for the East India Company’s navigators. This chart was used by Captain Peyton on the voyage of 1615, when Sir Thomas Roe went out to India.

The use of such charts by the East India Company’s pilots may well have been the result of Edward Wright’s appointment to lecture on navigation to the Company’s servants, and to correct its charts. For his voyages to the north-east Hudson appears to have used circumpolar charts, as would be expected in such high latitudes. The English whalers, of whom, of course, Baffin was also one, apparently used similar charts, for a remarkable Dutch circumpolar chart of Spitzbergen, published in 1613, was for ‘the greater part’ based on a chart by John Daniel. Extending between the latitudes of 66° N and 82 ½° N and covering the seas around Spitzbergen, it has a double network of spiral rhumbs. These, of course, could only have been drawn in correctly by using Wright’s table of rhumbs. The chart

1 THE TRUE HONOR OF NAVIGATION AND NAVIGATORS: Or, HOLY MEDITATIONS FOR SEA-MEN.
Written vpon our Saviour Christ his Voyage by Sea, MATTH. 8.23 &c. Whereunto are added certaine forms of Prayers for Sea travellers, suited to the former Meditations, vpon the seuerall occasions that fall at Sea. By IOHN WOOD, Doctor in Diuinitie. Psalm. 34.17. The righteous crie, and the Lord heareth; and deliuereth them out of all their troubles.
LONDON, Imprinted by Felix Kyngston, dwelling in Paternoster row, neere the signe of the Golden Cocke. 1618. [Wood described its contents as ‘Meditations . . . fitted especially for Sea-men. A worke wherein I know not any man that hath gone before me.’]


See also the reproduction of the ‘Map of Greenland, with the manner of killing whales, Morses and Bears’. Reproduced in Purchas his Pilgrimes, Hak. Soc., Extra Ser., Vol. 13.
Baffin drew to illustrate his track and survey work of 1615 has already been described as being on a circumpolar projection. His later charts unfortunately have not survived.

It is clear that the Elizabethan and Jacobean navigators in general lost no time in exploiting the hydrographical knowledge first put at their disposal in the works of John Davis, William Barlow, and Edward Wright in the 1590s. The chief credit for the use of circumpolar charts must go to John Davis, who publicized them, and William Barlow, who first described them. Behind both, however, claiming credit as the innovator is the presence of Dr. John Dee. To Edward Wright goes the credit for the general use of Mercator's projection, though Hariot who perhaps first calculated tables for it, Blundeville and Barlow who first publicized it, and Mercator who first inspired it, deserve their share of praise.

Trinity House, it will be recalled, received a new and important charter from James I in 1604, which confirmed its right to consult of and upon the conservation, good estate, wholesome government, maintenance and increase of navigation, mariners, and seafaring men, and of 'the cunning, knowledge or science of seamen and pilots'. That the members of Trinity House took their charge concerning the art of navigation seriously has already been shown, and is further indicated by the number of navigational books now dedicated to them, and by the writing of others by members of the fraternity. Closely connected with the art of navigation was that of ship design and construction. Trinity House now took a keen interest in this. As early as 1578 the English shipwrights had petitioned the Crown for incorporation on the ground that 'as all kinds of vessels are greatly increased, so are the artificers likewise augmented, only in number, but less in skill'—corroboration that the rise of the English mercantile navy began in the 1570s. It is to this period that the earliest draughts of English ships can be traced. But in the early seventeenth century the majority of English shipwrights still worked by rule of thumb. Captain Waymouth, who had made the 1602 voyage to the north-west, and was author of the Jewell of Arts, 'could never see two ships builded of the like proportion by the best and most skilful shipwrights, though they have many times undertaken the same ... because they trust rather to their judgment than their art, and to their eye than their scale and compass'. When the Prince Royal, the largest English warship built up to that time, was under construction in 1609 there was an inquiry into her design and materials. Phineas Pett and William Bright, her constructors and men of the highest technical repute, eventually required more than three times the amount of timber to complete her than they had originally computed. Nevertheless in the English shipwrights' art a scientific spirit too was abroad. Because he saw so many errors daily committed by shipwrights, Richard More published in 1602 The Carpenters Rule to measure ordinarie Timber.¹

¹ THE CARPENTERS RULE, Or A BOOKE SHEWING MANY plaine waies, truly to measure ordinarie Timber, and other extraordinary solids, or
Besides explaining the measurement of timber, he recommended all carpenters to study geometry, and reminded them of their 'especially good helpes' in the form of Billingsley's *Euclid*, of 1570, and 'the lecture at Gresham College'. As More seems to have been no more than a self-taught artificer he was an excellent example of the justification of Billingsley's faith that his *Euclid* would lead to increased technical skill and inventiveness amongst English craftsmen. It is also to be remarked that the Gresham professors were frequently consulted by the master shipwrights of the royal yards, and that it was during this period and with their help that a sound formula for calculating tonnage was arrived at. Meanwhile, and clearly on the advice of Trinity House, because of the frequent ill-building of ships, in 1605 a Charter of Incorporation was granted to the 'shipwrights of England' giving them wide powers of inspection and supervision. But vested interest in the many small shipyards proved too strong, and the charter was superseded by another, in 1612, for 'the shipwrights of Redrithe' (Rotherhithe) only. This effectively crippled the scheme, and ill-building continued throughout the seventeenth century to be common in English ships, but more attention was paid to design. The 'tender-sidedness' or crankiness of Jacobean ships, which seems to have been caused by attempts to mount a heavy armament—partly because of pirates and partly because of naval reserve requirements—and which was remedied by 'girdling', the addition of an extra skin to increase beam, seems to have been eliminated about the time of Captain Smith's death through a better appreciation of the problems of stability.  

Timber: WITH A DETECTION OF SVNDRIE great errors, generally committed by Carpenters and others in measuring of Timber; tending much to the buyers great losse. PVBLISHED ESPECIALLY FOR THE GOOD of the Com[pany of] Carpenters in London, and others also; and is very nec[essary]e for Masons, Shipwrights, Ioyners, and others us[ing] to measure Timber and Boord, and other superficies and solids. By Ri[CHARD MORE] Carpenter.  
AT LONDON Imprinted by FELIX KYNGSTON. 1602.


There is an excellent model of a merchant ship of this period in the Science Museum, South Kensington.


See also Appendix 27.
LXXI. Evolution of the Nautical Cross-staff down to 1631.
It has been stated at the beginning of this chapter that it was in Jacobean times that the most remarkable modern advances in astronomy were made. It might be supposed that they had little influence upon the art of navigation, but, as we shall see, they led to refinements in that art, which in turn led to greater accuracy of observation and calculation than ever before, and to a proposition for the determination of longitude, which, though it eventually proved impracticable, merits a brief description. In cataloguing the universe the greatest advances arose originally from the painstaking observations of the Danish astronomer, Tycho Brahe (1546–1601). Using only open-sight instruments he yet 'accumulated more new facts about the heavens than had been since the date of Hipparchus', and in particular he 'estimated with a degree of accuracy hardly surpassed at the present day the irregularities of the lunar motion'. Tycho Brahe will be found mentioned in numerous Jacobean almanacs and navigational manuals in connexion with the revised or additional astronomical tables printed in them. While they thus interpret for the navigator the results of Brahe's observations and calculations they do the same for the pilot by paying more particular attention to the moon's motions, especially in connexion with the tides. Tycho Brahe, however, condemned the Copernican system—the thesis that the earth rotates about the sun—formulating one of his own which attempted to reconcile the Copernican and Ptolemaic theories, and which was often reproduced in navigation manuals of the later seventeenth century. It fell to Brahe's pupil and assistant, John Kepler (1571–1630) to meditate upon and compute the real significance of his observations, and to propound the planetary laws which so brilliantly reconciled Brahe's observations with the Copernican system. The first two laws Kepler enunciated in 1609, the third nine years later in a work dedicated to King James. Arising from these came forth in 1627 the Rudolphine Tables (Ephemerides) under Kepler's editorship. Of them he wrote 'the book is to be read either now or by posterity—I care not which: it may well wait a century for a reader, as God has waited 6,000 years for an observer'. It was the death-knell, as has been truly remarked, of the old astronomy.¹ In England, indeed, the Copernican theory was pretty firmly established by the seventeenth century. Since 1576 it had been available for all to study in Digges's Prognostication, and in Jacobean days other almanacs publicized it, notably Bretanor's

¹ Gunther, R. T., *Early Science in Oxford* (1923), reviews the development in astronomy, and in instruments associated with the science and allied subjects.

Kepler's laws of planetary motion were:

1. The planets move round the sun, but in ellipses, not in circles, and the sun is at one of the foci of the ellipse.

2. The motion is not uniform; but the planet moves over equal areas, bounded by lines drawn to it from the sun, in equal times. (Kepler, *De Stella Martis*, 1609).

3. The squares of the periods of the revolution of the planets are to each other as the cubes of their mean distances from the sun. (Kepler, *Harmonica Mundi*, 1618).

23—A.O.N.
which appeared between 1605 and 1618. Men of science and theologians were to continue for long to dispute the theory, and the general public to continue to cling to the more immediately obvious Ptolemaic explanation of the universe, but by 1609 an invention, only a few months old in its commercial form, placed in the hands of astronomers the power to confound the theoreticians of the centuries. This was the ‘prospective glass’ or telescope. Telescopes were no sudden invention. The spectacular manner in which they were exploited from 1609 onwards was chiefly due to the salesmanship of the Dutch opticians who commercialized their manufacture, perhaps as a result of the Truce of Antwerp, which afforded the opportunity of releasing to all and sundry, even their enemies the Spaniards, an instrument developed for martial purposes, and in its way as valuable in war as radar was to be to the British three hundred and thirty years later; for like radar the telescope placed into the hands of an army commander, such as Prince Maurice of Nassau who used one in 1608, the means of forestalling the supposedly secret moves of the enemy. However that may be, Roger Bacon, who died about 1294, had written on optics and of ‘glasse or diaphanous bodies that might be formed so that the most remote objects might appear just at hand’. Chaucer mentioned ‘queynte mirours and . . . perspectives’ in the Squire’s Tale. According to Thomas Digges’s circumstantial account in Pantometrie of 1571, his father, Leonard Digges, made ‘proportionall Glasses’ using ‘concave and convex mirrors’, that is reflecting telescopes, ‘so that a small object might be discerned as plainly as if it were close to the observer, though it might be as far distant as the eye could descrie’. It is equally certain that as early as the 1550s Leonard Digges had made refracting telescopes of ‘Perspective Glasses duly scitate upon convenient Angles in such sorte to discover in every particularitie in the countrey rounde aboute’. Dr. John Dee in his preface to the Euclid of 1570 also wrote how a man ‘might wonderfully helpe him self, by perspective glasses’, while Bourne, probably in 1572, wrote a treatise, which he never published, ‘On the Properties and Qualities of Glasses for Optical Purposes’, treating at length of refracting telescopes and reflecting ones, referring to those of Digges and Dee in terms that make it clear that these English scientists, who played such an important part in the development of the art of navigation in England, understood the properties of, and made, ‘perspective glasses’. Indeed,

1 For example:
Bretmoe. 1615. A Newe Almanacke and Prognostication, for the yeare of our Lord God, 1615. Being the thirde after Leap yeare. Calculated & composed according to Art for the latitude and Meridian of the honorable City of London, and may well serue all the South parts of Great-Britaine. By Thomas Bretmoe professor of the Mathematicks & Student in Physicke in Cowlane, London. Fata mouere Deus, tollere fata potest. Cum privilegio.

2 Bourne’s optical treatise was reprinted by Halliwell in his Rara Mathematica.

The title of a religious book of 1603, Thorne’s A Kenning-Glasse for a Christian King, would seem to indicate that telescopes were not such rarities in England by the time of Elizabeth’s death as might be supposed on the evidence of references to their use.
another such was Thomas Hariot, who took to Virginia on the colonizing venture of 1585–86, perspective glasses with which he fascinated the natives. Nevertheless, the first practical, commercial, telescopes were contrived independently but simultaneously by Dutch lens-makers of Middelburg, Hans Lippershey and Zaccharias Jansen, and of Alkmar, James Metius. They were refracting telescopes with concave eyepieces and were first marketed in October 1608. Galileo, being in Venice in May 1609, there learnt how to construct them and was soon getting startling results from his study of the heavens by their use. By February 1610 telescopes were being made in London. By December Thomas Hariot had observed and recorded the presence of sun spots, but here it must be remarked that Hudson recorded an observation at sea on 21 March 1609, of ‘the sunne having a slake’, an entry which would appear to indicate that he was the first man to record a sun spot. At the time he was fixing the ship’s position with open sights in Arctic waters. Hariot’s observations of the sun continued into 1613, and enabled him to determine its axial rotation. Besides bringing sun spots before the wondering eyes of men, telescopes rapidly revealed to Englishmen like Hariot, Wright, and Wotton, and to the great Italian Galileo, the lunar mountains and valleys, the crescent shape of Venus, the ring of Saturn, star clusters, the Milky Way, the nebulae of Andromeda, the satellites of Jupiter and stars innumerable as the sands on the seashore ... and ‘I send herewith unto his Majesty’, wrote Henry Wotton, in March 1610 when resident in Italy, ‘the strangest piece of news (as I may justly call it) that he hath ever yet received from any part of the world; which is the annexed book [Galileo, Sidereus Nuncius] (come aboard this very day) of the Mathematical Professor at Padua, who by the help of an optical instrument (which both enlargeth and approximateth the object) invented first in Flanders and bettered by himself, hath discovered four new planets rolling about the sphere of Jupiter, besides many other unknown fixed stars; likewise the true cause of the Via Lactea, so long searched; and lastly that the moon is not spherical, but endued with many prominences, and, which is of all the strangest, illumined with the solar light by reflection from the body of the earth, as he seemeth to say. So as upon the whole subject he hath first overthrown all former astronomy...’ Thus 1610 saw the old astronomy, already shaken the year before by Kepler’s planetary laws, all but smashed by Galileo’s published observations. Final proof of the validity of the Copernican theory—the actuality of stellar parallax—had to wait two centuries before instruments of sufficient power enabled it to be observed. So far as Jacobean navigators were concerned, the immediate result of the application of the telescope to astronomy was Galileo’s proposition for finding longitude by the four satellites of Jupiter (nine, it may be remarked, are known at present, but the five smallest were not observed until telescopes of very much greater power were made at the end of the nineteenth century). The satellites, as they circle round Jupiter, are frequently eclipsed, and the times of the eclipses can be accurately predicted far in
advance. Owing to the vast distances involved these times are unaffected by the observer's position on the earth. Thus if a navigator could find from tables predicting an eclipse that it should occur at 11 hours 40 minutes 10 seconds at the prime meridian, and should observe it to occur at 5 hours 40 minutes 10 seconds local time he would know that he was \( \frac{360° \times 6 \text{ h}}{24 \text{ h}} = 90° \) East of the Prime Meridian. This was the theory. In practice it did not work out like that. The motion of the ship, however slight, prevented the satellites and Jupiter from being held in the field of the telescope long enough for an observation of an eclipse to be made. Even on shore it was no more practical. The eclipses are not instantaneous, and it was soon found that alterations in the atmospheric conditions, and even variations in the power of the telescopes used induced errors, so that the apparent time of the eclipses was altered. Finally the sun and Jupiter are often so close together that observation of Jupiter is impossible.

Although Galileo contrived a special telescopic helmet to facilitate observations, and calculated the necessary tables, submitting the results in 1616 to the Dutch and Spanish Governments for their promised awards to the inventor of the means of finding longitude, the method was considered, and remains, impractical at sea.\(^1\) Thus once again the hope of finding longitude, sprung from some scientific discovery, was thrust back. Unless and until more accurate timekeepers could be devised, the only practicable means offering prospects of perfection were those being used by Baffin, a method, incidentally, which Button was ordered to use on his voyage of 1612.

According to Mark Ridley, Edward Wright used telescopic sights on his instruments, but in doing this Wright was exceptional. Telescopes, often of extraordinary length, remained for many years the only astronomical optical instrument, and when the seventeenth century closed telescopic sights were still not fitted to nautical instruments. On the other hand telescopes were quickly in use at sea although, being very long and being constructed either of glazed or leather-covered tubes of papier mâché or wood for lightness, they were both unwieldy and far from robust. Sir William Monson, writing in Jacobean days of various 'Stratagems to be used at Sea', admits that more than one would have been excellent if 'prospect glasses had not been so common', and Captain Smith mentions them in his *Accidence* of 1626.\(^2\) The oldest known dated optical instrument in the world is a telescope by Maria de Rheita marked 'Ao 1645 — 6 M.R' in the National Maritime Museum at Greenwich. It has a magnification of 18 diameters, its tube is made of paper, and when extended it is six feet six inches in length.

Although at sea telescopic sights were not used, examples of observations of latitude accurate to within 5°—10° have been cited from the journals of Hudson, Baffin and other Jacobean navigators. How did they obtain

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\(^1\) Gould, R. T., *The Marine Chronometer* (1923), discusses this at greater length.

\(^2\) Smith, Captain John, *An Accidence for Young Sea-men* (1626).
such accurate results with open-sight instruments? Partly by reason of the greater accuracy of the ephemerides that they used; partly by reason of the corrections they now knew how to apply for parallax, height of eye, refraction and, if the sun’s centre were not observed, for the sun’s semi-diameter; partly by reason of instrumental improvements.

All instruments used in Navigation, of what form or shape soever they be, John Davis had written in 1594, ‘are described or demonstrated upon a Circle, or some portion of a circle, and therefore are of the nature of a Circle.’ The astrolabe was a complete circle. The Spanish ones of the sixteenth century, as we have seen, were small and weighty, measuring some 5 or 6 inches in diameter. By the end of the century Blundeville had noted that the English were using astrolabes several inches larger in diameter in order to gain the advantage of a larger scale. In this they were apparently not followed by foreign navigators, although the Jacobians continued the trend, Elias Allen’s superb example of 1616 being no less than 15½ inches in diameter, and complete with a diagonal scale in one quadrant. Such an instrument continued to find favour at sea, for it could be used when the horizon was ill-defined. Some navigators preferred quadrants, their particular advantage being that for an instrument of the same over-all dimensions as an astrolabe the scale was twice as large. Thus, Richard Polter, the Master of Trinity House, to whom Edward Wright had dedicated The Haven-finding Art, and who was himself author of a navigational book, The Pathway to Perfect Sailing, preferred, even for use at sea, ‘a large quadrant of brasse with a moveable perpendicular’, of the kind illustrated by Waymouth in his Jewell of Artes. For use on shore Baffin, it will be recalled, used a quadrant, clearly a wooden one mounted on a stand, which was 4 feet in diameter. Waymouth, in 1605, had used, we have seen, an astrolabe, cross-staff and ‘ring-instrument’, and ‘semi-sphere’, the latter probably a double quadrant in the form of the upper half of an astrolabe suspended by a ring at the centre. His ‘ring-instrument’ was probably the same as John Davis’s Ring-Astrolabe or Sea-Ring. This Davis had illustrated at the end of his Seamans Secrets, but not as his invention. The sea-ring had a 90° scale double the size of that on an astrolabe of the same diameter. This was achieved by admitting the sun’s rays through a cone-shaped hole drilled in the circumference of a ring along one or other of the upper 45° radii. Suspended by a thumb ring and aligned with the sun, the latter’s rays were focused by the hole into a spot of light falling upon the scale graduated on the inner surface of the ring. This scale extended along one half of the ring’s circumference, and was thus twice as long as in the astrolabe, where the 90° scale occupied only one quadrant. Polter said he preferred a brass quadrant because in a sea-way, or sea-gate as he termed it, an astrolabe swung about too much, and a cross-staff, besides necessitating the simultaneous observation of

1 See Pl. LXIX.  
2 See Pl. LXXI.  
sun and horizon, induced errors if it were not held in the vertical plane. With the quadrant he presumably used a plumb-bob which ensured that the instrument was held vertical and provided the datum line for measuring the sun’s altitude. Thus in taking a sight the sun’s centre only had to be observed. For all that, in a sea-gate it must have been as unstable as an astrolabe. The real reason for his preference probably lay in its larger scale.

We have already seen that by the 1590s there were a variety of cross-staves in use at sea, and the first back-staves.¹ Like the cross-staff the back-staff was limited by considerations of ease of handling to an over-all length of three feet. It was improvements designed to increase the size of the scale without increasing the size, or weight of the instrument, that led to the rapid transformation of the original back-staff from an instrument on the lines of a cross-staff to one on the lines of a quadrant. Indeed it soon came to be known as a Davis quadrant, or just plain quadrant. Davis’s first back-staff had been an octant, an instrument measuring an eighth of a circle, 45°.² The graduations had all been on the staff. A reading had been made by putting the transversity at the estimated altitude of the sun and subsequently sliding it to and fro along the staff until the shadow it cast had fallen on the horizon slit at the instant that that was level with the horizon. In Davis’s earliest quadrant a scale had been marked on both the staff and the lower transom. As in the octant, the initial setting had been made by setting the upper transom to the estimated altitude of the sun. The final reading, however, had been obtained by sliding a sight vane up and down the lower transom, which was arc-shaped, until the shadow cast by the upper transom was seen to coincide with the horizon.³ Then the reading of the two scales was added together. Within a few years the back-staff had been modified, incorporating the principles underlying this latter method on the lines of a quadrant. One version was popularized by being illustrated in the 1620s in a Dutch waggoner. In this the transoms formed chords of arcs, suitably braced, on which the scale was graduated. It retained the arrangement wherewith the longer chord cast the shadow. The other version was altogether superior. Both transoms were arcs of circles, suitably braced. That casting the shadow, by means of a shadow vane, was the smaller and being close to the horizon vane as well as arcuate cast a shadow of high definition as well as one of constant length. The larger arc carried the sight vane and, though measuring only 30°, could carry a scale six times larger than one on an astrolabe of comparable size. Further, because of its arcuate form a given movement of the sighting vane resulted in the same angular change irrespective of the position of the vane on the scale. This too made observation easier. Although called back-staves as well as quadrants, as Waymouth pointed out in the Jewell of Artes, in which he illustrated both versions, these quadrants served ‘to take ye altitude of ye sunne foreward and backwards, and any starre foreward’.⁴

¹ See Pl. LXX.
² See Pl. LIV.
³ See Pl. LV.
⁴ See Pl. LXXI and Fig. 26.
In the Davis quadrant the shadow vane arc was commonly divided into 60° by 5° or 1° divisions, the sight vane arc into 30° by a diagonal scale reading to 2', 5' or 6'. Moreover, the line of sight, unlike that of the cross-staff, was concentric with the centre-line of the scale and consequently instrumental parallax was eliminated. It was these features that enabled such accurate observations to be taken. The diagonal scale dates from the 1550s and, according to Digges, who gives an illustration of one in his *Alae seu Scalae Mathematicae* of 1573, was the invention of Richard Chancellor.1

The precursor of the diagonal was the *Nonius*. It was the invention of Pedro Nuñez and was first described by him in 1542.2 The principle was the subdivision of a quadrant into fractions of arc and the subsequent conversion of any given fraction into degrees, minutes and seconds. This was achieved by drawing a series of equally spaced arcs inside and concentric with the outer arc already divided into 90° divisions. Then each arc was divided into progressively fewer equal divisions. Nuñez graduated his quadrant with forty-four concentric inner arcs so that the forty-fourth was divided into 46 equal parts. These numerous subdivisions ensured that the alidade of his quadrant, when he made an observation, fell more or less precisely across one division, and only one. For instance, if it cut the arc divided into 55 equal parts at the 45th subdivision on it the angle cut was clearly 45.55ths of 90°. By the rule of proportion this is 73° 38' 11''. Tycho Brahe graduated at least one of his instruments with a nonius, but he found it a cumbersome method. Waymouth illustrated a quadrant and other instruments with a nonius in his *Jewell of Artes*, but it is quite certain that the ordinary navigator never used a nonius. Few understood its principle, and even fewer were prepared to go through the labour of calculation necessary to convert each reading into degrees and minutes. The diagonal was far superior. It consisted of a series of concentric circles, arcs or straight lines, according to the shape of the portion of the instrument engraved with the scale, crossed by diagonal lines. Usually six or ten parallel or concentric lines were drawn and either two or three diagonal lines between the limits of one degree on the scale. Then the number of sub-divisions so made divided into 60' (1°) gave the value of each sub-division in minutes. For example, a diagonal scale consisting of six concentric arcs crossed, inside the limits of one degree, by one diagonal

1 See Pl. LXXII. ALAE SEV SCALAE Mathematicae, quibus visibilium remotissima Coelorum Theatra conscendi, & Planetarum omnium itinera nouis & inauditis Methodis explorari: tum huius portentosy Syderis in Mundi Boreali plaga insolito fulgore coruscantis, Distantia, & Magnitudine immensa, Situsq; protinus tremendus indicari, Deiq; stupendum ostentum, Terricolis expositum, cognoscii liquidissimè possit.

THOMA DIGGESE0, CANTIENSI, Stemmatis Generosi, Authore. Londini, Anno Domini. 1573.

2 See Pl. LXXII. PETRI NONII Salaciësis, de Crepusculis liber unus nunc recès & natus et editus. ITEM Alacen Arabis utetussissimi, de causis Crepusculorum Liber unus, à Gerardo Cremonensi iam olim Latinitate donatus, nunc uero omni primum in lucem editus. [1542]
resulted in each intersection measuring 10', that is one-sixth of a degree. Similarly ten concentric arcs, crossed within the limits of one degree by three diagonal lines, divided the degree into thirty parts or subdivisions of 2'. In his Alae Digges showed a rectilinear diagonal scale with a zig-zag arrangement of transversals, each transversal being divided into tenths by short horizontal strokes on opposite sides; other methods employed transversal lines of dots all sloped one way, or zig-zag lines of dots, or zig-zag transversals drawn across equally spaced parallel lines. In navigational instruments the transversals usually all sloped the same way, in the manner illustrated by Waymouth.\(^1\)

The idea of the sea-ring for doubling the scale of an instrument probably came from a ring-dial. This was a solar time-finder in common use in the sixteenth century. It consisted of a ring, graduated to show hours and latitude, and incorporating a device for applying the sun's declination. It could be carried in the pocket, and being brought out, adjusted for latitude and declination and suspended to the sun, focused the latter's rays through a hole in the circumference upon the widely-spaced hour lines on the inner surface.

From the ring-astrolabe or sea-ring it was but a logical step, for a man so inventive as Davis, to improve the scale of his recently devised quadrant by incorporating the discovery of how to enlarge a scale without enlarging the instrument concerned; had he not written 'all instruments used in Navigation . . . are of the nature of a Circle'? The solution, at once so simple and so practical, as the diagrams indicate, commands respect; even Edward Wright could not improve on it. His sea-quadrant was a cumbrous thing by comparison, in which the scale was kept large by being engraved upon a single quadrantal arc of large radius and, though it incorporated an ingenious aid for the navigator taking a Pole Star sight, it seems to have remained only a curiosity. It was essentially the product of a theoretician and not of a man like Davis, who was primarily a practical seaman. His quadrant was light, easy to manipulate, robust, and yet embodied a scale on which angles could be read off to the greatest accuracy procurable with the unaided eye. It was a brilliant example of geometrical knowledge turned to practical ends.

To take an observation with his Davis quadrant the Jacobean navigator withdrew it from its case, fitted the horizon vane, distinguished by its slit, to the horizon end of the staff; the plain, bevel-edged shadow vane he fitted to the small 60° arc, and the sight-vane, with its eye-hole, to the large 30° arc. It was now customary to graduate these arcs in the Portuguese fashion so that either the altitude or the zenith-distance—the distance from the zenith (90° — altitude)—of the heavenly body observed could

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\(^1\) Angle readings determined on an arcuate scale by means of straight line transversals are slightly in error. This was appreciated by Tycho Brahe, who used such scales, but in his view the errors produced were so small compared to the errors caused by the unrefined construction of the instruments that they were acceptable. Kiely, E. R., *Surveying Instruments* (1947), p. 180.
be read off. In observations of the sun the use of the zenith distance scale eliminated one step in the working out of the latitude. He adjusted his shadow vane to within 15° or 20° of the sun's estimated zenith distance, but not in excess of it, then turning his back to the sun and lifting up the quadrant he looked through the sight vane, sliding it up or down its arc until the shadow-vane cast its shadow on the horizon vane slit at the moment that he sighted the horizon. To find the sun's meridian passage, or greatest altitude, he continued his observation so long as, on moving his sight vane lower and repeating his observation, he found the sea and not the horizon appearing through the horizon slit when the sun's shadow fell on it. As soon as he found the sky appearing he knew the sun had passed its zenith. He then took his last reading. As this was of the sun's upper limit or edge he had then to apply a correction for the sun's semi-diameter in order to obtain the zenith distance of the sun's centre.

It was remarked in the previous chapter that a variety of instruments were quickly developed to incorporate Hood's—and Davis's—shadow principle. Waymouth illustrated a sea-quadrant converted into a backstaff by being fitted to the upper edge of a staff, and with an alidade pivoted to its centre. While simpler to manipulate than the Davis quadrant, it forfeited its large scale. On the other hand as the converted sea-quadrant's shadow vanes were pierced with pin-holes, the rays from the sun's centre were measured and the correction for semi-diameter thereby eliminated. In the latter part of the century this feature was to be incorporated by Flamsteed into the Davis quadrant by making a hole in the shadow vane and fitting in it a double convex lens so that the sun's rays were contracted into a small bright spot on the slit in the horizon-vane. This, besides making observations in clear weather more precise than formerly, made back-observation of the sun possible in hazy or cloudy weather—but this is to anticipate developments. Cross-staves were often used by the Jacobeans as back-staves, a brass horizon-vane being fitted to the original eye-end of the staff and a brass sight vane to the lower end of a transversary, the upper end of which cast the sun's shadow on to the horizon vane. Often the 10° transom was cut in such a way that it could be transformed into a horizon vane.

Richard Polter's The Pathway to Perfect Sayling showing briefly 'the saxe

1 Wright in the second edition of Certaine Errors (1610) opens Chapter VIII of The Division of the Whole Art of Navigation, as follows: 'Another manner of accounting by the Sunne, as they use in Portugall.' 'Some Astrolabes there bee, whose account beginneth not from the horizon butt from the zenith ...' This was a translation of Zamorano's Compendio del Arte de Navegar, Seville, 1588. The Dundee astrolabe of 1555 is the oldest known example.

2 The Seaman's Tutor, explaining geometry, cosmography, and Trigonometry, with requisite Tables ... Compiled for the use of the Mathematical School in Christ's Hospital—London, His Majesty Charles II, his Royal Foundation. By Mr. P. Perkins, late Master of that Mathematical School, London, Printed for Obadiah Blagrave, at the Bear in S. Paul's Church Yard. 1682.

(A copy is preserved in the Admiralty Library, Whitehall.) This explains and ascribes the development to Flamsteed.
principlall pointes or groundes' of navigation has already been mentioned as appearing in 1605. It was published, claimed Polter, 'for the common good of all Maisters, Pilots, and other Seamen whatsoeuer', and as he was an official of Trinity House, his claim was probably genuine. Reprinted in 1613 and 1621 and again in 1644, the book, though it made no pretence of being a comprehensive manual, evidently enjoyed considerable popularity. It did so probably for two reasons: because it summed up what the leading navigators of the day considered to be the six most important points in navigation, and because it contained information and hints and tips on matters dealt with only briefly or by inference in the standard manuals. The six principal points or grounds, said Polter, were: Card; Compass; Tide; Time; Wind; and Way. Polter's treatment of his subjects is not always easy. His language is at times unnecessarily intricate and circumlocutory, but he tells us some things about late Elizabethan and early Stuart navigational matters not to be found elsewhere. About the compass he sums up four erroneous beliefs or 'absurdities', about charts, nineteen although it is clear that he himself did not really understand the difference between a great circle and an E-W rhumb line. He is enthusiastic about, and describes the advantages of, 'The Sphericall Description of the Globe, with the Astronomical deducture of the Compasse accordingly, which by some sort of men, is called the paradoxall Compasse', in other words the paradoxal or circumpolar chart. This he considered 'a notable knowledge & light in Navigation'. Indeed it was probably because of the timely publication of this commentary on them—at the commencement of a new cycle of voyages to the north-east and north-west and following the publication of tables for use with such charts—that paradoxal charts became common in the early seventeenth century, and the voyages were able to be charted with such a degree of accuracy. In treating of the compass Polter explained the effect of variation upon courses and tracks, and then he committed a blunder which has sent him down in history with a reputation himself for absurdity. Yet we should be grateful to him and indulgent, for he has set on record the beliefs current in his time of a very considerable body of English seamen: '... when Robert Norman dyed (who had a good Stone) Sea-men had a great losse ...', he wrote, for '... the Variations delivered by many stones are different ...' In other words Polter was a student of Medina rather than of Cortes, and wrongly believed variation to be the result of the properties of the particular lodestone used to magnetize a compass needle, and of the manner in which it was touched. After Norman died his place as a skilful compass-maker was filled, in

1 The Pathway to perfect Sayling. Being a delierie in as breewe manner as may bee, of the sixe principall pointes or groundes, concerning Navigacion: Written by Mr. Richard Polter, one of the late principall Maisters of the Navie Royall. And now published for the common good of all Maisters, Pilots, and other Seamen whatsoeuer.

LONDON Printed by Edward Allde for John Tappe, and are to be solde at his Shop on Tower-Hill neere the Bul-warke Gate. 1605.
Polter’s opinion, by ‘Master Mullinux of Lambeth’, for he had an even ‘better stone and was as careful and as perfect as ever Master Norman was’. Polter named no successor to Molyneux. It was ‘touching’ in Polter’s opinion that also accounted for the fact that ‘there cannot generally be set doune a certaine variation for any one place . . .’.

On tides Polter dilated upon the errors arising from the practice, still common, of taking a 45-minute daily change in the time of high and low water instead of a 48-minute one, and upon the error arising from the eccentricity of the sun and of the moon. As far as English mariners were concerned this was the first book designed for their use to mention these phenomena, which will be discussed further shortly. As the eccentricity of the sun affects the length of a solar day, and as seamen used a ring-dial or some other form of sun-dial for ascertaining noon-tide, and kept their time by hour and half-hour running-glasses, the lengths of their days were variable. Also as they often took their tidal information from tide-tables with the faulty 45-minute interval, and the time for tidal information by using the compass fly as a sun-dial or a moon-dial without correcting for the effect of latitude, or of variation (unless they happened to use a common sea-compass which was off-set correctly to cancel out the effect of variation), they were liable to hazard a loaded or ‘charged’ ship whenever they entered or left port. A master entering the Thames, for instance, who reckoned the time to be six o’clock when the moon bore east would be an hour and a half out if the moon had 5° N declination. If his fly was deflected a point by variation it could put him a further forty-five minutes out. Indeed it was probably the desire to avoid this error quite as much as to avoid having to correct courses and bearings for variation that led northern seamen to off-set their compass flies.

In Polter’s opinion Molyneux had made the best running-glasses. The trouble about running-glasses was that the ordinary maker and vendor of them cared ‘but little what error more or less was delivered in those glasses in 24 hours, nay’, Polter exclaimed, ‘in halfe an houre . . .’.

Compasses were as carelessly made also, he added, echoing Barlow’s complaint. Therefore every master should remember, he pointed out, that ‘compasses and glasses had neede to be carefully respected . . .’ otherwise ‘the security . . . of the Navy of England was greatly indangered by them’. In addition to errors caused by careless manufacture, running glasses were liable to error through the limitations of the materials with which they were made, and through their mode of assembly.

It is not known when or where sand-glasses were invented but in the light of existing evidence it seems likely that they were developed in the western Mediterranean in the eleventh or twelfth century as naval time-keepers.1 They measured time by the action of gravity. They consisted of two pear-shaped glass bulbs with flattened bases placed neck-end to neck-end and protected and held in position by a metal or wooden frame. The filling, of iron filings, fine sand, fine marble-dust or powdered

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egg-shell, was placed in one bulb before assembly. The angle of the double cone connecting the two glass bulbs was made equal to the angle of repose of the kind of sand used. The glass was blown from a heavy, thick, and only semi-transparent metal, with a faint greenish tinge, and there was a pronounced indent, with a rough scar at the base end where the glass-blower’s puny-rod had been broken off. At the neck-end the lips of each bulb were turned over and, in better models, flattened and ground true, to form flanges. During assembly a paper-thin metal washer, with a small regulating hole through the centre, was slipped between the flanges. The size of the hole was proportioned to the fineness of the filling and determined the length of time measured by the sand emptying from one bulb to the other. The flange joint was sealed by putty or wax and in better finished glasses the joint was further strengthened by being bound round with coarse linen, and finished off for neatness with a band of leather held in place by a strong thread carefully spaced to give a wicker-work finish. Ship’s running glasses were generally protected by an oak frame of round or square top- and bottom-discs held together by from four to eight oak legs. Through the base-plates two cords were rove and spliced to form double bights from which the glass could be suspended so that the helmsman could keep his eye on it as well as on the compass, or, as Cock Lorell expressed it in about 1510, so that ‘one [man] kept ye [com]pas, & watched ye our glasse’. To protect the bulbs from sudden shocks their bases were sometimes kept from actual contact with the base-plate by a strap of leather which rested edge-on on the base-plate round the inside of the frame so as to support the glass bulb on the curve just below its largest diameter. Nowadays we are accustomed to the tiny egg-timer sand-glasses. In Elizabethan and Jacobean days no doubt, as in the eighteenth century, ship’s glasses were no such things. A watch glass—a four-hour glass—might measure a foot in diameter and two feet in height, weigh several pounds and need both hands for the turning. A half-hour glass would be about half the size, but a half-minute glass for use with the log-line might well measure 5 or 6 inches in height and 2 or 3 in diameter.

Clearly, to obtain accuracy, given, in the first place, an accurate standard—which was no easy thing in days before the properties of pendulums were understood—the greatest care had to be taken in the preparation of the sand—which was usually red. Marble dust, which was used when great accuracy was required, was first ground as fine as possible in a mortar, then boiled in wine, dried, reground and sifted as often as nine or ten times before the required quantity was measured off and put in the bulb. An even flow of sand could only be obtained with sand of absolute uniformity of size. In glasses filled with iron filings, if the filings ran freely,

1 Hughes, G. B., ‘Old English Sand-glasses’, Country Life (1951). This is a short but informative illustrated article (including a photograph of a ship’s four-hour sand-glass of the seventeenth century).

There is an excellent collection of sand-glasses, including ship’s watch and log glasses, in the Science Museum, South Kensington.
in course of time they wore the regulating hole larger, and so gave a short reading; on the other hand at sea they were peculiarly liable to rust, the moisture getting in through the joint at the waist. When they rusted the filings increased in size and stuck together, and so ran through too slowly. Actual sand-glasses were apt to be filled with coarse sand, leading to irregularity of flow; glasses filled with powdered shell were affected by humidity. On the whole Polter preferred glasses with a metal filling. The need for running-glasses was imperative, he reckoned, for longitude-finding, since watches and clocks were still too imperfect. Although Polter does not mention it, in an effort to eliminate the various running errors to which the glasses were subject the prudent navigator turned two or three simultaneously. This practice probably accounts for the large number of running-glasses carried by Frobisher in 1576. Later, if not in Elizabethan or early Stuart times (for there are no examples of those times), batteries of running-glasses, as many as four glasses in one frame, were carried. This avoided any mistake about the simultaneous turning of several glasses and enabled a mean reading of several glasses to be taken easily. In other models the rate of flow of the four glasses was so regulated that they registered respectively, quarter, half, three-quarters and one hour intervals.

With the great interest being shown in Polter’s day in the question of longitude it is not surprising to find him referring to the matter. He does so over this very question of time measurement. He, for the first time as far as English navigators were concerned, raised the question of the equation of time. While we regulate our days by the sun, we measure our time to all intents and purposes by the stars—actually by measuring the interval between two successive transits of a star across the meridian of any place. We do this for the very good reasons that while the rotation of the earth is constant and always performed in the same time, of all the heavenly bodies only the stars are as it were fixed in space, and so they alone give us days of equal length. The sun, the moon, and the planets do not keep the same fixed positions with respect to each other. If they did, the apparent revolution of all the heavenly bodies would be performed in the same time, and all days—sidereal, planetary, lunar, solar—would be of equal length. As it is, all except sidereal days are, as already remarked, of variable length. The fact that the length of the solar day, as measured by a sun-dial, varies throughout the year, inevitably introduced an error into longitude calculation on voyages of any considerable duration, since running glasses were turned afresh, daily if possible, at local noon-tide—apparent solar noon. The reason why the apparent solar day varies in length is that the earth in its annual course round the sun traces out, not a circular path centred upon the sun but an elliptical one embracing an area in which the sun is not at the centre but towards the ‘winter’ end of the longitudinal axis, and also that the earth is inclined at an angle of $23\frac{1}{2}^\circ$ to the plane of the equinoctial or celestial equator. The effect of the earth’s eccentrically centred elliptical track is to make the daily angular change of position in
THE EQUATION OF TIME

relation to the sun and the stars vary. Or, to put it another way, when in summer (July) the sun is in aphelion, i.e. farthest from the earth, it appears to traverse the heavens, to change its daily position in relation to the stars, more slowly than in winter (January) when it is in perihelion or closest to the earth. The effect of the earth’s inclination to the equinoctial is to make the sun change its daily position in relation to stars not along the line of the equinoctial but along a line inclined at 23½° to the equinoctial, the ecliptic. The result is that the horizontal component of the sun’s motion along the ecliptic is constantly changing. Polter himself adduced three reasons why the sun’s path was ‘eccentric’: its variable motion through the heavens; its change of size—its diameter is largest in perihelion, smallest in aphelion; and the different duration of eclipses. These reasons were not original but were derived from studying the astronomical works of Copernicus, Stadius, and Joannes Reinhold.

The variable length of the apparent solar day had long been recognized by astronomers as a source of error in time-keeping and they had evolved the mean solar day. The mean solar day is based upon an imaginary sun termed the ‘mean sun’ which is considered to move round the celestial equator at a constant rate and to complete its passage around the equator in the time that the true sun takes to pass around the ecliptic. The mean sun is sometimes in advance of the true sun, sometimes behind it. The difference between ‘mean solar time’ and ‘apparent solar time’ is known and tabulated as ‘the equation of time’. The elliptical track of the earth accounts for differences reaching a maximum of 8 minutes in April and again in October, the horizontal component of the sun’s path along the ecliptic to differences reaching a maximum of 10 minutes four times a year—none at the equinoxes and solstices. The combined result is that the true sun is nearly 16¾ minutes slow on the mean sun in early November and nearly 14¾ minutes fast about 12 February. Thus in the course of the year the length of the apparent solar day changes by as much as 30¾ minutes.

Polter, in his section on winds, had useful observations to make upon their effect upon course steering, and the changes in wind strength and direction likely to be experienced off headlands. But as to the area over which winds blew and storms were experienced, there was, he confessed, uncertainty. This arose not so much from lack of data, for every shipmaster logged the wind direction, as from lack of an organization for systematically studying ships’ logs for the purpose of determining the prevalence of winds and the extent of storms. Also without instruments for mensuration—the barometer, thermometer, and anemometer still lay in the future—meteorology was powerless to become scientific. Nevertheless, within a few years the start was to be made. Francis Bacon’s Novum Organum was published in 1620. It contained a description of a thermoscope from which in all probability the earliest weather-glasses were evolved ten years later. This work was also important in nautical affairs for the discussion of winds and tides in which he put forward as alternatives the stationary wave (seiche) theory and the progressive wave theory of tidal ebb and
flow (Bk. II. Aph. 36.), and approached the question of the world distribution of winds.¹

Throughout his book Polter took it that the master of a ship used a ‘paradoxal chart’, plotted his track upon it every 20 leagues, and checked his course so as to ensure that he was following a great circle track. For finding the variation Polter recommended the use of a ‘Topographical instrument, otherwise called a Theodolite of brasse’, because he considered none other suitable in a sea-gate. He also advised finding the variation, if the latitude and declination of the sun were known, by a simple observation at 3 p.m. when the sun’s rate of change of azimuth was greatest. In order to get the variation from such an observation the pilot had to ascertain the true azimuth, for the variation was the difference between the observed azimuth and the true azimuth. Polter thus assumed that the navigator carried a planisphere, a celestial globe, a universal astrolabe, or some similar but simplified instrument like the analemma illustrated in Cortes’s Art of Navigation for finding the time of sunrise and sunset, the duration of twilight, and the sun’s azimuth. Cortes had given a very clear explanation of the manner of drawing and using the various lines, and such instruments, either in the form of astrolabes or astrolabe quadrants, and with various refinements added, continued in popular use throughout the seventeenth century. The disadvantage of Polter’s method of finding variation was that it was less exact than the double altitude method. The smaller the globe, astrolabe, or quadrant used the more approximate was the reading obtained of the sun’s true azimuth. It was in the use of such instruments that Robert Tanner’s A brief treatise of the use of the globe, of 1616, and Edward Wright’s The Description and use of the Sphaere, published three years before, were helpful.² In later editions

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¹ The whole title-page is engraved, including the lettering, which is as follows: FRANCISCJ DE VERULAMIO Summi Angliae CANCELLARIJ Instauratio Magna. Multi pertransibunt & augebitur scientia. LONDONI Apud Joannem Billium Typographum Regium. Anno 1620.

We are informed on page 33 that the first part of this work is wanting, and that, in fact, all we have is the second part, of which the title follows, and is as given below:

PARS SECVNDAY OPERIS, QVAE DICTTVR NOVVM ORGANVM, SIVE INDICIA VERA DE INTERPRETATIONE NATVRAE

Taylor, E. G. R., Late Tudor and Early Stuart Geography, 1583–1650 (1934), comments upon Bacon’s tidal and wind theories.

² Wright, S., The Description and use of the Sphaere (1613). The full title will be found on p. 195.

Tanner, R., A brief treatise of the use of the globe Celestiall and Terrestriall (1616). The title of the first edition was: Anno Domini. 1592. A briefe Treatise for the ready use of the Sphere: Lately made and finished in most ample large manner. By Robert Tanner Gentleman, Practitioner in Astronomie and Phisicke. In the which Globe or Sphere, there is added many strange Conclusions, as wel Celestiall as
LXXII. The Diagonal Scale and the Nonius Scale, 1604.
of his work Tanner increased its value for navigators by including the use of the terrestrial globes also.

Besides frequently checking the variation to ensure that the correct course was being steered, Polier was emphatic about 'the care of the Steeridge', declaring he had seen helmsmen make errors '3 or 4 points of eyther side of the course commanded to be kept'. Nor was he exaggerating. Steering errors could be serious. Sir Richard Hawkins recounted in his Observations how in 1595, 'the night comming on . . . we sett the watche, having a fayre fresh gale of wind and large. My selfe with the master of the ship, having watched the night past' gave 'the care of the steeridge to one of his mates; who . . . being drowsie, or with the confidence which he had of him at the helme, had not that watchfull care which was required; he at the helm steered west, and west and by south, instead of west-south. . . . As the night wore on the master being in his dead sleepe, was suddenly awaked, and with such a fright that he could not be in quiet . . . and so taking his goune, came forth upon the deck', and coming from the darkness of the 'tween decks 'had his sight more forcible, to discerne the difference of the sea, and the shore', and immediately saw the shore hard by ' . . . so that forthwith he commanded him at the helme, to put it close a star board, and tacking our ship wee edged off . . . ' and sounding they found to their horror 'scant three fathom home water.'

'The land being sandy and low', explained Hawkins, 'those who had had their eye continually fixed on it, had been dazzled with the reflection of the brilliancy of the starres' in the water on this fair tropic night off Brazil, 'and so had been hindered from the true discovery thereof', besides being misled by the ill-steering of the helmsman. 'In this poyn of steeridge', he continued, 'the Spaniards and Portingalls doe exceede all that I have seeene, I mean for their care, which is chiefest in navigation. And I wish in this', he remarked, 'and in all their workes of discipline, wee should follow their examples . . . In every ship of moment, upon the halfe decke, or quarter-decke, they have a chayre or seat; out of which whilst they navigate, the pilot, or his adjutants (which are the same officers which in our shippes we terme the master and his mates), never depart, day nor night, from the sight of the compasse; and have another before them, whereby they see what they doe, and are ever witnesses of the good or bad steeridge of all men that take the helme . . . For a good helme-man may be overcome with imagination', he truly observed, 'and so mis-take one poyn for another; or the compasse may erre, which by another is discerned.' Yet such care, he declared, had before now 'beene neglected' in even 'our best shippes'.

With the growth in size of ships in the sixteenth century their steering

Terrestrial, the like heretofore neuer devised by any. Necessary not onely to those that followe the Artes of Navigation: But also to the furtherance of such as bee desirous to have skil in the Mathematicall Disciplines. Thou O Lord in the beginning hast laid the foundations of the earth: and the heavens are the woorkes of thy hands. Psalme, 102 ver, 25

24—A.O.N.
had become a serious problem from the mechanical point of view. The big Spanish and Portuguese ships solved the problem by simply fitting immensely long tillers into the rudder-head and attaching tackles from the end of the tiller to eye-bolts on either side of the tiller-room—which is the practice in large Chinese junks today where 15-foot to 20-foot tillers are not uncommon. In fair weather one man could manage the helm, but in rough weather additional tackles had to be fitted, and as many as twelve to fourteen men would be used to man them in order to keep the play of rudder and tiller under control. In English ships, except those of the largest size, the whip-staff had come into use by Jacobean days, and is described by Captain Smith in his *A Sea Grammar*. This device, probably derived from an analogous arrangement in the river barges of the Netherlands, enabled the helmsman to be housed a deck higher than the tiller flat, and so with his head above upper-deck level, whence he could see how the foot of the mainsail drew, and be himself seen by the pilot or his mates or whoever was entrusted with the care of the steerage. It also gave him good control of the helm in fair weather with little effort. The whip-staff consisted essentially of a vertical pole or lever pivoted in the deck at the helmsman’s feet, about one quarter of its length being below, and three-quarters above this deck level. At the lower end of the lever was an iron ring which fitted over the end of the tiller. 1 By heaving over on the longer, upper part of the whip-staff the helmsman was able to exert considerable leverage on the end of the tiller. He of course moved the tiller or helm in the opposite direction to that in which he moved the staff. As steering by the helm was the older method, the traditional orders for conning the ship continued to be used. Thus when the helmsman was ordered to ‘starboard his helm’, he moved his end of the whip-staff to port. When, at the end of the seventeenth century, the wheel began to displace the whip-staff, the same custom was observed. In English ships, up to the 1930s, the steering orders were still always given in terms of helm. To alter course to port the order ‘starboard [your helm] 15° [or any amount up to “Hard a-starboard”, 35°]’ was given. On receiving it the helmsman put his wheel to port, and the ship’s head swung to port.

As the whip-staff worked in a fulcrum fixed in the deck and the tiller, to the end of which it was loosely connected by the ring, was rigidly fixed to the rudder-post, the sweep of the helm was limited to about 10° either side of the centre line. Consequently in heavy weather, when greater rudder movement was often necessary, the whip-staff had to be dispensed with and tiller-tackles substituted.

The design of a ship’s underwater lines could greatly influence her handling qualities by affecting the flow of water over the rudder, and so determine her responsiveness to the helm. Polter had some not very penetrating observations on the sailing characteristics of ships, such as

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1 Vaughan, H. S., ‘The Whipstaff, I and II’, *M.M.*, Vols. 3 and 4, contains an authoritative study of the origin, development and operation of the whip-staff, illustrated with sketches and line drawings of installations.
that some ‘cast to Portward, and some other to starbord’, that some were
‘flottye’, others swift, and so on. In short he reminded navigators that
every ship is a wayward ‘she’, and needs handling accordingly. Then he
finished his little book with directions on how to write up ‘Your Diurnall[,] by some called A Traverse booke, wherein you keepe reckoning of the
ships way at the seas’. After the heading, which he said should consist of
the date of commencement of the voyage, he laid down that there should be
ten columns drawn, to contain respectively the day and month in sequence;
the hours spent on various courses; the wind prevailing; the course, cor-
rected for variation; the leagues run on each course; the latitude in degrees;
the latitude in minutes (if any); ‘the degrees prevailing; the course, cor-
rected for variation; the leagues run on each course; the latitude in degrees;
the latitude in minutes (if any); ‘the degrees of longitude delivered by the
time and Latitude’; the same, in minutes, (if any); and the narrative
as necessary. The fact that Polter included improved instructions for the
writing up of log-books makes his book important, particularly as it
evidently had the blessing of Trinity House. Indeed, extracts from Jaco-
bean journals already quoted show that the layout of Jacobean log-books
did allow for recording and in an orderly manner, the more detailed entries
which he stipulated. Sir Thomas Roe’s model journal of 1615 contained
even more entries than Polter laid down. In addition to those detailed by
Polter it had columns for the variation, currents, soundings and capes as
well as one connected with ‘traversing’.

The popular demand for John Tapp’s The Seamans Kalender was such
that a second edition had appeared in 1605, but no copy seems to have
survived. Three years later a third edition, containing examples for 1605
and ‘Newly corrected and enlarged, with a bridged Table of Signes, and
some propositions thereupon, concerning Arithmetical Navigation’, came
out. It did indeed contain tables of natural sines, and examples of their
use in navigation. It included also a short treatise on ‘The Extraction of
rootes’; ‘A Table of the Sunnes right ascension in houres and Minutes’,
with explanatory notes on its use; declination tables for the years 1608
to 1631; directions ‘How to appropriate the Tables of Declination to any
other Meridian’; ‘A Note for going into Dublin’; and two important
rutters. One, like the notes on Dublin, reflected the growing importance
of Ireland in English affairs, for it was ‘A Rutter, for the courses round
about Ireland’—the first printed English one; the other served for all
the trades between the White Sea and the Canaries. It was similar to the
MS. rutter of 1577 noticed in an earlier chapter. These additions increased
the usefulness of the Kalender, and were symptomatic of the wide interest
in mathematical navigation and the problem of longitude. The next year,
1609, Tapp brought Cortes’s Art of Navigation up to date by revising the
examples and the declination tables and substituting an accurate table for
the old diagram of leagues ‘to raise and lay a degree’. Incidentally he com-
mended the use of the quadrant devised by Edward Wright and of the
backstaff ‘now much in use’. It was the year John Searle brought out his
almanac, An Ephemeris for nine yeeres . . . which Baffin used for his lunars

1 See Pls. LXVII and LXVIII.
six years later. Searle defended his production, when there was 'such a pluralitie of Ephemerides', on the grounds of the scarcity of the principal ones, such as Origanus's, and the errors detected in them. He also drew special attention to the necessity for correcting the tables for longitude 'in any other place than the Ephemerides is calculated for', and included a table for converting degrees and minutes into time and another of the equation of time. As a further aid to longitude-finding he explained what eclipses would occur each year and where they would be visible. The book is a striking contrast to Linton's evasive treatise of the same year.

As we have seen it was partly as a result of the raising of so many hopes at this time over the question of longitude-finding by magnetic means that Edward Wright brought out the second edition of Certaine Errors in 1610. Possibly also it was timed to appear with the completion of the building of the Prince Royal, begun in October 1608.

Amongst the additions in this issue is the explanation of how Wright found the corrections for height of eye, 'based upon the earth's semi-diameter', by observations made near Plymouth Sound in 1589, and 'concerning which', he explained, 'there is great varietie of opinions amongst learned authors'. Determined as ever that astronomical observations should be as accurate as possible, he included a table of corrections for refraction drawn from Tycho Brahe's observations. Refraction Wright explained as 'refraction of the beames of the sun or stars, which we observe, by reason of the vaporeous thickeesse of the ayre that is betwixt us and them, especially when they are neare the horizon'. This explanation is correct. But refraction affects all heavenly bodies equally, so that in giving different corrections for the sun and the stars—the sun's correction ranged from 34' at 0° to 5' at 45°, the stars' from 30' at 0° to zero at and above 21° altitude—Wright was in error. On the other hand his correction for refraction when the sun was on the horizon—34'—was remarkably accurate. It is given nowadays as 35' 24''.

To facilitate variation-finding Wright had devised special 'sea-rings'. These were evidently intended as an improvement upon Cortes's 'Instrument general', and Coignet's 'nautical-hemisphere' for finding the time and variation, but as they depended upon a plumb-bob for their correct alignment and levelling they were quite as impractical at sea as Wright's quadrant. The sea-rings are illustrated in the second edition of Certaine Errors on the left-hand of the title-page, below the sea-quadrant and 'Universal Dial' and the rutter.¹

The sea-quadrant, which was illustrated in the text and on the title-page, Wright had designed for observation of the Pole Star by two observers. One automatically applied the correction for the Pole Star's distance from the pole by means of a nocturnal attached to one end of the quadrant arc in the form of a 'Rectifier of the Pole Star', while the other measured its altitude above the horizon. While Wright's sea-quadrant and sea-rings

¹ See Pl. LXXIII.
are evidence of his enthusiasm for improving navigation, they show, from their impractical nature, how divorced from the sea he had become with the passage of years.

Wright's tables of meridional parts had been criticized by Simon Stevin; Wright therefore improved them in the second edition by substituting meridional parts for 1° of latitude instead of every 10'. To bring his work right up to date he included a 'table of Magnetical inclination' at every degree of latitude, based on 'observations and calculations'. A dip-ring or 'inclinometer' of the sort to be used with it was illustrated on the title-page. But what made this edition of Certaine Errors into a navigation manual suitable for all seamen was the inclusion of a translation, made by a friend, of a standard Spanish navigation manual of 1588, Zamorano's Compendio del Arte de Navegar.1 Very much on the lines of Cortes's, it was a straightforward, admirably lucid work treating of the day-to-day Spanish navigational instruments and manner of using them, and containing the usual tables of distances and declination. This, it should be noted, was the third Spanish navigation manual of the sixteenth century to be translated into English and to become a standard English work. Except for Bourne's Regiment, avowedly based on a Spanish model, and Davis's Seamans Secrets, there were no original English works comparable to the Spanish standard navigation manuals. Wright very wisely left intact Zamorano's excellent description of the making and use of a plane chart, since plane charts were still the most general, referring the reader to his own section in Certaine Errors on the new, Mercator, chart projection. Similarly he was content to leave Zamorano's tables of 'leagues to each degree of latitude' untouched, and to correct it by printing alongside it another 'more precise'. The various tables 'for the improvement of navigation' included in this edition of Certaine Errors were, incidentally, the work not of Wright but of his friend Briggs, the Professor of Geometry at Gresham College.

The works of Arthur Hopton, a competent surveyor and almanac writer of this period, must have been in the hands of many Jacobean navigators and hydrographers. His Baculum Geodaeticum of 1610, describing 'The Geodeticall Staffe' invented by him for making 'astronomical and geometrical' measurements, was intended to enable 'the unlearned never trained in the study of these arts before' to 'accomplish those things that learned men have passed over the moety of their lives to find out'.2

1 COMPENDIO DEL ARTE DE NAVEGAR, del Licenciado Rodrigo Camorano, Cosmografo y Piloto mayor de su Magestad. CATEDRATICO DE Cosmografia en la casa dela Contratacion de las Indias. CON PRIVILEGIO. IMPRESSO EN SEVILLA en casa de Iuan de Leon. Ano 1588.

2 BACVLVM GEODAETICVM, SIVE VIATICVM. OR The Geodeticall Staffe, Containing eight Bookes: The Contents whereof followe after the Epistles. Newly devised, practised, and published by Arthur Hopton Gentleman. AT LONDON. Printed by Nicholas Ohes for Simon Waterson, dwelling at the signe of the Crowne in S. Pauls Church Yard. 1610.
It would, he claimed, 'let the Navigators speake of true directions in the unknown path of the seas'. It was indeed an excellent surveying manual, helpful to the navigator bent on exploration, and to the seaman wishing to learn how to project the sphere onto a plane for chart-making. Better still was his Speculum Topographicum Or the Topographicall Glasse of 1611, an able, excellently illustrated book on surveying with an interesting prefatory discussion on the value of traditional and scholastic knowledge and contemporary scientific learning. In support of the latter he cited 'the commodity of the Compasse, Sea-cards, and new Maps . . . that have beene lately set forth more beneficial than any heretofore . . .' In the hundredth section or chapter he described how 'To make a glasse whereby to discerne any small thing, as to reade a letter a quarter or halfe mile off', adding that it could be had made in brasse from Elias Allen. But of more strictly navigational importance were his full explanations of refraction, with tables derived like Wright's from those of Tycho Brahe, and of the error induced by 'the Paralaxes of the Sunne'. He included an example of one of Brahe's solar observations, made in June 1588, corrected for refraction and parallax, from whence 'commeth it', he explained, 'that the Pole's elevation observed by the Meridian Altitude of the Sunne or starres, and by the Pole itself differ, if you conferre two of these Altitudes together' uncorrected, a phenomenon that had vexed the minds of some Elizabethans. The topographical glass itself was a form of theodolite with various engraved dials and circles which enabled it to be used, in addition to survey work, for the solution of problems normally performed on an astrolabe, quadrant or tide computer, such as the amplitude of a heavenly body, the phases of the moon, and the time of high water. It was graduated with a diagonal scale reading to 10'.

In the following year Hopton published A Concordancy of Yeares, a popular perpetual almanac, calendar and handbook of general information remarkable for its description of the heliocentric theory. It also contained a tide-table of a novel kind, in the form of 'A Table to know the hour of

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1 Speculum Topographicum: Or the Topographicall Glasse. Containing:

- The use of the
  - Topographicall Glasse.
  - Theodolitus.
  - Plaine Table, and
  - Circumferentor.


2 A Concordancy of Yeares. Containing a new, easie, and most exact Computation of Time, according to the English Account. Also the use of the English and Roman Kalender, with briefe Notes, Rules, and Tables, as well Mathematicall and legal, as vulgar, for each private Mans Occasion. Newly composed and digested, by Arthur Hopton, Gentleman. The Contents follow after the Epistles. Printed for the Company of Stationers, 1612. Cum privilegio.
the night by the Moone, her comming to the South, the quantity of her shining, and full sea through England
d. The time of high water of various listed ports was found by adding ‘the houres and minutes placed by the name of each Haven unto the houre of the Moones comming to the South’. This form of tide-table is to be found subsequently in other almanacs. Hopton more than once referred to the continued popularity of *The Shepheards Kalender*, Digges’s *Perpetuall Prognostication*, and Cortes’s *Arte of Navigation*, all of which were appearing in new editions. It was, he said, because they nevertheless still contained errors in their ephemerides that he had produced his *Concordancy*. He might have mentioned Bourne’s *Regiment* as being still popular. Only the year before it had been republished with new ephemerides and, on the expiration of the ephemerides of the 1592 and 1596 editions, with a new title-page, showing a navigator shooting the sun with a cross-staff, holding a compass and wearing a seaman’s call, or whistle, and two seamen each holding a lead and line. It provides an excellent illustration of the rig of Jacobean mariners. Other favourites to be reprinted at this time were the *Seamans Kalender* and Hues’s *Tractatus de Globis*, Norman’s and Borough’s treatises on magnetism and variation, Norman’s *Safeguard of Sailers*, and Blundeville’s *Exercises*. This steady flow of navigational books affords further evidence of the revolution that had occurred in English nautical thought and practice, in so far as it concerned navigation, since the 1570s. Whereas half a century before the great bulk of English seamen had been essentially medieval in outlook and in navigational technique, they were by now unmistakably modern. Moreover, they were ahead of most of their countrymen in the application of mathematics, the language of science, to their profession. Their ships were rapidly becoming the most complex mechanical contrivances yet assembled and put together by human hands, while in the navigator’s chest was stowed the widest selection of instruments of precision and of books of systematized knowledge in general use. This is not to say that their mathematical knowledge was extensive by modern standards, but that it was by contemporary ones. John Brinley, author of *Ludus Literarius; or the Grammar Schoole*, published in 1612, considered, for instance, that boys should learn numbers by letters, that is Roman numerals, so that they could tell the number of pages, sections, and chapters in a book. This, he said, was ‘fully as much as is needful for

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1 *LVDUS LITERARIIVS: or, THE GRAMMAR SCHOOLE; SHEWING HOW TO PROcede from the first entrance into learning, to the highest perfection required in the GRAMMAR SCHOLES, with case, certainty and delight both to Masters and Schollars; onely according to our common Grammar, and ordinary Classical Authors: BEGYN TO BE SOUGHT OVT AT THE desire of some worthy fauourers of learning, by searching the experiments of sundry most profitable Schoolemasters and other learned, and confirmed by tryall: Intended for the helping of the younger sort of Teachers, and of all Schollars, with all other desirous of learning; for the perpetuall benefit of Church and Common-wealth. It offereth it selfe to all to whom it may doe good, or of whom it may receive good to bring it towards perfection . . . LONDON, Printed for THOMAS MAN. 1612.*
your ordinary Grammar Scholar', and declared that it was often beyond the powers of students going up to universities! Numeration by figures he dismissed in a single paragraph. John Tapp therefore, in dedicating a year later his Path-way to Knowledge; containing the whole Art of Arith-meticke to Sir Thomas Smith, 'governor of the Muscovy and East India Companies and of the Company of Discoverers for the North-West passage and Treasurer for the plantation of Virginia' acted wisely, for it was mostly amongst the servants of these companies and of merchant adventurers of smaller interests than Sir Thomas that he would find his sales.¹ For this reason too he 'adioyned a briefe order for the keeping of Marchants Bookes of Accompts, by way of Debitor and Creditor'.

To increase its general interest Tapp also devoted a part of the book to 'the art of Cossicke Numbers' or that 'kind of Arithmetick commonly called by the name of the Great and mighty Art of Algebra', and which at this time Thomas Harriot was reducing to its modern form. We have seen how, under Sir Thomas's inspired direction, English voyages of exploration, colonization and commerce had grown in number and in extent since the opening of the century, and that when Hood ceased his navigational lectures it would appear that Sir Thomas engaged Edward Wright to continue with mathematical lectures, permitting them to be given in his house and contributing largely towards their maintenance. These lectures were ill-attended, said Tapp, but none the less it was to them and the recent publications of English mathematicians that he attributed the growth in the numbers of capable navigators. Part of the cause of the poor attendance at the lectures (which clearly included those at Gresham College) he added, lay in the fear of many seamen 'to be taxed with want or imperfections in some such things, whereof they professe themselves exquisite'; part in the fact that mathematicians, in the persons 'of those that are practisers and professors of Navigation, which are generally all the better sort of Marriners and Sea-men', were few; and part in the fact that most mathematicians were 'gentlemen of the Country, or such in the Cittie, whose Law business or other occasions in the terme time, [when, it will be recalled, the Gresham lectures were delivered] hinders them from those excellent exercises'. He therefore pleaded for the establishment of a distinct

lecture of Navigation, a profession which a multitude of people make their onely living by. And to be read in such a place, where they shall

¹ THE PATH-WAY TO KNOWLEDGE; Containing the whole Art of ARITHMETICKE, both in whole Numbers and Fractions; with the extraction of Roots; as also a briefe Introduction or entrance into the Art of Cossicke Numbers, with many pleasant questions wrought thereby.

Digested into a plaine and easie methode by way of Dialogue, for the better understanding of the learners thereof.

Wherewith is also adioyned a briefe order for the keeping of Marchants Bookes of Accompts, by way of Debitor and Creditor. AT LONDON, Printed by Th. Purfoot, for Tho: Pauier. An. 1613.
not onely bee seen, knoune, and noted, (for well-spending their time) by their oweners, setters fourth and principall emploiers, but also their daily and frequent business attracting and necessarily drawing them thither, there is no question to be made of a very sufficient Auditory and great benefit to be reaped thereby, as . . . hath already been effected by the late readings, in less freqüēt & eminent places before time.

His plea, like earlier ones, did not meet with the hoped-for response. On the other hand it may well have prompted Sir Thomas to get the East India Company to pay Wright for lecturing to its servants, and so to place his lectures on an official footing. With official encouragement, perhaps the reasoning ran, the Company’s servants might attend them more readily. The innovation, as we have seen, was short-lived. Neither a lecturer nor a hydrographer was appointed to fill Wright’s posts on his death in 1615. Nor was this omission unreasonable, at least as regards a lecturer, for the Gresham College lectures on matters mathematical and navigational, as we shall see in the next chapter, were coming fully up to their founder’s expectations.

While the foregoing developments for improving oceanic navigation had been taking place others had been made in the interests of safer pilotage and coastal sailing. By the opening of the Stuart era the English had been largely ousted by the Dutch from many of their time-honoured carrying trades. Even before the end of Elizabeth’s reign the Dutch had captured the increasingly important English coal export trade centred upon Newcastle upon Tyne, Sunderland, and Blyth on the north-east coast. Although four hundred English vessels were engaged in this coastal trade, two hundred on the supply of London alone, it was reckoned that not more than twenty carried coal overseas, and that not less than two hundred Dutch craft carried it from the Tyne and adjacent coal ports to France, Holland, and Germany, making six to ten voyages a season and occasional winter ones. By 1615 the Dutch had a preponderant share in the Norwegian and Muscovy trades, had monopolized the Baltic trade, and were such keen competitors in the Biscay and Peninsular trades, that they carried back the salt from the age-old Biscayan and Peninsular salt-panns for sale at the English east coast fishing ports. With such evident superiority in the home trades it is scarcely surprising to find the Dutch maintaining their position as the best compilers and editors of runters and waggoners for home waters. The originally Dutch Safeguard of Sailers continued in steady demand, as already indicated, throughout the early Stuart period, being revised in form by Edward Wright in 1605, and John Tapp in 1612, and no competitor appeared on the English market. A second edition of Ashley’s Mariners Mirrour was brought out in 1605, but the plates only were in English, the text was in Dutch.¹ The original work was by then over twenty

years old and a more up-to-date waggoner, particularly for the south-east coasts of England and the shoal-infested waters off the Low Countries, was badly needed. In Holland the Licht der Zeevaerdit of 1608, by Willem Janszoon Blaeu, met the demand, and four years later, translated into English and published in Amsterdam under the title of The Light of Navigation it promptly satisfied the needs of English pilots for a ‘lively portrayal of all the Coasts and Havens of the West, North, and East Seas’.

As the Mediterranean was not included they had still to rely on Barentszoon’s original Dutch waggoner of 1595 unless they availed themselves of the French translation of 1609, Description de la mer Méditerranée.

Blaeu made no claim to originality for The Light of Navigation, but he did claim that its original source (Wagenaer’s Spieghel der Zeevaerdit) was ‘corrected from manie faults, and inlarged with manic new Descriptions and Cardes . . . beside . . . new tables of the Declination of the Sonne, according to Tycho Brahes Observations, applied to the Meridian of Amsterdam’.

‘What great good and profit had been procured until all Sea faring men by books of Seacardes’ by Wagenaer, Barents, and others it was, asserted Blaeu with truth, ‘impossible to declare’. For that very reason, he explained, ‘because some Havens and Chaneles in the Seas had been in process of time cleane altered and changed since they were described’ and ‘some wholly abolished and stopt up whereby such descriptions were verie hurtful’, he had followed up Wagenaer’s expressed intention of correcting and amending the ‘manie notable faults in his book’. ‘As touching the Cards I have’, Blaeu claimed, ‘especially much bettered them’ by inserting the true compass direction and enlarging them and, ‘according to the example of the best cardes so corrected them that therein you not onely see how you may saile into and come out of all Havens and Chaneles but also how farre they reach and are in widenesse and length

1 See Pl. LXXV. THE LIGHT OF NAVIGATION. WHEREIN ARE DECLARED AND LIVELY POVRtrayed, all the Coasts and Havens, of the West, North and East Seas. COLLECTED PARTLY OVT OF THE BOOKS OF the principall Authors which have written of Navigation, (as Lucas Johnson Waghen- aer and divers others) partly also out of manie other expert Seafaring Mens writings and verball declarations: corrected from manie faults, and inlarged with manie newe Descriptions and Cardes. Divided into two Books.

HEERVNTO ARE ADDED (BESIDE AN INSTITUTION in the Art of Navigation) newe Tables of the Declination of the Sonne, according to Tycho Brahes Observations, applied to the Meridian of Amsterdam. Together with newe Tables and Instructions to teach men the right use of the North-starre, and other firme starres, profitable for all Seafaring men.

By WILLIAM JOHNSON.

AT AMSTERDAM.

Printed by William Johnson, dwelling upon the Water, by the Old Bridge, at the Signe of the Golden Son-dyal. Anno 1612.

Cum Privilegio.

2 Guillaume Bernard, Description de la mer Méditerranée. Amsterdam. Corneille Nicolas, 1609.
distant from each other: which never heretofore (be it spoken with out boasting) was so perfectly and so beneficially done for the good of seafaring men.' Blaeu's claim was perfectly justified. He had shown in his charts the leading marks, bearings, and transits to be observed when entering and leaving many harbours and he had discarded Wagenaer's method of enlarging the havens in the coastline in the interests of pilotage. By enlarging the scale of his charts, and including more charts, Blaeu had covered the same ground as Wagenaer, but had enabled harbours to be correctly delineated according to the scale of the chart as a whole. It will also be found that Blaeu largely discarded Wagenaer's system of including coastal elevations on the charts—he included them in the letterpress—and that the delineation of the coastline is more accurate and less pictorial. Round the coasts of England more buoys and beacons will be found. This was the result, not of greater care by Blaeu in the insertion of such aids to navigation, but of the greater powers conferred upon and the activity of Trinity House since Wagenaer's day. An example is the buoying of the important Spits shoal in the Thames Estuary.\(^1\) A further improvement in the charts of 'the West Seas' was the inclusion of a latitude scale. But 'touching the East Seas [Arctic and Baltic] I could not bring that to pass', confessed Blaeu, 'because we wanted the true collection thereof for that the same, that Lucas Waghenra writeth thereof is false and he contradicteth himself'. This, of course, is scarcely surprising. In these high latitudes the errors of the plane chart became so exaggerated that it was impossible to reconcile courses and distances with latitudes. Wagenaer had had to rely upon the accuracy of distances 'according to the common guessing' alone and to ignore reported latitudes. It was the publication, in the form of the *Mariners Mirrour* and his other publications, of the results of his synthesis of the conflicting hydrographical information supplied to him that enabled comparison to be made by local experts and discrepancies to be revealed. These, reported and recorded, enabled material to be accumulated for the production of a revised edition such as Blaeu's. For all their faults Wagenaer's pioneer works must rank amongst the greatest of all hydrographic developments.

Besides the revised charts in the *Light of Navigation* there were sailing directions, admirably and systematically arranged under appropriate headings, giving times of high and low water, the direction of tidal streams, the soundings in which the coast could be sighted or was lost from view, the courses and distances between places—incidentally leagues had by now entirely superseded kennings—and their latitude.\(^2\) As became a Dutch work there were special—and very necessary—chapters on 'How to sayle into the havens of Flanders' and 'The situation and stretching of the Flemish bancks', correct for the year 1607, with the warning, 'everie man must be very warie and take heed . . . ' that 'the Flemish bancks may be sounded with the lead at 15 and 16 fathome, and the channel is 24 and

\(^1\) See Pl. LXXVI.  
\(^2\) See Pl. LXXVII.
25 fathome deepe. But’, and a caution follows as lively to those seeking shelter in the Downs today as ever it was in Blaeu’s time and in times before him, ‘Goodwin is steepe and uneven, for at one casting of the lead you shall have 26 fathome, and at another cast of the lead you shall be fast upon the sand . . .’ And, he might have added, doomed to destruction.

‘Besides this [the improvements to charts and sailing directions] I have hereunto added a brief Institution touching the Arte of Navigation’, explained Blaeu, ‘wherein is perfectly shewed what knowledge of Astronomie is necessarie for a seafaring man . . . But unnecessarie things I have

![Chart Symbols](image)

**Fig. 27**

**Chart Symbols used in Blaeu’s The Light of Navigation (1612)**

omitted . . . ’1 Omitted also was any mention of ‘lengths’, or longitude, despite the claims of many to be able to find it ‘by direction of the Needle or altering of the Compass’ as perfectly as latitude. That claim, wrote Blaeu, ‘is not onely unprofitable but also (if a man should trust thereunto) both hurtful and deceitfull . . .’. His ‘Institution touching the Art of Navigation’ was an expanded and revised version of Wagenaer’s treatise on navigation in the *Mariners Mirrour*. It forms in itself a brief manual of navigation

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1 See Fig. 27.
adequate in all respects for the pilot confined to the home trades. The main
circles and lines of the sphere are clearly defined and explained with admir-
able illustrations; the declination table, for the years 1612–31, 'for the
longitude of the Lower Countreyes' is according to Tycho Brahe's observa-
tions, and is followed by a long chapter on the 'fixed stars'. This has
numerous woodcuts showing 'how men may easily learne to knowe them',
and contains their 1608 declination according to Tycho Brahe, and a com-
plete explanation of the change in the time of the stars transiting during
the year. This is supplemented by a table of the hour at which 'Syrius or
Canis major the great Dogge' transited every month of the year 'stilo
novo'. The nocturnal he described, unlike earlier ones, had only the hours
between 4 p.m. and 8 a.m. engraved, the space where up to now the
remaining—daylight—hours had been inscribed being left blank. It was
designed for use with 'The hinder wheeles of the Great Wagon' [the
 pointers of the Great Bear] only, these transiting south at midnight on
1st September. Mariners were reminded that if these pointers were ob-
scured and they used 'the Watchers', the guards of the Little Bear, instead,
the time was four and a quarter hours later than the nocturnal indicated.

The chapters on taking sun-sights by astrolabe and cross-staff are lucid,
and a series of medallion-like illustrations, derived quite clearly from
Medina's works, amplifies the rules for correctly applying declination when
calculating the latitude. The manner of marking out a cross-staff with
three transoms, both geometrically and mathematically, is explained, also
how to avoid ocular parallax. This is followed by a dissertation upon lati-
tude.

Instruction in star-sights was coupled with Tycho Brahe's explanation
and tables of refraction and, for the doubting Thomas, a drawing of a tub
of water with 'a staffe slope in it'. This demonstration of a scientific
phenomenon must be one of the earliest popular scientific explanatory
drawings ever printed.

The principal ingredient in the making of a good pilot, said Blaeu, was
'expertness at sea'. Much of the knowledge which could be obtained only
by experience concerned tidal information. This, of course, was because
of the inadequacy of the existing tide-tables and, more particularly, of the
data on tidal streams. Only experience—the storing up of multitudinous
observations of often conflicting facts—could compensate for that, par-
ticularly when it came to a pilot having 'to set his tydes and course, that
he might staye his tydes'. Just how important such skill could be Frobi-
sher had demonstrated in 1588 when he had foxed the Armada off Portland
Race. How useful and necessary it was to a channeller, Sir Richard Hawkins
recounted in his Observations. He did so, citing specifically his experience
in the Channel at the start of his voyage of 1593, in order to illustrate the
fact that 'the principall parts required in a mariner that frequenteth our
coastes of England, is to cast his tydes, and to know how they set from
poynt to poynt, with the difference of those in the Channell from those of
the shore'. He had cleared the Downs with a south-east wind, he explained,
and had made his way down Channel as far as the Isle of Wight on this friendly breeze. But there, after he had set his Thames pilot on shore, the wind had veered to southerly and, before he had come to Portland, had gone round to west-south-west, dead in his teeth. With a vessel that could sail at best within six points of the wind and make good seven, whose speed through the water was probably at most six knots, and whose speed down Channel against the tidal stream was consequently not more than one and a half knots, and more probably one, it was worse than useless to attempt to go down Channel at the flood. The reason was that the flood stream between Portland and Plymouth has a speed up Channel of up to one and a quarter knots, and that farther up Channel the speed of the flood stream rapidly increases, reaching a maximum of five knots in the Strait of Dover. With the aid of the ebb tide Hawkins had made Portland. All night, while the flood tide streamed up Channel, he had lain at anchor. At dawn, with the renewal of the ebb, he had set sail again but, ‘being cleere of the race of Portland’, the wind had begun to blow ‘with fogge and misling rain’—real Channel weather—which for three days had forced them to remain with shortened sail ‘the wind never veering one poyn, nor the fogge suffering us to see the coast’. The third day the fog had suddenly lifted, in the way sea fogs do, and they had found themselves under the beetling brow of Berry Head, east of Dartmouth, on an ebb tide. When, that evening, the ebb had spent itself, they had anchored off Dartmouth. On the next ebb, Hawkins explained, ‘wee set sayle again. And the next morning early, being the 26th of Aprill, wee harboured ourselves in Plimmouth.’ Great, he claimed, had been the wonder of his father and other knowledgeable mariners that, despite ‘the wind contrary and the weather such as it had beeene, wee had been able to gain Plimouth’. It was indeed a brilliant feat of tiding-over.

Blaeu advised mariners to memorize their courses between ports and the establishments of ports, and he included tide-tables with specific instructions to elevate the compass fly when using it as a dial ‘so that the pinne in the middle sheweth time right to the pole’. Accompanying the tide-tables was an almanac for the moon and notations of all eclipses.

Blaeu explained the popularity of the waggoner with its plane charts, in an age when Mercator’s charts were coming into increasing use, on the grounds that, although they were often incorrect in some places, especially in northern parts, in the coastal waters of Europe the faults were now so small that they could not be a serious hindrance to the pilot, and had the advantage of simplicity. ‘Our Old fore-fathers, which first practised them did great pleasure and profit vnto all mariners’, he remarked truly. However, he explained their deceptiveness on a long triangular voyage, such as from the Channel to the Canaries, on which the outward passage was made down the African coast, the homeward by way of the Azores, or to the West Indies and back. The printed maps, ‘made by us’, of the West Indies enabled ‘all such places to be mad even’, he explained, evidently referring to charts on Mercator’s projection. None of these charts survives,
and indeed it is considered unlikely that any were in fact printed by Blaeu at this time. It would appear that the earliest printed chart of the Atlantic, Blaeu’s *West Indische Paskaert*, was probably published in 1630. This covered the whole of the Atlantic area on Mercator’s projection, and became immediately the standard chart for navigation to America and the Cape of Good Hope. It was often copied, although of the original only one example survives, in the collection of the Bibliothèque royale at Brussels.¹ ‘Amongst manie Pilots there is’, commented Blaeu, ‘an opinion that they had rather use written mappes, then such as are printed, esteeming the printed mappes to be imperfect . . .’. This they did on the grounds that as manuscript charts were drawn every day, they were every day corrected so as to embody the latest hydrographical information. This view, Blaeu pointed out, ignored the fact that the drawing of charts was a slow business at the best of times, and that what generally happened was that they were ‘all one after the other, with the least labour copied out, and many times, by such persons that have little or no knowledge therein’. He therefore, and with justice, explained the advantages of his superior printed productions. The originals of these were, he claimed, ‘in every point with all care and diligence made perfect’ before copies were printed off, consequently every copy was equally perfect.

The *Light of Navigation* was twice reprinted, in 1620 and 1622. In each edition only the ephemeredes were changed in order to bring them up to date.

The costly printing presses, the organization for collecting, sorting and

¹ See Pl. LXXVIII. See, Gerncz, D., and Destombes, M. ‘La West Indische Paskaert de Willem Jansz. Blaeu de la Bibliothèque Royale.’ *Communications de l’Académie de Marine de Belgique.* Tome IV. The chart measures 78 cm. × 99 cm. The main cartouche reads:

*West Indische || Paskaert || WAERIN DE GRADEN DER BREEDDE OVER WEDER || ZIJDEN VANDE MIDDELIJN WASSEnde soo VERCROeten || DAT GEPROPORTEERK SYT TEGEN HUNNÉ || NEVENSTAEDE GRADEN DE TENLNGDE || Vertonendi (behalven Europaes zuydelijkste) || alle de zeekusten van Africa en America, || begrepen in Octroy bij de H.M.H. Staten generael der vereenichde Nederl. verleent || aende generale West Indische Compagnie IN DE GROOTE ZYVD ZEE || BESCHREVEN DOOR Willem I. Blaeu MITSGADERS DIE VAN PERU EN CHILI.*

[Nautical Chart of the West Indies in which the degrees of latitude, on either side of the equator, are enlarged in proportion to the degrees of longitude at each latitude, showing (besides the southern coasts of Europe) all the maritime shores of Africa and America, made in accordance with the Charter of T. H. the States-General of the United Provinces to the West India Company, also those of Peru and of Chile on the great South Sea; traced by Willem I. Blaeu.]

The inset has a cartouche which reads:

*OVERMITS || DE AMERICAENSCHEN || KUSTEN VAN R. DE PLATA || AEN D’OSTZIJDE EN VAN LA || CONCEPTION AEN DE WESTZIJDE || ZUYDWAERT, IN DESE KAERT || AEN EEN VERVOLGENS NIET || VERTOONT KONDEN WORDEN ZYN DIE HIER IN EEN || BESONDER TAFELKEN || VERVAET.*

[Note that the American coasts, in a southerly direction, from the River Plate on the east coast, and from Concepcion on the west, cannot be represented on this chart in one piece; they are enclosed therefore in a special inset.]
assimilating hydrographical information, such as was represented by *The Light of Navigation*, called for heavy capital outlay. Such capital had been available to the Portuguese and Spanish seamen through the medium of their respective Casa de Guinea e India at Lisbon and Casa de Contratación at Seville. For all its faults the Casa de Contratación’s system of supervision, training, and examination of pilots for oceanic navigation and of collecting and disseminating hydrographical information for their guidance was remarkable in conception and in creation. It is a common error nowadays to disparage the achievements of the Portuguese and the Spaniards on the seas in the sixteenth and early seventeenth centuries. This was characteristic of neither the Elizabethans nor the Jacobins. It is true that by the middle of the seventeenth century both great nations had lost much of their supremacy at sea. An examination of the causes is not germane to our subject; what is, is the fact that in Elizabethan and Jacobean days the Spanish, and by implication the Portuguese, navigational systems were held up as an example to be imitated, if possible, by Englishmen. It should be recalled, before adverse comment is made on Iberian seamanship in the period under review that, as already pointed out, the standard manuals of navigation in England, Holland, Italy, and France, as late as 1630, were Spanish; that the sea-astrolabe and cross-staff were of Portuguese conception; and that almost all the hydrographical knowledge of the world beyond the shores of North-West Europe and the Mediterranean incorporated into charts and sailing directions was derived either from the Portuguese or the Spaniards. Shaking free from Spanish rule, with long experience in printing, book-binding and engraving, and with a flexible economic organization, the Dutch were able to take over the lead in hydrographical matters from their late masters at the close of the sixteenth century. England had neither the economic organization nor a sufficiency of technical skill to enter into serious competition. She had her brilliant individualists, academic hydrographers like Hood and Wright, practised seamen like Davis, Hudson, Baffin, and Daniel, but two wars with Holland, and a revolution, were to rack the land before Englishmen were to challenge the supremacy of continental houses in the field of hydrographic publications.

Although the Master, Wardens, and Assistants of the Trinity House of Deptford Strand had taken on increasing responsibilities during Elizabeth’s reign for the provision and maintenance of coastal navigational aids, the buoys, sea-marks and beacons that they provided were of use only in day-time. Until about 1600 the only lights exhibited on the English coast for the guidance of mariners were the two maintained at North Shields, at the entrance to the Tyne, under the charter of 1536 of the Trinity House of Newcastle upon Tyne. These ‘firebeacons’, as the Jacobean waggoners called them were, as might be expected in that locality, of ‘fire-coals’. Since the granting of the second Elizabethan charter to the Newcastle Trinity House, instead of being exhibited continuously at night as originally stipulated they were burnt nightly from half- or quarter-flood to half-ebb only. Their purpose was not so much to indicate the entrance
LXXIV. Title-page of the Second Part of *The Mariners Mirrour*
LXXVI. Chart of the Thames Estuary in Blaeu's *The Light of Navigation* (1612).
of the Tyne as to facilitate the safe passage of shipping by night, when the state of the tide served, through the lower reaches of the river past a dangerous shoal off the north shore. For this purpose the fire-beacons were exhibited in two stone towers at different levels and some distance apart, the lower one being to seaward of the upper one which was so sited that when the two lights were in transit the shoal was safely passed to the southward.

It has already been pointed out that Hubrigh’s rutter of 1569 mentioned these lights. Wagenaeer, in the Mariniers Mirrour of 1588, gave directions for using the two ‘sea towers’ as leading marks, but made no specific reference to their use at night as beacons. The sailing directions in The Light of Navigation of 1612 for entering the Tyne are, however, explicit.

Seven or eight leagues south from Coket Iland there lyeth Tinbuy or Tinmouth [Tynemouth] . . . South from Tinmouth there lyeth an out-point called Sonderla: [Sunderland] betweene this point and Tinmouth the Riuuer of Newcastle runneth in, wherein there is twelve foote water at halfe flood. From the point of Tinmouth there shooteth off a stonic banck, which you must saile in by, but the southeast ende is flatte, there you may goe in with the lead at tenne foot half flood. The markes to sayle into this Riuuer are these: there are two fire towres which stand on the north side of the haunen, you must set them one ouer against the other, and sayl in upon them, along by the said stony banck, vntill you are in . . .

In about 1600 a single light began to be exhibited nightly at the entrance to the Tees, no doubt as a result of the rapidly increasing coal trade, and perhaps in the same year one Bushell commenced exhibiting two lights at Caister on the north-east coast of Norfolk. It is not clear from the evidence available whether these lights were of coals, as at the Tyne, or candles, nor how the cost of either was defrayed. It is probable that coals were burned and that the lights were paid for by agreement with the shipowners and merchants of the respective ports. A few years later two candle-lights were established at Lowestoft by the Trinity House of Deptford Strand for the direction of ships which crept by night in the dangerous passage between Lowestoft and Winterton, through the channels lying close inshore. These latter lights were the first to be established by the Trinity House of Deptford Strand, which also took over at about this time, 1609, the two Caister lights. The introduction of these additional navigational aids can be traced in the waggoners of this period. Thus whereas The Light of Navigation of 1612, being an English translation of the Dutch Licht der Zeevaardt of 1608, makes no mention of the Norfolk lights its successor of the 1620s, The Sea Mirrour, directs that

If you will run through frō before Leistof [Lowestoft] with[in] these banks [the ‘bancks or Holmes of Yarmouth’], thē looke out for the fire-beacons which stand by Leistof, which are two litle white houses, the

25—A.O.N.
one standeth beneath upon the chindle [shingle] on the sea side, and the Innermost upon a little hommock, somewhat farther within the land. In the night there is alwaies fired upon the, for to sail in there also by night. Bring these foresaid firebeacons n.w. & by north, or somewhat more northerly from you, & saile in so right with them either by night or by daie.

If you will sail from Yarmouth forth through within the banks to the northwards [continues the directions], sail along by the land, & keep sounding of the shore in 5, 6, or 7 fathome, until you have the two first beacons (which stand a little to the northwards of Castor) one in the other, sail then right with them, either by day or night (in the night there is fired upon them) you shall so run over a flat, through betwixt two buies [buoys] which be each of them upon a tail of a sand, sail bouldlie in, with the foresaid firebeacons, untill you come againe neare the shoare, in 5 or 6 fathome. then run again along by it until you come before Winterton.

On the accompanying chart the fire-towers are suitably represented, as are the lines of transit and bearing, and the shoals and buoys.

In 1615, with the approbation of Trinity House, who declined to erect one, Sir Edward Howard commenced exhibiting nightly an open coal-light at Dungeness on the south-east coast of Kent. Being at the western entrance to the Dover Strait it marked a new development for it was intended not so much to serve as a leading or thwart mark to coastal shipping as to warn deep-sea shipping working its way up Channel that it was in the vicinity of the coast. Four years later a similar light began to be exhibited at the Lizard, the most important landfall on the English coast, and, after Ushant, on the coast of North-West Europe. This light, however, was not maintained with regularity, and in 1623 it ceased to be displayed.

On the Norfolk coast, however, three more lights had been successfully established. One, of coals, was at Winterton, two, of candles, were both at Wintertonness, and all had been first exhibited in 1617 by Sir William Erskine and Captain John Meldrum, who were granted the dues levied to maintain them.

Thwarte of Winterton runneth off a dangerous rif, [warned the sailing directions in The Sea Mirror]. To the southwards of that rif upon the land, standeth a firetoure, which is verie good to be knoune, with a fire beacon, & also a little white house, when these come one in the other, then you are thwarte of the point of the riffe.

To the northwards of this rif upon the land stand two firebeacons, whereupon there is fired by night, for to avoid this rif. When as you come thwart of the point, then are these also one in the other, so that these doe serve for thwart markes, & the other to the southward of them for longst marks [leading marks], for those that wil saile about it frō the southwards...
With the development of modern transport it is difficult today to realize
the important part that coastal shipping played in former times in the
distribution of food-stuffs, raw materials, and manufactured goods, and
in the conveyance of travellers. In Jacobean times the trade on the east
coast was steadily growing, fed in particular by the ever-increasing demand
for coal from the north-east coast ports to fire the insatiable furnaces
and hearths of the metropolis. The lights exhibited on the Norfolk coast
from the 1600s did much to ensure the flow of this traffic. Off these low
shores, in waters laced with innumerable shoals, the flicker of the braziers
or the golden glow of the candle lights guided many a mariner on a dark
and blustery night to shelter and safety. Lack of a light to the southward,
however, where the Suffolk coast at Orfordness swings to the south-west-
ward, to the estuary of the Thames, continued until the middle 1630s
to make night-sailing off the East Anglian coast a hazardous task during
the long dark nights of winter. In the course of a single night, for instance,
the night of 28th October 1627, no less than thirty-two ships were cast away
on Orfordness for lack of a light. Other disasters, but this one in particular,
led after a period of experiment to the establishment in 1637 of two lights
on this low promontory, one being of coals, the other of candles, and each
being housed in a specially constructed timber building. The patent for
these lights was granted to one Gerard Gore, who in due course became
an Alderman of London. Two or three years earlier those equally important
turning-points for shipping bound to or from the Thames from the south-
ward, the North and South Forelands, had also been lighted. In 1634
Sir John Meldrum by writ of the Privy Council had established one or
two fire-beacons on the South Foreland. In 1636 he had received the
patent to exhibit at the North Foreland one, and at the South Foreland
two open coal-lights, and of course to collect the dues levied for their
maintenance.

It will by now have been appreciated that the light dues levied on ships
entering or leaving ports where lights were exhibited or which had passed
coastal lights, and which ranged between a farthing and a penny per ton,
could be remunerative, and that the private individuals who undertook
to exhibit lights were animated by a sense of personal gain as well as of
philanthropy. It may be wondered how it was that despite the Trinity
House charter and the Act of 1565, and the grant of thirty years later
concerning sea-marks, private individuals were able to establish fire
beacons. There were a number of contributory reasons. While Trinity
House was responsible for the provision and maintenance of coastal navi-
gational aids it was also—and this was one of its most important functions
—responsible for the maintenance, out of the revenues, of almshouses for
aged and maimed mariners and for the granting of aid to distressed sea-
men. At the close of Elizabeth’s reign its existing revenue did not permit
of the great increase in expenditure involved in the establishment and
maintenance of lights, and as a corporate body it could not risk meeting
the cost by levying additional dues which might turn out to be insufficient;
the levying of such dues could probably have been successfully resisted on the grounds either that Trinity House had only recently been granted the buoyage and beaconage of the Thames to meet its additional responsibilities and expenses (and it might have been contended that these included the provision and maintenance of beacons for use by night as well as by day), or else that, as ‘fire-beacons’ were neither stipulated nor implied in the charters, grants, and Acts concerning sea-marks, Trinity House could neither claim a monopoly of them, nor levy dues for them without special authority. It was a nice legal point whose resolution the Master, Wardens and Assistants evidently felt would be more profitable to lawyers than mariners, and though it is clear that they often resisted the establishment of lights, they were unable to exert authority over the licensees of lights other than by agreement with them. The result was that in due course and for generations a variety of lights were exhibited around the coasts of England by individuals more interested in the profits accruing from them than the safety of seamen. While this was to stultify developments in the improvement of lights when better methods of illumination were invented—such as the screening of coal and candle lights by glass, the use of oil—this, in Jacobean days, was a risk that, if foreseen, had to be accepted. Trinity House could not gamble in the provision of lights, individuals could; if they won their gamble, everyone profited—the merchants who paid the dues, because they had fewer wrecks, the licensees, because they pocketed the profits, and the seamen because they were saved from death by drowning; if the gamble failed no one except the licensee was a whit the worse off.

Trinity House, it has been said, often opposed the institution of lights. For instance in 1590 and again in 1618 proposals were made for the exhibition of a light at Spurn Point, that long-hooked isthmus that thrusts its crooked finger into the Humber’s mouth, but each time the Deptford Trinity House successfully resisted the project. The Lizard light exhibited in 1619 and for some time longer was eventually extinguished by their efforts, and they later opposed—unsuccessfully—the establishment of the Foreland lights. This opposition was prompted in the main by a blending of patriotism and a sense of responsibility to mariners.\footnote{The best authority on early lights is Whormby, J., \textit{An Account of Trinity House and of Sea Marks} (1740). Cotton, J., \textit{Memoir on Trinity House} (1818), has useful observations on the procedure establishing early lights. Further information may be gathered from studying Blaeu’s \textit{The Light of Navigation} (1612); \textit{The Sea Mirror} (1625); Jacob Columnne’s \textit{The Fierie Sea Columnne} (Amsterdam, 1637). See also Appendix No. 22.} Trinity House maintained that England would be betrayed in time of war by coastal lights—and she was at war and under threat of invasion throughout the closing years of Elizabeth’s reign—and that in time of peace she would be spied upon under the cloak of darkness by men eager to learn the secrets of her approaches for use in war. In Jacobean days, as we have seen, foreign pirates ravaged shipping in the surrounding seas and harried the coastal
villages and towns of the south-west. They even raided shipping off the Thames. Trinity House's fear that lights would facilitate the pirates' work was genuine. In any case it contended that shipping had no need of lights at points like Spurn Point, the Forelands and the Lizard, to aid them in their landfall, because if they were coming from overseas they held off from the coast for the very reason that night landfalls were so hazardous. The counter to this was that the art of navigation was not yet so precise that masters could be sufficiently sure of their position to avoid a premature and consequently disastrous landfall on an unlighted coast. To this Trinity House riposted that a light visible less than three leagues—nine miles—from seaward was a snare to the seaman who entrusted the safety of his ship to it, and that the worse the weather the poorer the light given by the unscreened candle. In this there was much truth, and one of the determining factors was undoubtedly the visibility distance of the lights not on clear, dark nights, when no moon shone, but on the nights of blackness when sea, coast, and sky met in a welter of waves, rain, and spindrift, and the clouds drove close overhead. Then the mariner who trusted to seeing the light would see it, but often suddenly close aboard or high overhead, as like as not, on a dead ice shore with no chance of clawing his way clear of the rocks or shoals on to which he was fast being driven. Thus there was much sound sense and experience behind the Trinity House opposition, and this is shown further by the fact that the leading- and thwart-lights designed to facilitate the passage of coastal craft into ports or past off-shore reefs, were not opposed by Trinity House. The crude candle-lights and open braziers of the fire-beacons served such purposes well; even on stormy nights their visibility distance sufficed. In short Trinity House, ever conscious of its responsibilities towards ensuring the conservation and good estate of the realm's shipping in peace and in war approved of those lights which in its opinion contributed on balance towards these ends, and opposed those lights which in its opinion would prove less a safeguard to shipping than a leading light to foes. The times were still rude. The populace, a tithe of what it is today, inhabited innumerable scattered villages and hamlets inter-connected only by rough tracks. Only few roads, generally impassable in winter, lay between the larger towns. The isolation of outlying communities was very real, and the threat to them of sudden descents by pirates or foes had to be guarded against.

The early years of the Jacobean era were excited by a heated scientific controversy relating to navigational matters, between a divine and a physician. William Barlow, the divine, we have already met in discussing the state of and improvements to the mariner's compass. The physician, Dr. Mark Ridley, a member of the College of Physicians, had been at one time physician to the Czar of Russia. Like Dr. Gilbert, Queen Elizabeth's physician in her later years, whose important De Magnete was discussed in the previous chapter, Dr. Ridley was a keen student of magnetism. When Linton, in 1609, had published his claim to a secret solution of the problem of longitude, Barlow, as a tutor to the Prince of Wales, had felt
impelled to point out the fallaciousness of de Nautonier's work of 1602-4, with which Linton's was evidently related. This had been all the more necessary as de Nautonier had dedicated one of the sections of his work to King James, now king of England. Barlow had put his views on paper but had not published them, preferring to circulate them, as was commonly done, in manuscript. Ridley, however, on the appearance of Linton's book was inspired to publish his views on the use of magnetism in position-finding. His *Magneticall Bodies*, as he entitled his treatise, appeared in 1613. After recounting the various misbeliefs about the healing and other powers of magnetism, and giving a useful summary of the theories current in Elizabethan times of the source of magnetic attraction and the cause of variation, he came down roundly in favour of Gilbert's theory as expounded in *De Magnete*. He then truly, if unkindly, pointed out that de Nautonier and Linton, while holding to the view 'that the Magneticall needle and Compasse do move and turne themselves upon the Magneticall meridian always unto their oune Magneticall poles' so that it was possible to compute the variation on any given meridian, had each 'set forth different Magneticall poles . . .', so that they had 'found instead of the longitude of places, a longitude of unprofitable labors'. Having poured scorn on their pseudo-scientific labours he then proceeded to be equally unscientific himself, for, he wrote, 'when travelling or sailing . . . it will be very necessary for thee to be stored with the Marriners Compasse for the sea . . . to know the way . . . and also to have the Inclinatory-needle truly placed in his ring, and a Directory needle, or a little flie Magneticall in the boxe, fastened at the bottome . . . for to know under what latitude thou art every day of thy voyage . . .'. Now one of the chief purposes of his book was to describe the benefits that would arise from the use of 'the Directory-Magneticall-needle . . . for the description of Ports, Havens, Forelands, Capes, Bayes, and Rivers, for the more perfect making of Sea-cardes . . . and all Mathematicall instruments for measuring and surveying . . .' and to explain the manner of using it. Yet the instrument was fundamentally unsound, for the mutual attraction and repulsion of the magnetic needles in close juxtaposition, such as he envisaged, foredoomed it to failure because of the resultant errors. But we must give Dr. Ridley his due. He was, like de Nautonier an dmany others, seriously endeavouring to further the art of navigation by the exploitation of recent scientific discoveries.

1 The tables, with separate title-page of 1602, were in the Scots tongue. According to Taylor, E. G. R., *Late Tudor and Early Stuart Geography* (1934) the engraved title-page with long titles in Scots, French, and Latin, and the following directions in the same three languages on how to use the tables, were added in 1603, and these sections were subsequently prefaced by the treatise in six books on the lodestone: this is in French only.

2 A SHORT TREATISE of Magneticall Bodies and Motions. *By Marke Ridley Dr in phisicke and Philosophie Latly [sic] Physition to the Emperour of Russia, and one of ye eight principals or Elects of the Colledge of Physitons in London. LONDON. Printed by Nicholas Okes. 1613.*
TYPES OF COMPASS NEEDLES

Ridley must be one of the earliest English writers to illustrate, explain, and recommend the carrying out of popular scientific experiments. In this connexion he had quite a lot to say about the qualities, textures, and shapes of lodestones for experimentation: 'the adamant stone, and the Osmound stone in our Iron-mongers shops', the lumps of iron ore whose name was derived from 'os mundi, the bone of the world'. Compass-makers and ship-masters, he considered, should have 'a Magnet well capped that taketh up at one end halfe a pound weight at lest . . . ', a 'capped magnet' being a lodestone strapped and capped with iron bands. In succeeding chapters Ridley described and illustrated the weights, wires and compass needles to be used in experimentation, and incidentally he confirmed, what comparison of surviving instruments of the period reveals, that compass needles were 'arrow-like for dyalls and instruments', but for compasses were now of two types, the original double-bowed type of wire, and a new type, broad and flat, but tapering to a point at each end.

In one chapter Ridley deals with the rotation of the earth and with the latest astronomical discoveries 'both by Galileus and Kepler . . . by helpe of the truncke-spectacle', then he goes on to deal with 'the variation of the compass from the true Meridian' and illustrates, with two circumpolar plans of the continental land masses, the theory of land-mass attraction whereby, to quote him again,

The West shore of a magneticall continent doth make the variation of the compass Easterly, and the East-shore of a maine-land beholding the Sunne rising attracteth on the North-side of the aequator, the Lilly of the Compasse that it decline West from the true Meridian . . .

South of the equator, he explained, the needle was attracted in the opposite sense. It will be recalled that two years later Sir Thomas Roe was proving the contrary off the Cape. Ridley's illustration of this theory is interesting on account of the inclusion of Terra Australis in the southern hemisphere.

Ridley included detailed descriptions of all the various ways of finding the variation of the compass. Like Richard Polter, he favoured a single observation, by simultaneous observation of the sun's altitude and azimuth, and then specified the use 'at pleasure and leysure' of 'M. Blaggrave's Mathematicall Jewell' for ascertaining the sun's true azimuth, and thus the compass error or variation. He preferred Blaggrave's astrolabe to Gemma Frisius's because the latter lacked the special rotatable network of lines or rete found in Blaggrave's. By means of this rete the sun's true azimuth could be easily found. For example, if the horizon line on Blaggrave's rete were set to the altitude of the pole and the point on it where the sun's observed altitude or almacantar, and bearing, crossed the sun's declination for the day, the sun's true azimuth was indicated. For observing the sun's azimuth, or bearing, Ridley recommended the use of a compass, fitted with a vertical brass wire at the centre for casting the sun's shadow on a graduated verge ring set to compass north. Other means for finding
the sun's true azimuth which he detailed included the analemma; the equinoctial dial; 'Universall Dyall, having a directory needle in a boxe'—this he called 'finding the variation by the Rings', and was Wright's method; the 'Horizontal Dial' or sun-dial; and 'the doctrine of triangles'.

It was the last ten chapters of the book that were devoted to dip, the 'inclinatory needle', and their use in navigation. They included Briggs's table in Blundeville's Book, The Seven Planets, a similar one of his own calculation, and the description of a quadrant for finding latitude by dip. By these means, he claimed,

the ingenious Pilot knowing the elevation of the pole... by keeping a true, not a dead reckoning of his course in pricking his Carde aright, and observing the way with the logge-line with other currants and occurrants, will give a very artificiall coniecture of the elevation of the pole in that place where he is, though he see neither Sunne nor Starres.

There is nothing new in this except his recommendation of the use of the 'logge-line'. However, his ingenuity was by no means exhausted. He also recommended the use of a chart, marked out for the degrees of dip as well as of latitude, a dip traverse-board of a type designed by him, and illustrated in the text and on the title-page of his work, a 'directory-inclinatory' instrument hung 'pendant before the Mariner at the helme with the Compasse and Traverse boards for them both', and 'a perfect Sea-card for your voyiage, with the lines of the winds, & the lines of the longitude and latitude placed thereon...'. Thus equipped, when he could 'see neither Moone nor Starres' and was at his wits' end, the poor navigator, he claimed, could with confidence, and with the use of his two Magneticall needles only, prick his card both for longitude and latitude. This he was to do by observing by the log-line the way that the ship had made in an hour. This done, he was to prick the way on the chart 'out of the Traverse board for the point of the Compass' sailed on, and prick the latitude according to the observed dip. The meridian passing through the meeting point of these 'two sorts of pricking' would show the longitude of the place. Vain hope and, as we have seen from the journals of those days, vain labour of Dr. Ridley in devising his quadrant, tables, traverse-board and dip scheme!

Perhaps it was Ridley's book which inspired the fifth edition of The newe Attractive and Borough's Variation of the Cumpas, in 1614; it almost certainly prompted Barlow to publish his manuscript of 1609, with addi-

1 Ridley did not include the valuable tables of amplitudes recently prepared for Spanish pilots and used, for instance, by the Nodals on their voyage to the Strait of Le Maire in 1618–19, nor did any English writer of the period. (But see Appendix 30 concerning Hariot's tables). The Nodals also made important tidal observations and calculations off the Patagonian coast. Their journal and valuable navigational observations were published in Spain in 1621, and reproduced in Magellan's Strait. Hak. Soc., Ser. 2, Vol 28.
tions, in 1616.¹ Inevitably he covered much of the ground already traversed by Ridley and, before him, by Gilbert. Indeed this book, which contained the fruits of forty years’ research into magnetism, he frankly admitted contained many excerpts from Gilbert’s work of relevance to navigation. Nevertheless, Barlow could proudly claim,

I was the first that made the inclinatory instrument transparent to be used pendent, with a glass on both sides, and a ring on the top . . . and moreover I hanged him in a compass box, where with two ounces weight he will be fit for use at sea. I first found out and showed the difference between iron and steel, and their tempers for magnetical uses . . . I was also the first that showed the right way of touching needles . . .

And in making these claims he was of course accusing Ridley of making unacknowledged use of his inventions; Ridley, whose impious ‘truncke-spectacle(s)’, he wrote as he thought scathingly, ‘are his means of knowledge’; whose blatant Copernicanism was also anathema to a pious divine. There is no need to probe the contents of Ridley’s commentary on Barlow’s work of 1616, _Magnetical Animadversions Vpon certaine Magnetical Advertisements From Maister William Barlow_, published in 1617; nor of Barlow’s riposte, of 1618, _A Breiefe Discovery of The Idle Animadversions of Marke Ridley_; nor yet of Ridley’s Appendix or an Addition . . . unto his _Magnetical Treatise in answer to M. Barlow of the same year_.² Ridley’s enduring work was his _Short Treatise of 1613_, already discussed; Barlow’s his _Magnetical Advertisements_ of 1616, reprinted unchanged except for the title-page in 1618, despite Ridley’s criticism.

Barlow, like Ridley, treated of the properties, making, capping and cementing of lodestones, and he described Gilbert’s theory that the attraction of land masses was the cause of variation, but his most valuable

¹ MAGNETICALL Advertisement: or _DIVERS PERTINENT_ observations, and approved experiments concerning the nature and properties of the Load-stone: _Very pleasant for knowledge, and most needfull for practise, of travellings, or framing of Instruments fit for travellers both by Sea and Land._

Act. 17.26. _He hath made of one bloud all nations of men for to dwell on the face of the earth, and hath determined the times before appointed, and the bounds of their habitation, that they should secke the Lord, &c._

LONDON, Printed by Edward Griffin for Timothy Barlow, and are to be sold at his shop in Pauls Church-yard at the signe of the Bull-head. 1616.


_A BRIEFE DISCOVERY OF THE IDLE ANIMADVERSIONS OF MARKE RIDLEY_ Doctor in PHISICKE vpon a Treatise entituled, Magnetical Advertisements [rule].

—_mouveat Cornicula risum Furtiuis nudata coloribus_—[rule] [ornament].

LONDON, Printed by Edward Griffin for Timothy Barlow, at the signe of Time in Paules Churchyard. 1618.
contribution lay in the field where he had already won distinction. The common sea-compass, its manufacture, and its maintenance were still his main care and consideration. He recapitulated the most obvious common faults in manufacture—poor iron used for the wires, the finish rough, the fly not mounted symmetrically. Then he went on to describe two fundamental discoveries he had made concerning the directional properties of the compass-needle; one concerned its manufacture, the other its touching. Hitherto needles had been touched, as prescribed by Cortes, by rubbing the ends of the wires to and fro on the lodestone. Barlow discovered that this was a very imperfect way of magnetizing the needle and that a better way was to stroke the needle four or five times with the lodestone from the centre towards each end, using the north end of the lodestone to stroke the north end of the needle and the south for the south. By this method he discovered that the directional power of the needle was quadrupled, even when the paper of the fly intervened during the touching. He also discovered that if a steel needle and not an iron one was used, the compass's directional power was increased tenfold, and he described how to make such needles. The importance of Barlow's two discoveries was considerable. The increased directional power derived from correct touching and the greater retentiveness of steel needles improved the reliability of the well-made common sea-compass enormously. They relieved the prudent navigator like Sir Thomas Roe of the necessity of frequently touching his compass in order to ensure its accuracy and made variation determination much more accurate. Accurate course-steering must also have been facilitated.

Barlow confirmed Ridley's description of the types of compass-needle in general use, indicating that a narrow straight plate was in great demand, though the most popular was still the traditional loop of wire, pinched into an oval with extended ends. He considered that the ideal was a loop of steel, or an arrow of steel, riveted to a brass plate bearing the capital, width being necessary to give support and stability to the fly. He also recommended that the capital should be deep to render the fly less lively, and of brass, to avoid rust, and that the pin should likewise be of brass, or of copper. At the same time he drew attention to the improvements described in The Navigators Supply that he had already introduced into compasses, including open sights for taking bearings. The inference here is that they were not as widely known as they might have been.

Such then were the non-mathematical developments in the art of navigation that affected most navigators in the first twenty years of James's reign, the years in which Englishmen were first successfully settling the North American continent and were laying the foundations of an empire in the east. The mathematical developments made in this period, because they as yet affected few navigators, will be discussed in the following chapter. Of the developments so far reviewed some were made by seamen, some by craftsmen, others by scholars and scientists. Despite corruption in high places, piracy on the high seas, and sharp practice on shore, the
English seamen held their own. Robert Norman pays an appropriate tribute to their labour and endurance in the *Safeguard of Sailers*:

In Commendation of the painfull Sea-men

Whoso in surging Seas, his season will consume,
And means thereof to make his onely trade to live
That man must surely know the shifting Sunne & Moone,
For trying of his Tides, how they doe take and give.

So must he dueley seeke the Eclipticke course of Sunne,
How he from West to East his proper course doth keepe:
His labour then (God knowes) as yct is but begunne,
For he must watch and ward, and shake off sluggish sleepe.

And have a carefull eye, to hand that is at Helme,
For many one there is, that false his course will pyle,
And swelling Seas likewise, the Ship may over whelme,
Or set her on the shore, without the Pylots eye.

When Boreas is abroad, and blustering blasts do blow,
In season must he seeke to short in loftye sayle.
For that, if not in time he very well doth knowe,
That all too late indeede, no labour will prevayle.

But when the raging stormes doe swinge the ship on hye,
Ofte times (against his will) he spoones before the seas:
Else in goes all the sayles, and takes her from her trye,
In haste to drive or hull, till God the same appcase.

Thus when he all the night, with wearies toyle hath tride,
And sees the swelling seas hath set him from his waye:
Then when a little slacke of calme he hath espide,
With joyfull heart to take the height he doth assay.

His Astrolabe then he setteth for the Sunne,
Or Cross-staffe for the starre called Ballastile:
And thus with help of them and declination,
How land doth beare of him, he knowes within a while.

Then by his Compasse straighte he duly sets his course,
And thus he brings the ship in safetie to her Porte,
Where of his hazards past he makes a great discourse,
And each man (by desert) doth give him good reporte.

If Pylots painfull toyle be lifted then alofte,
For using of his Arte according to his kinde:
What fame is due to them that first this Arte outsought,
And first instructions gave to them that were but blinde.¹

¹ Norman, R., *The Safeguard of Sailers*, 1584. The context of the reference to declination, that is variation, in the third verse from the end might imply that the pilot used it for ascertaining his longitude. On the other hand it might mean no more than that he corrected his sights for solar or stellar declination or his course for variation, and so was able to fix his position by a traverse corrected for variation, and an observation for latitude—the normal practice.
Chapter Four

ARITHMETICAL NAVIGATION

'... there is another knowledge of Navigation, which so far excelleth all that is before spoken, or that hath hitherto been vulgarly practised, as the substance his shadow, or the light surpasseth the thick obscured darkness: and this sweet skill of saying may well be called Navigation arithmetical, because it wholly consisteth of calculations, comprehended within the limits of numbers, distinguishing courses not only upon the points of the compass, but upon every degree of the horizon, and giveth the distance of any Travers for the particular elevation of minutes, yea, and less parts assure your self: it giveth longitudes and latitudes to the minute, second, and third: in so great certainty, as that by other means the like cannot be performed, it teacheth the nature of angles and triangles, as well spherical as plain superficial and solid commensurations, the effect of lines strait, circular & paradoxal, the quantities and proportions of parallels, the nature of Horizons, with every particular distinction of any alteration whatsoever, that in Navigation may be required to a most wonderful precise certainty: for there can nothing be required, that by this heavenly harmony of numbers shall not be most copiously manifested to the Seamans admiration & great content...' 

John Davis, The Seaman's Secrets, 1595.

It will be recalled from the opening chapter that that part of the art of navigation which guides a ship through the ocean to a secure landfall can be done scientifically only by finding a ship's position in terms of latitude and of longitude, and that to do this the navigator must use 'arithmetic, geometry, trigonometry, and astronomy'. Now this statement would not have been regarded as true by many Elizabethan and early Jacobean navigators. Most would willingly have conceded that they used astronomy and arithmetic and a little geometry. As for trigonometry, even after 1595 when the word was first coined, most would have confessed that they scarcely knew what it was. Many would have declared that they had as little to do with longitude as possible. They would have said with justice that, as they could neither measure, plot, nor calculate longitude accurately, they saw no point in wasting their time on it. For as Baffin's journal, quoted in the preceding chapter, made clear, most navigators in the first two decades of the seventeenth century still practised plane sailing. That is they observed the ship's latitude at noon, daily if possible, and, after resolving the various traverses since the previous noon, plotted their position on a plane chart, taking as their position the point where their track cut the observed latitude. They made as little deliberate use of mathematics as possible. Nevertheless, since the 1580s a small coterie of English navigators, of whom Davis was the mouthpiece, in an endeavour to obtain greater precision in position-finding on the oceans, had been practising
making greater use of mathematics. They were the apostles of John Dee and Thomas Digges, and were the professional counterparts of men like Wright, Hariot, and Hues. If it is uncertain whether Stephen Borough expounded mathematical navigation, there is no doubt that his brother William did, for it will be recalled that in his *Discours of the Variation of the Cumpas* of 1581 he included examples of the mathematical solution of astronomical problems which seamen normally solved instrumentally on the astrolabe or celestial globe. But the lack of suitable mathematical tables to facilitate calculation, and of charts on which to plot the results accurately largely frustrated the efforts of these pioneers.¹ Then in the 1590s the possibilities latent in mathematics rapidly became practical propositions. Blundeville’s *Exercises* of 1594, with its pocket-size tables and explanatory text of what are now called the trigonometrical functions, and with its outline of Wright’s solution of Mercator’s projection, marked the turning-point. Wright’s *Certayne Errors* of 1599, with its full explanation of and tables for drawing Mercator charts, made the way smooth. In the next two decades Richard Polter brought the virtues of the circumpolar chart to the fore in *The Pathway to Perfect Sayling*, and there were other and fundamental developments. It was in the years from 1594 to 1631 that navigation made some of its greatest advances towards becoming a science. Nevertheless, it was not until 1614 that the ordinary master began to be admitted to a knowledge of the latest secrets of his profession.

This advance was as important and exciting to the Jacobean shipmaster as are the latest calculating machines to scientists, the so-called ‘electronic brains’; for, just as these have telescoped the time taken over complex mathematical calculations and made practical the solution of many that could not otherwise be attempted, so in Jacobean days instruments and tables were being devised that also telescoped time. They affected many men engaged upon practical daily problems of life, like surveyors and ship-masters. They enabled a ship-master, for instance,

¹ Borough, W., *A Discours of the Variation of the Cumpas* (1581).
After giving examples of finding variation by the globe Borough wrote:

> These examples that I have shewed, and suche like experementes to bee done upon the Globe, are easie to be conceived, and the reasons very manifest: but the truth of the matter consisteth in the exactness of the Instruments, and the orderly application and handling of them. In this he summarizes the virtues and the limitations of globes in navigation. He then gave

> How to finde the variation by Arithmetical calculation vpon any one observation in the fornoone or afternoone, the Latitude of the place, and declination of the Sunne beyng giuen,

and continued,

> I might heere have annexed the maner, how upon two observations of the sunnes eluation in the fornoone or afternoone, and difference of the Azimuths, to calculate the premisses more exactly by the table of Sines and doctrine of sphericall triangles: but that it is a very tedious waye . . .
See also Appendices 8B and 30.
faced with the daily problem of the ship's position during the course of a voyage from, say, the Chesapeake to the Channel, or from London to Madeira, to solve it *mathematically*. It was almost unbelievable. A few years before, such calculations which reduced the ship's position into terms of latitude and longitude would have taken a skilled navigator hours to complete. Now, an apprentice, if need be, could make the calculations in as many minutes. Indeed by the time of Captain Smith's death in 1631 English navigators could face with equanimity the thought of solving a problem of interception at sea such as Richard Norwood posed in the *Appendix* to his *Trigonometrie* of 1631, 'Annexed chiefly for the use of Seamen on the application of Trigonometrie in the three principall kindes of sailing'. 'A Merchant man', he wrote, 'being in the latitude of 43 degrees fell into the hands of pirates' which plundered her cargo and stole the ship's compass. While these hell-hounds of the sea rejoiced over their booty the merchantman slipped away and, holding a steady course between south and west (as well as the crew could judge) met after two days, when they had sailed about 190 miles, a man-of-war. The latter, being desirous of capturing the pirates, elicited the above information from the merchantman, and then set off in pursuit. 'What course should the man of war shape to finde these pyrats?' demanded Norwood, if, on the day before she met with the merchantman, she too had been in latitude 43°, but had sailed since 111 miles south-east by south? ¹

Richard Norwood's life is an apt illustration of the enthusiasm with which the Jacobean's welcomed the unfolding of the possibilities of mathematics in navigation. He was born of gentilefolk in 1590 in the Hertfordshire village of Stevenage. When fifteen, his family having apparently fallen on hard times, he was apprenticed to a London fishmonger. The

¹ *TRIGONOMETRIE. OR, THE DOCTRINE OF TRIANGLES*: Divided into two Bookes: The first shewing the mensuration of Right lined TRIANGLES: The second of Sphericall: With the grounds and demonstrations thereof. *Both performed by that late and excellent invention of LOGARTHIMES, after a more easie and compendious manner, than hath beene formerly taught. Whereunto is annexed (chiefly for the use of Seamen), A Treatise of the application thereof in the three principall kindes of sailing. With certaine necessary Tables used in NAVIGATION.*

*By RICHARD NORWOOD, Reader of the Mathematicks in London.*

LONDON, Printed by WILLIAM IONES, 1631.

Norwood put his problem thus:

A Merchant man, being in the latitude of 43 degrees, falls into the hands of pyrats; who amongst other things take away his sea-compasse. But when he is gotten cleare, he sailes away as directly as he can, and after two dayes meetes with a man of war; who also had bin the day before in the latitude of 43 deg: and had sayled thence s e b s 37 leagues: He desirous to finde these pyrats, the merchant man tells him, he left them lying to and fro where they tooke him, and he had sailed since at least 64 leagues, betweene the south and west: what course shall the man of warre shape to finde these pyrats? (Answer: ene, 6 degrees 14' northerly.)

Today the answer would be expressed as 'NE ⁴ E'.
latter's premises were of course much frequented by seamen, and here the eager youth heard them 'discourse of their sea affairs and of the art of navigation'. He promptly resolved to see the world and to master this art which seemed to him 'to reach as it were to heaven', ran away to sea, and got apprenticed to a coaster, in all probability a collier, plying between London and Newcastle. In this harsh school he learnt the rudiments of the art, and then, accident and parental wisdom playing their parts, he learnt the basic principles of mathematics. One day, on a voyage to Newcastle, his ship lost her anchors off Yarmouth and was nearly stranded. Anchors being costly articles, the Master decided to drag for them to recover them. It was whilst the crew was so employed that Richard succumbed to the charm of mathematics. He was now eighteen. In the three weeks that the little vessel lay in Yarmouth Roads he went through Recorde's *Arithmetic*, which his father had given him a little time before, 'in whole numbers and fractions'. So deep was the absorption of the lone student in his self-imposed task (for the crew preferred the flesh-pots ashore in their leisure hours) that, in the dark cabin of the little coaster, he forgot time and hunger. When the lapping of the water along the sides, or the slatting of blocks against the mast when the tide turned roused him from his studies, he would snatch a bite of food—the first that came to hand—see that all was secure aloft and on deck, start the cable slightly to change the point of chafe, check that the anchor buoy was watching and that the helm was securely lashed, then plunge below to take up his book and lose himself again in the sweet mystery of numbers. On such a diet and on such an irregular routine he caught 'a spell of the scurvy' before recovery of the anchors brought his studies to an end. Convinced that he could learn no more of navigation from his master than he himself knew, and being desirous of seeing the world, Richard signed on in the Royal Navy. He served for a while in the *Anne Royal*, formerly Raleigh's *Ark Raleigh* and Howard's *Ark Royal*, his flagship during the Armada fights. Then he quitted, and, after seeking service in the Low Countries, and finding none, for the truce of 1609 had ended hostilities, he found himself in 1610 in Naples, yearning for England. Without more ado he shipped himself home in an English ship lying in the port and, shortly after arrival in England, bound himself for five years to a master-mariner of Limehouse. His ship was the *Resistance*, a vessel that the gifted young shipwright, Phineas Pett, had built in 1604. In her, between October 1610 and March 1612, Richard Norwood made two voyages into the Mediterranean. It was during these two voyages, particularly the first, that the desire to master mathematics and the art of navigation welled up in him again and overflowed into a passion of absorption in the subjects.¹ There sailed with them on the first voyage a passenger with a library of mathematical books, amongst them Digges's *Pantometria*. With this young Norwood was 'extraordinarily affected'. So passionate was his interest in the

book that when they got to sea he spent his time writing out all the principal propositions in it until he had thoroughly grasped them. Indeed, he recalled in later life that, so long as he had that and other of Digges's books, which was for three months, he never lay down in his cabin. By day he stayed on deck studying, and at night, if it was not his watch, he sat by the binnacle, in which the gunner had made a little hole so that the candlelight might fall upon the pages of his book sufficiently brightly for him to see to read, yet not so brightly that the ship should be betrayed to pirates. The sleep that he had during these three months was in the time of his watch on deck 'at some spare times when sleep came upon him'. Yet, he declared, 'I had such inward cheerfulness and encouragement that I think I never had thrived better nor ever been more active, lively, and healthful in mind and body before, so that nothing seemed tedious to me . . .'. On the next voyage Norwood brought his own library with him 'as Lansberger's Doctrine of Triangles, Clavius's Algebra and others, and Euclid's Elements . . .'. In these and the like he continued his studies, though not altogether, he confessed, with such singleness of purpose as before. Nevertheless if the fire in his blood had not made him a master of a ship it had made him a master of navigation. When the Resistance was sold to Captain Henry Mainwaring in July 1612, it was Norwood whom the latter engaged as his master's mate and 'tutor to himself in the art of navigation' for his intended voyage to the East Indies. But the death of Prince Henry in November led to the voyage being cancelled—if the truth be known the East India Company would stomach no interlopers—and Mainwaring had to think of other seas. The fathers of the East India Company were probably wise, for it was now that Mainwaring took himself off to the Barbary Coast to become the scourge of the Mediterranean until King James threatened to bring him to book if he did not return and seek pardon. Mainwaring returned to receive pardon and a knighthood, and later to write his seaman's dictionary. Meanwhile Richard Norwood, who had prudently preferred not to join him on his piratical venture, had found employment elsewhere. In loading the stores and equipment for Mainwaring's voyage some gear, including a gun, had fallen overboard. Norwood was determined to save the valuable articles, and, being of an original turn of mind, contrived a diving-bell out of a weighted cask. In this, with the bottom knocked out and a plank placed across the open end, he had himself lowered to the sea-bed, where he secured lifting tackles to the gear and so recovered it. It was at the time that the Bermudas were being settled. One of their attractions was supposed to be the exploitation of the pearl-beds. Norwood, with his diving skill, news of which had soon spread about, was just the man to assist in this, and of course was at once invited to do so. With his urge to see the world, to be asked to go out to the islands was for him to accept.

Once in the Bermudas Norwood found full scope for his versatility. In 1614 and 1615, for instance, he surveyed the islands. The resultant chart is preserved in the British Museum. When he returned to England
LXXVIII. West Indische Paskaart by William I. Blaeu, c. 1630.
LXXIX. Thomas Hood’s Sector, 1598.
two years later Norwood set up in London as a teacher of mathematics. He followed this profession for twenty years until, falling foul of Archbishop Laud, he sought sanctuary in the Bermudas. Here he established himself as the islands’ schoolmaster and, here, full of years, he died in 1665. In his time he had done more than most men to advance the art of navigation. Besides his *Trigonometrie* and *Appendix* of 1631 he published other books, measured the length of a degree, and corrected the knotting of the log-line. But these are later affairs. It is with his studies and teaching as a young man that we are concerned now, for even if he cannot be called typical—indeed he was obviously exceptional in his attainments—he does reflect the Jacobean enthusiasm for arithmetic and navigation.

Henry Gellibrand, born in 1597 at St. Botolph’s, Aldersgate, and from 1615 a student at Trinity College, Oxford, also exemplifies, though in a different way, the Jacobean interest in mathematics. Norwood was in a literal sense the man of action and the teacher; Gellibrand was the scholar *par excellence*. When he took his B.A. in 1619 he was not much thought of as a student. But one day, to avoid the fine of a groat for non-attendance at a lecture, he heard by accident one of Sir Henry Savile’s mathematical lectures. So persuasively did Sir Henry lecture that Henry Gellibrand was inspired there and then to devote his life to the study of mathematics. So assiduously did he study that before he took his M.A. in 1623 he was acknowledged a master of his subject, and four years later became Professor of Astronomy at Gresham College.

The Jacobean and Caroline almanacs and mathematical text-books frequently carry a page advertising the various mathematical sciences and accomplishments taught by the author, such as geometry, trigonometry, surveying, navigation, and the use of the globes. Norwood was typical of these teachers, and undoubtedly taught many seamen—including his son—the art of navigation. Others, who had a good grasp of mathematics, attended, as we have seen, the Gresham College lectures. Nevertheless, it should be emphasized that even at these they listened to nothing abstruse, or difficult; for it was the lecturers’ task to make plain to plain men both the object and the subject of their discourses on the application of arithmetic, geometry, trigonometry, and astronomy to the art of navigation. We use more or less effortlessly our skill in the five special parts of arithmetic, numeration, addition, subtraction, multiplication, and division, but this is a phenomenon of modern times. As we have previously seen, mental calculation was a rare accomplishment in Stuart and earlier times. The professional men who used mathematics—merchants, physicians, and astronomers, surveyors, builders, sappers, and gunners, shipwrights and navigators—relied upon tables, their fingers, or the abacus for the multiplication of even small whole numbers. The working out of fractions was particularly tedious because, as the decimal system, first made public in 1585 when Stevin published *La Disme*, was only just coming into use, both multiplication and division were involved. Thus it was not until 1608 that an English translation, by Robert Norton, of Stevin’s work.

—A.O.N.
on decimals was published.\(^1\) Although the merits of the decimal system were then rapidly appreciated it was many years before a standard notation was adopted for it.

Besides the five parts of arithmetic there were various ‘rules’ of arithmetic. One had for long been in constant use in the counting-house and in the master’s cabin. This was the Rule of Three, known also because of ‘its excellent use’, Blundeville informs us, as the Golden Rule. By this rule, given three numbers, a fourth in proportion can be found. For instance, if a shipmaster from Dartmouth laded 10 tuns of wine at Bordeaux at the cost of £200, and found, when all was complete, that he had stowage for half as much again, he had to decide whether he could afford to lade the extra cargo. He could do this by using ‘the rule of three direct’. On the bulwark he would chalk out, ‘ten tuns cost two hundred pounds, what will fifteen tuns cost?’ writing it down in the order tuns, pounds, tuns, pounds, as:

\[
\begin{array}{c|c|c|c|c}
\text{Tuns} & 1 & \text{tuns} & 1 \\
\hline
10 & 200 & 15 & ? \\
\end{array}
\]

He found the answer—the unknown cost—by dividing the known cost by the quantity of which he knew the cost, and multiplying by the quantity desired. In other words he divided the second number (£200) by the first number (10 tuns) and multiplied by the third number (15 tuns) to get the answer:

\[
\frac{\text{Known No. of Pounds}}{\text{Known No. of Tuns}} \times \text{A No. of Tuns} = \text{A No. of Pounds}
\]

In this example:

\[
\frac{\£200 \times 15 \text{ Tuns}}{10 \text{ Tuns}} = \frac{\£3,000}{10} = \£300
\]

The only difference was that he did not then write out his computation in so direct a way.

For other problems he would use ‘the rule of three in reverse’. There is no need to go into the question of when one rule was used and when another. To us the importance of these mathematical rules was that by using them the ship-master got used to solving problems involving proportion, and so, when he came to tackle navigational problems, he found the principles underlying their solution easy to understand, since the solution of many involves proportion.

Having mastered arithmetic, the budding navigator next learnt certain useful definitions and problems of geometry. Geometry—literally land measurement—is the science concerned with the mensuration of lines,

\(^1\) DISME: The Art of Tenths, OR, Decimall Arithmetike, Teaching how to performe all computations whatsoever, by whole Numbers without Fractions, by the foure Principles of Common Arithmetike: namely, Addition, Substraction, Multiplication, and Division. Invented by the excellent mathematician, Simon Stevin. Published in English with some additions by Robert Norton, Gent. [device] Imprinted at London by S.S. for Hugh Astley, and are to be sold at his shop at Saint Magnus corner. 1608.
surfaces, and solids, and with their various relations. Nowadays children learn at school the definitions employed in geometry and many of the problems it can be used to solve. The Jacobean ship-master learnt no more. Like a present-day boy he first learnt the definition of simple everyday terms such as ‘a point’, ‘a line’, ‘an angle’, ‘a circle’, ‘a triangle’, ‘parallel straight lines’. From these he progressed to ‘geometrical problems’: how to draw or ‘raise’ a perpendicular from the middle and from the end of a line, how to ‘drop’ a perpendicular from a given point onto a line, how to draw a line parallel to another line, how to bisect a line, how to draw an angle equal to a given angle, how to bisect an angle, how, with three given sides, to make a triangle, and so on, all problems that can be done with a straight edge, a black-lead pencil, and a pair of compasses. By knowing how to do these things the navigator could draw any plane triangle, and, having learnt how to do this, he could learn how to lay down, geometrically, any problem of plane sailing. From this he could progress to the geometrical solution of problems plotted on a Mercator chart—problems of ‘Mercator’s sailing’ it was called. It might be supposed that such simple geometrical knowledge had been common amongst Elizabethan navigators. After all, Davis in The Seamans Secrets had called their methods ‘geometrical’. So in truth they were, but most Elizabethan navigators had practised them, it must be emphasized, without knowing much about geometry. For instance, Blundeville, when he had written his Exercises in 1594 ‘for young gentlemen desirous to have knowledge in the Art of Navigation’, had included a treatise on elementary arithmetic, but none on geometry. Only in his treatise on Plancius’s map is there an explanation of a geometrical problem—‘How to make with your Compasses a perpendicular line to fall from any point given upon another right [straight] line, making therewith right Angles without the helpe of any squire [set square].’ The reason for this omission is not far to seek. Indeed Blundeville provided it—the inaccuracy of the scales on the plane chart. These made nonsense in the higher latitudes of any geometrical plots of any size, such, for instance, as the track of a ship sailing out to America and back, or from the Lizard to the Canaries and back again via the Azores, examples already cited in the previous chapter in a different context. As long as the Elizabethan navigator had known what was meant by his rhumb, and could lay it off with a pair of compasses from the lines of rhumbs, as previously described, could prick off his estimated distance run, and correct his estimated position by pricking off his observed latitude, he knew enough about geometry to fix his position on his chart as accurately as was possible. Actually for short voyages, as has already been made clear, the scales on the plane chart were accurate enough for all practical purposes. Knowing this a clever Elizabethan navigator like John Davis could, if he wished, plot his position on a sheet of plain paper, using geometrical methods, and transfer the result to his chart. It was for such that Barlow had devised his plotting board and protractor in the ’90s. No doubt he had foreseen also the possibilities inherent in Wright’s solution of Mercator’s projec-
tion, for with charts drawn on this projection a ship’s position could be accurately plotted, and as Davis had hinted, even calculated geometrically, no matter how long or intricate the voyage might be. But to do either, a navigator had need of a thorough grasp of geometry and of trigonometry—tri-angle-measurement.

The first English book to contain ‘the first principles of geometrie’ has already been stated to have been Robert Recorde’s *The Pathway to Knowledge*, of 1551. Although fifty years passed before English navigators as a whole began to perceive the practical value of its contents, like Cortes’s *Arte de Navegar* which had appeared in the same year, at Seville, Recorde’s *Pathway* was of fundamental importance in the development of the art of navigation in England. So excellently did Recorde treat his subject that, just as his *Ground of arts* of 1543 became the pattern for later mathematical text-books, so did his *Pathway to Knowledge* become the model for all subsequent geometries. The recognized users of geometry in his day claimed it as ‘a peculiare science for them’. He on the other hand believed that ‘every kinde of men had some benefit’ from it, and broke into verse to explain who they were. Although he did not mention the navigator, he placed him by implication first in order of importance, for he started with the merchant and his ships, and ended with the surveyor—and thus the hydrographer—and his measurings of land.

*Sith Merchautes by shippes great riches do winne,*

*I may with good righte at their seate beginne.*

*The Shippes on the sea with Saile and with Ore,*

*were first founde, and stylly made, by Geometries lore.*

*Their Compas, their Carde, their Pulleis, their Ankers,*

*were founde by the skill of witty Geometers.*

*To sette forth the Capstocke, and eche other part,*

*wold make a great showe of Geometries arte . . .*

and ended:

*Suryayers have cause to make much of me . . .*

... *I . . . measure all truely . . .*

In his wisdom Recorde was prescient, for he also wrote:

*I wyll not onely write of suche pleasant inuentions . . . but also wil teache howe a great number of them were wroughte, that they may be practised in this tyme also. Wherby shallbe plainly perceaued, that many thynges seme impossible to be done, whiche by arte may very well be wroughte . . .*

It was knowledge of geometry that enabled Wright to do what had seemed impossible to be done, to reduce the curved surface of a sphere to a plane one on which courses and distances could be plotted accurately.

The circumference of a circle is customarily divided into 360 equal parts, and each part subtends an angle of one degree at the centre. A radius (*pl. radii*) is a line drawn from the centre to the circumference. The part of
the circumference cut off by two radii is called an arc. The part of a circle cut off by two radii is a sector. The part of the circle cut off by two perpendicular radii, i.e., two radii at right angles or at 90° to each other is called a quadrant; two quadrants make a semi-circle and thus subtend an angle of 180° at the centre. In all plane triangles the sum of the three angles is equal to two right angles, that is, to 180°. So if two angles of a plane triangle are known to be, say, 35° and 65°, the third must be 180° – (35° + 65°) = 80°. If the plane triangle is right-angled, if, in other words it contains an angle of 90°, the other two angles must add up to 90°. So if only one of the angles of a plane right-angled triangle is given, its complement, the amount by which it differs from 90°, can be found. All that has to be done is to subtract the known angle from 90°. Now, if the three angles of a plane triangle are known, the ratio of the three sides—the proportions that they bear one to another—can be found; consequently if the length of only one of the sides is known, the lengths of the other sides can be found. A plane right-angled triangle is a peculiarly convenient sort of triangle to deal with, because from the foregoing it is apparent that if the

---

1 See Fig. 28a.  
2 See Fig. 28b.
size of only one other angle and the length of only one side be known, the size of the other angle and the lengths of the other sides can be found. It was this knowledge that the English began to put to practical use at sea towards the end of the sixteenth century. Barlow's protractor and plotting board of 1597 were amongst the first nautical instruments designed to exploit it—with the aid of compasses, lead, and a straight-edge. As we have seen, the Muscovy Company, in the sixteenth and early seventeenth centuries, mustered amongst its servants some of the ablest navigators in the realm—the Boroughs, Baffin and Hudson, to name only the most outstanding—so we may suppose that the navigators in its employ at the close of Elizabeth's reign were exponents of the latest navigational developments. We may visualize one, bound on a voyage to the Company's factory at Wardhouse in North Russia. As yet he is in the North Sea over between Scotland and Norway. Before daybreak, wrapped in his long sea cloak, he comes upon deck from his box-bunk in the great cabin aft. He glances at the dimly lit compass in the binnacle to check the helmsman's course, then scans the darkling sea for sight of the loom of the land or the thicker darkness that betrays the close proximity of another ship. Satisfied that all is well, that the risks of stranding or collision are remote, and that the course ordered is being steered, he sweeps the heavens with a careful eye for weather portents, and to watch for the dawn. The little vessel, heeling slightly under fore and main topsails and courses and the mizzen, is reaching easily before a crisp south-west breeze. As the morning twilight spreads across the heavens he sees the skylines sharp and firm to the north, and the Pole Star still visible high in the sky. At 60° elevation he has still, he notes, a good chance of taking a stellar sight with a cross-staff. On shooting Polaris, and after correcting the observation by the Rule of the North Star as indicated by his nocturnal, he finds that he is in latitude 60° N and pricks his position off on the parchment plane chart which he has unrolled and pinned on the cabin table.

All the forenoon the ship creams to the north-eastward. At noon, with a clear sky, he observes the sun's meridian passage with his back-staff. Correcting the reading with the sun's semi-diameter and declination he finds his latitude to be 60° 26' N. He reckons that since dawn he has made good a course of N 30° E, but being new to the ship he is not sure that his estimation of her speed and thus of the distance run is reliable. So, (Fig. 28c) taking his plotting board, he draws a meridian upon it, and using an appropriate scale, pricks off on it two points A and B, 26' apart—the observed difference of latitude, 'd. lat'. From these, using the geometrical method explained by Blundeville, he raises two perpendiculars—the parallels of latitude. With the aid of his protractor he lays off the course angle, N 30° E, from point A, and with his straight-edge and lead produces the line AC until it cuts the parallel through B at C. The line AC is his track, the distance he has run since his morning star-sight. Measuring this with his dividers, and transferring it to the scale, he finds the distance sailed to have been 30 miles—ten leagues as he would have expressed
it. By measuring BC he finds his departure (dep.) to be five leagues to the east of his dawn position. Thus from knowing only his difference of latitude and his course the navigator has been able to construct a triangle, a plane right-angled triangle, from which he has been able to determine the distance he has sailed along his track, and the distance, in miles, that he has sailed east—his departure. Had he wished he could also have found the complement of his course. All this his Stuart successor learnt, but learnt more besides. In addition to learning how to find out such things by geometrical construction he learnt how to find them out by calculation, by comparing the sides and angles together. He learnt, in fact, something of 'the Science of Plane Trigonometry' or of 'the Doctrine of Triangles'. He learnt that the sides of like triangles are proportional and that, as a result, if the lengths of three lines be given it is possible to find the length of a fourth proportional line, that is, of a line that contains or is contained by the third line as often as the second line contains or is contained by the first. He learnt, too, how to compare the sides and angles together of triangles so that three measurements being given, either sides, angles or both, a fourth measurement can be found.

Although the sides and angles of a plane triangle are measured in different units, there nevertheless exist certain relations between them. These relations, or ratios, are the trigonometrical functions to which reference has already been made in an earlier chapter. The trigonometrical functions, or ratios, most commonly employed in navigation are sines, cosines and tangents; from these, the remaining functions, cosecant, secant and cotangent are readily derived.

These are defined as follows. Consider the angle A in the triangle ABC which is right-angled at B.\(^1\) AC is the hypotenuse, and AB and BC are defined as the side adjacent to, and the side opposite to, the angle A respectively.

Then the ratio: \(\frac{BC}{AC}\), or \(\frac{\text{opposite side}}{\text{hypotenuse}}\), is the \textit{sine} of the angle A,

and is written sin A;

\(\frac{AB}{AC}\), or \(\frac{\text{adjacent side}}{\text{hypotenuse}}\), is the \textit{cosine} of the angle A,

and is written cos A;

\(\frac{BC}{AB}\), or \(\frac{\text{opposite side}}{\text{adjacent side}}\), is the \textit{tangent} of the angle A,

and is written tan A.

The remaining ratios, cosecant, secant and cotangent are obtained by inverting the above three ratios respectively. Since the angle C is the \textit{complement} of the angle A, i.e. is equal to (90° − A) it will be clear from the diagram that

\[
\sin C = \cos A \\
\cos C = \sin A
\]

\(^1\) See Fig. 28d.
The value of each of the above ratios depends upon the magnitude of the angle, and that alone. Consequently any one of them can be used as a measure of the angle.

The medieval mathematician also spoke of the chord of the angle, a chord being the straight line joining any two points on the circumference of a circle. In this he was following the Greeks who invariably spoke of the chord of an angle, i.e. the length of the chord of a circle subtended by an angle at the centre of the circle. There is clearly an equivalence between the chord of an angle and what we today call the sine of an angle. For in Fig. 28f if the angle AOB be denoted by $2\alpha$, AB is chord $2\alpha$. But AB is also twice BD, which for a circle of unit radius is sin $\alpha$. Hence we may write $\frac{1}{2}$ chord $2\alpha = \sin \alpha$, or chord $2\alpha = 2 \sin \alpha$.

Using a circle, the circumference of which was divided into 360 equal parts, and whose diameter was divided into 120 equal parts, Ptolemy, in the second century A.D., was able to construct a table of chords of all angles from $\frac{1}{2}$ to $180^\circ$ in steps of half a degree. For example, he found that the chord of $60^\circ$ was equal to 60 of the 120 parts into which he had divided his diameter; the chord of $90^\circ$ to be 84.84, and that of $120^\circ$ to be 103.92 of the 120 parts into which the diameter was divided. The student will readily recognize in these the values of $\sin 30^\circ$, $\sin 45^\circ$, $\sin 60^\circ$ respectively. Ptolemy’s table of chords was still in use in the Middle Ages. It had been developed by certain Hindu mathematicians, notably Aryabhata (6th century A.D.) who stated that the ratio of the circumference of a circle to its diameter was equal to 3.1416. This ratio is usually denoted by the Greek letter $\pi$.

It will be observed that the Greeks regarded the trigonometrical functions as lengths, not as ratios, as is done today. Thus the sine of an angle was half the length of the chord subtended by double the angle in a circle of appropriate radius. Today it is customary to regard these functions as ratios, thus $\sin 30^\circ = \frac{1}{2}$, $\cos 30^\circ = \frac{\sqrt{3}}{2}$ or 0.866, $\tan 30^\circ = \frac{1}{\sqrt{3}}$ or 0.5774, and so on for other functions. Tables, or canons, showing the value of these functions for all angles from $0^\circ$ to $90^\circ$ have at various times been constructed; a portion of such a table, correct to 4 figures, is here shown:

<table>
<thead>
<tr>
<th>Angle</th>
<th>Sine</th>
<th>Cosine</th>
<th>Tangent</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>0.000</td>
<td>1.000</td>
<td>0.0000</td>
</tr>
<tr>
<td>10°</td>
<td>0.1736</td>
<td>0.9848</td>
<td>0.1763</td>
</tr>
<tr>
<td>20°</td>
<td>0.3420</td>
<td>0.9397</td>
<td>0.3640</td>
</tr>
<tr>
<td>30°</td>
<td>0.5000</td>
<td>0.8660</td>
<td>0.5774</td>
</tr>
<tr>
<td>40°</td>
<td>0.6428</td>
<td>0.7660</td>
<td>0.8391</td>
</tr>
<tr>
<td>50°</td>
<td>0.7660</td>
<td>0.6428</td>
<td>1.1918</td>
</tr>
<tr>
<td>60°</td>
<td>0.8660</td>
<td>0.5000</td>
<td>1.7321</td>
</tr>
<tr>
<td>70°</td>
<td>0.9848</td>
<td>0.3420</td>
<td>2.7475</td>
</tr>
<tr>
<td>80°</td>
<td>1.0000</td>
<td>0.0000</td>
<td>infinitely large</td>
</tr>
</tbody>
</table>

1 See Fig. 28c.
Simple rules enable us to find the values of the different functions for angles beyond 90°. It should be noted that the sine and cosine never exceed unity. This follows from the definitions.

The values of the sine and the cosine of all angles can be both measured and calculated. For instance if a right-angled triangle be drawn with an angle of 23½° the sine of this angle will be found by measurement to be 0·398 of the length of the hypotenuse; if the angle be 30° the length of the sine will be found to be half the length of the hypotenuse; if the angle be 45° the sine will be found to be seven-tenths (0·707) the length of the hypotenuse.¹

When, in the middle of the fifteenth century Peuerbach, and his pupil Regiomontanus, Professors of Mathematics at Vienna University, prepared the first modern sine tables, they kept the 360° division of the circle used by the Greeks but, in order to avoid awkward fractions, they divided the diameter much more minutely, into 20,000 parts. This of course made 10,000 the unit of measurement of the radius. Their sines were consequently tabulated as so many 10,000th parts of the radius. Regiomontanus adopted the same method for his tables of tangents and secants. Peter Apian first published the sine table in 1533, Georg Joachim Rhaticus (1514–76) first published, in 1551, all six ratios—sines, tangents, and secants and their complements—giving them for arcs at intervals of every 10' between 0° and 90° based on a radius of 10,000,000 units—a stupendous feat of calculation. These tables, being printed in folio-size books, were essentially works for the scholar’s desk and the astronomer’s observatory; they were not suitable for ship-board use. Clavius, a Jesuit, corrected the tables, improved their layout—coining the terms tangent and secant in 1583 to clarify the significance of the ratios listed—and published them in quarto, thus making them generally available on the Continent, for, as Blundeville pointed out, it made them portable. It was Blundeville, it will be recalled, who, by reprinting these tables, together with explanations of their use, in his Exercises of 1594, gave Englishmen the first complete canon of trigonometrical functions printed in England. That this was over forty years after their first publication on the Continent provides clear evidence of the mathematical backwardness of the English until navigational problems in the 1580s and ’90s stimulated their mathematical curiosity.

¹ Tangents and cotangents were listed in the ninth century by Arabian mathematicians in the form of the lengths of two kinds of shadows. One, which medieval and Elizabethan writers called the umbra recta, was the length of the shadow (umbra) cast on a horizontal surface or sun-dial by an upright (rectus) gnomon, the other, which they termed umbra versa, was the length of the shadow cast on a vertical surface or sun-dial by a horizontal or “turned” (versus) gnomon; the length of the shadows being expressed in terms of the length of the gnomon. In the fifteenth century these tables, which seem to have been forgotten for several centuries in Europe were recalculated, and in 1583 Clavius gave the name tangent to the umbra versa. Forty years later Edmund Gunter called the umbra recta the cotangent. Both these names were quickly adopted.
A simple table of sines, tangents, and secants runs as follows:

### TABLE 5

<table>
<thead>
<tr>
<th>Angle</th>
<th>Sine</th>
<th>Tangent</th>
<th>Secant</th>
<th>Angle of Complement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1°</td>
<td>0.017</td>
<td>0.017</td>
<td>1.001</td>
<td>89°</td>
</tr>
<tr>
<td>10°</td>
<td>0.174</td>
<td>0.176</td>
<td>1.015</td>
<td>80°</td>
</tr>
<tr>
<td>20°</td>
<td>0.342</td>
<td>0.364</td>
<td>1.064</td>
<td>70°</td>
</tr>
<tr>
<td>30°</td>
<td>0.500</td>
<td>0.577</td>
<td>1.155</td>
<td>60°</td>
</tr>
<tr>
<td>40°</td>
<td>0.643</td>
<td>0.839</td>
<td>1.305</td>
<td>50°</td>
</tr>
<tr>
<td>50°</td>
<td>0.766</td>
<td>1.192</td>
<td>1.556</td>
<td>40°</td>
</tr>
<tr>
<td>60°</td>
<td>0.866</td>
<td>1.732</td>
<td>2.000</td>
<td>30°</td>
</tr>
<tr>
<td>70°</td>
<td>0.940</td>
<td>2.747</td>
<td>2.924</td>
<td>20°</td>
</tr>
<tr>
<td>80°</td>
<td>0.985</td>
<td>5.671</td>
<td>5.759</td>
<td>10°</td>
</tr>
<tr>
<td>90°</td>
<td>1.000</td>
<td>Infinity</td>
<td>Infinity</td>
<td>0°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Angle</th>
<th>Cosine</th>
<th>Cotangent</th>
<th>Cosecant</th>
<th>Angle of Complement</th>
</tr>
</thead>
</table>

A table of sines was printed by Blundeville as:

### TABLE 6

'The Table of Sines'

<table>
<thead>
<tr>
<th>[Degrees]</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0000</td>
<td>174524</td>
<td>348995</td>
<td>523364</td>
<td>697565</td>
</tr>
<tr>
<td>1</td>
<td>2909</td>
<td>177433</td>
<td>351902</td>
<td>526265</td>
<td>700467</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>[Minutes]</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5818</td>
<td>8727</td>
<td>103250</td>
<td>354809</td>
<td>529170</td>
<td>703369</td>
</tr>
<tr>
<td>1</td>
<td>180341</td>
<td>103250</td>
<td>357716</td>
<td>532075</td>
<td>706270</td>
<td>700467</td>
</tr>
<tr>
<td>2</td>
<td>5818</td>
<td>8727</td>
<td>103250</td>
<td>354809</td>
<td>529170</td>
<td>703369</td>
</tr>
<tr>
<td>3</td>
<td>5818</td>
<td>8727</td>
<td>103250</td>
<td>354809</td>
<td>529170</td>
<td>703369</td>
</tr>
<tr>
<td>4</td>
<td>5818</td>
<td>8727</td>
<td>103250</td>
<td>354809</td>
<td>529170</td>
<td>703369</td>
</tr>
<tr>
<td>5</td>
<td>5818</td>
<td>8727</td>
<td>103250</td>
<td>354809</td>
<td>529170</td>
<td>703369</td>
</tr>
<tr>
<td>6</td>
<td>5818</td>
<td>8727</td>
<td>103250</td>
<td>354809</td>
<td>529170</td>
<td>703369</td>
</tr>
<tr>
<td>7</td>
<td>5818</td>
<td>8727</td>
<td>103250</td>
<td>354809</td>
<td>529170</td>
<td>703369</td>
</tr>
</tbody>
</table>

These tables were printed at one minute (1') intervals for arcs between 0° and 90°. It was Clavius who introduced the practice of printing the complement of the angle at the foot of the column to avoid the necessity of subtracting an angle from 90° whenever its complement was required. Blundeville's tables, it will be seen, were in effect to seven places of decimals; the radius being 10,000,000 units in length the sine of 1° was shown as '174524' which in the decimal system—then only just being developed—is written as 0.0174524, i.e. \( \frac{174524}{10,000,000} \). In 1596 tables of all
the functions calculated by Rhaeticus to a radius of 10,000,000,000 units, the equivalent of ten places of decimals, were published by Otho at Neustadt under the title of Opus Palatinum, and in 1613 Pitiscus published Rhaeticus’s tables of sines to the equivalent of fifteen decimal places, at Frankfurt in his Thesaurus mathematicus. These remain the standard tables of the natural trigonometrical functions. They were a triumph of devoted computation, for their closely printed pages represent a vast labour of common multiplication and division.

We have said that with the aid of trigonometrical tables it is possible to solve a triangle by calculation. For instance, the Stuart successor to our Elizabethan navigator bound for Wardhouse, would have said (see Fig. 28c): If in the triangle ABC, right-angled at B, AB is the observed latitude, the distance sailed will be $AB \times \text{secant of angle CAB}$, i.e., $26 \times \sec 30^\circ = 26 \times 1.547 = 30$ miles. Similarly, he could have calculated his departure to be $26 \times \tan 30^\circ = 26 \times 0.5773502 = 15^\prime$.

John Davis’s praise of ‘Navigation arithmetical’ can now be better appreciated. We have taken simple figures. But the solution of problems involving awkward distances and courses, like 113 miles and $67\frac{1}{2}$, can be worked out just as simply, and, as Davis claimed, far more accurately than can be done geometrically, unless an inconvenience of large scale be used. To Elizabethan navigators there was only one discouragement, it involved a great deal of multiplication and, for many problems, of long division, so that even Borough described it as a verie tedious waie’. However, Blundeville actually included examples of the use of the sine, tangent, and secant tables in the solution of common astronomical problems met by navigators, for example, ‘How to find out the declination of the sunne at any time, his place in the Zodiac being given’, and ‘How to know the right ascension of the Sunne . . .’. The right ascension of a heavenly body, it should be explained is the angle between the meridian of the First Point of Aries and the meridian through the heavenly body, measured eastward along the equator. It resembles terrestrial longitude just as declination resembles terrestrial latitude.¹

Blundeville’s example of finding the sun’s declination on 11 April 1591 gives some idea of the multiplication involved. By multiplying the sine of $30^\circ\ 33^\prime$ by the sine of $23^\circ\ 28^\prime$, or $5082/901$ by $3/982/155$ he

¹ Declination and Right Ascension, although having strong resemblances to terrestrial latitude and terrestrial longitude, should not be considered as their celestial counterparts. Celestial latitude and celestial longitude are quite different, celestial longitude being measured along the ecliptic from the First Point of Aries to the meridian through the pole of the ecliptic and the heavenly body, celestial latitude being measured along this meridian from the ecliptic. Neither is used in navigation.

As the earth is turning continuously inside the celestial sphere the connexion between right ascension and longitude and between declination and latitude is never more than instantaneous. Only once during each period of the earth’s rotation is the Greenwich meridian, for instance, in the same place as the meridian through the First Point of Aries and also directly beneath it.
obtained a product of ‘20/240/890/631/655’. This he divided by ‘10,000,000’ and so obtained an answer of ‘2/024/089’ which the tables showed to be 11° 41’. The division by 10,000,000 was necessary because, in the absence of a generally accepted and widely understood decimal system sines, tangents, and secants were still thought of and tabulated as lengths, not ratios. The sine, tangent, or secant taken out of the tables had therefore always to be compared with the length of the radius. Blundeville explained that the radius of his tables was 10,000,000 units. Blundeville’s example of how to find the sun’s Right Ascension by use of the sine tables provides a very good example of how ‘verie tedious’ was the long division involved. Briefly the calculation necessitated multiplying sine ‘8/611/860’ by the total sine 10/000/000 and dividing the product ‘85/118,600/000/000’ by sine ‘9792818’. Blundeville assured the reader that the quotient was ‘8 794/057’ and that this represented the sine of the complement of the sun’s Right Ascension—61° 34’, the sun’s Right Ascension being therefore 28° 26’. Though less accurate than such calculations, the method of obtaining answers instrumentally on the globe, planisphere or astrolabe had the merits of simplicity and speed, and for many years understandably continued side by side with the methods of arithmetical calculation. Nevertheless, Blundeville’s publication of the trigonometrical functions in the handy quarto form marked a big step forward, for it enabled ordinary men to tackle the solution of ordinary problems, and this they were soon doing.

While Blundeville had laid the emphasis upon the use of the tables in celestial problems, there were other men who were teaching their use in terrestrial ones also. It will be recalled, for instance, that Thomas Hood had translated La Ramée’s The Elementes of Geometrie in 1590 for the especial benefit of the students of his mathematical and navigational lectures. Long must he have pondered upon the practical problems of geometry, for it was in 1598 that he produced a work of real originality already briefly referred to, The making and use of the Geometrical Instrument, called a Sector. Whereby many necessarie Geometrical Conclusions concerning the proportionall description, and division of lines, and figures, the drawing of a plot of ground . . . may be mechanically performed with great expedition.1 It

1 See Pl. LXXIX.

Thomas Bedwell, Trinity College, Cambridge, 1562, B.A. 1566–7 and later ‘Keeper of the Ordnance stores in the Tower’ was a mathematician and military engineer of ability. He was responsible for the military defences of the Medway at the time of the Armada. He invented a ruler or ‘mesolabium architectonicum’ to facilitate carpenters’ calculations. He died in 1595. His nephew, William Bedwell (1561–1632) the father of Arabic studies in England, was also a first-rate mathematician, and in 1612 wrote Trigonican Architectonicum for the use of carpenters, and in 1614 De Numeris Geometricis, explaining the use of the trigonicon or ‘carpenter’s square,’ and the ‘ruler’ or mechanical contrivance for carpenters’ computations devised by his uncle. In 1631 he published Mesolabium Architectonicum, containing a further description of it. He was a friend of Briggs. Hood may also have got the idea of the Sector from these instruments.
was not merely the book but the instrument which he had invented, and the making and use of which he described, that marks Hood out as an ingenious as well as gifted teacher. Just as his shadow-staff of the '80s was the precursor of radically improved instruments for taking celestial observations, so his Sector of the '90s was an outrider of mechanical aids to calculation. It was the ancestor of the slide-rule and of the calculating machine. The fact that a man more renowned than Hood, the great Galileo, also invented a Sector in this same year, 1598, has obscured the originality of Hood's genius, and the importance of his invention. Possibly Hood conceived the idea of the Sector from the gunner's quadrants by now in common use, of which Humphrey Cole was making superb examples, some of which survive to this day.¹

The 'geometrical rule' embodied in Hood's Sector was the one that affirms that 'the sides of like Triangles are proportional' for he embodied this 'ground of all the Doctrine of Triangles' in a three-legged instrument capable of resolving problems involving proportion. As his excellent illustration of his Sector makes clear and as he expressed it, 'A sector is a mathematicall instrument consisting of 2 feet, one moveable an other fixed, making an angle, and of a circumferential limbe . . . ' on whose top were engraved 'equal parts. On the backsides are the several chords of a circle subtending such a portion of the whole circumference as is signified by their numbers'. From this description and what has already been said about lines, triangles, and circles, it should be clear that Hood's Sector enabled proportional lines, triangles, and circles to be easily, rapidly, and mechanically computed. By means of the scales of equal parts and of chords, the sliding index bar, the fixed 'circumferential limbe' and the rotatable 'right foote', the data given could be set on and the data sought be read off. Thus the surveyor had now the instrumental counterpart to the astronomer's astrolabe. Trigonometry, the celestial art, had become a terrestrial science. Indeed Hood's Sector linked the twain together. It could be used for surveying the land and for surveying the heavens—it could easily be adapted for the measurement of angles between terrestrial objects or between celestial bodies—and the solution of astronomical problems as well as those of surveying. As a sun-dial it could measure time.

Although the form of Hood's Sector rendered it of no use to navigators unless they were engaged on survey work on shore, it was not long—a matter of seven or eight years—before it was adapted for use at sea. The first impetus for this development was given by the publication of Edward Wright's Certaine Errors in the following year, 1599, with its table and explanation of meridional parts, with its mathematical explanation of Mercator's projection, and its description of the method of constructing charts on it. With this book and Barlow's earlier description of circumpolar charts in The Navigators Supply, Richard Polter's eulogy of them in his

¹ See the illustrated article on Humphrey Cole's instruments by Gunther, R. T., Arch., Vol. 76.
Pathway to Perfect Sayling, and Blundeville’s trigonometrical tables, enough had been published by the opening years of James I’s reign to render arithmetical navigation a practical proposition to navigators with a flair for figures; for it was now practicable to find positions by calculation and to plot them in terms of latitude and longitude. As yet, however, no teacher had attempted to explain to the ordinary ship-master how he could calculate distance and course, latitude, and longitude, nor how he should use Blundeville’s tables for the solution of terrestrial problems. What was needed was a widely available exposition of arithmetical navigation akin to Robert Hues’s description in his De Globis et eorum usu of 1594 of the use of the terrestrial globe in the solution of navigational problems. The need was soon partly met; nor is it surprising, in view of the fertility of English navigational inventiveness at this time, to find that it was supplied by an Englishman.

Edmund Gunter had been born in Hertfordshire in 1581, educated at Westminster School, and then at Christ Church, Oxford. It is probable that while there he was influenced by Sir Henry Savile’s lectures on mathematics. At least it is certain that he soon showed himself to be a mathematician of the first order with a gift for instrumental invention. At the age of twenty-two he gained the entrée of the mathematical world in England by a manuscript entitled A New Projection of the Sphere. Perhaps John Tapp’s Seamans Kalender of 1602 had come into his hands and he, like William Barlow a generation earlier, had come to believe that, in Tapp’s words, ‘as the Mathematicall Sciences are the grounds of Navigation, so is Navigation the onely meaneas, whereby the excellency of those Arts and Sciences are proved and layde open to the view of the world’. Perhaps he had decided to study the problems of navigation because it really was, to use Tapp’s words, ‘the tryall of Artes’—the test-bench of science. However that may be, about the time he became Master of Arts, in 1606, Gunter circulated another manuscript, in Latin, on the application of mathematics to navigation. He called it, probably, De Sectore, for it centred upon an instrument which he had devised for the instrumental solution of navigational problems, and which he called ‘a Sector’. For reasons best known to himself Gunter did not publish his work for about seventeen years. He did, however, allow many copies to be ‘transcribed and dispersed’. In consequence its contents became known in circles other than strictly mathematical ones. Indeed the fame of his Sector became such that many ‘not understanding the Latine yet were at the charge to buy the Instrument’ which Elias Allen made in brass, and tried to use it—not to pass a pleasant hour in studious practice, but to solve, when they were at sea, the daily problem of the ship’s position. It was not until 1623, when more than sixteen years had elapsed, that Gunter, partly to satisfy the importunity of those ignorant of Latin but eager to improve their navigation, and partly to relieve himself of the trouble of expounding the contents of his manuscript, was content ‘to give way that it come forth in English’. The published work appeared under the title of De Sectore &
Radio, or, as another impression had it, The Sector and Cross-Staff. Properly speaking the published book represents two distinct works, three 'Books of the Sector', each divided into various chapters, and for 'the most part' consisting of the Latin manuscript of 1606 or 1607, and three 'Books of the Cross-Staff', incorporating Gunter's subsequent mathematical inventions and his explanation of later mathematical developments. The originality and fundamental nature of much that was contained in the books of the Sector will become apparent if it is remembered that most of the manuscript was written more than sixteen years before the books were published.

Just as it is reasonable to suppose that Gunter got the inspiration for devising his Sector from Hood's earlier one, so is it possible to see that in demonstrating the mathematical solutions of navigational problems he was following the pattern of Hues's Tractatus de Globis of 1594, and embodied, perhaps unknown to Gunter, in Hariat's unpublished manuscript of the same year or earlier, The Doctrine of Nauticall Triangles Compendious and in Dee's unpublished manuscript The British Complement of Perfect Navigation, compiled in 1575. Nevertheless, Gunter's De Sectore & Radio must rank with Eden's translation of Cortes's Arte de Navegar and Wright's Certaine Errors as one of the three most important English books ever published for the improvement of navigation. Eden's Art of Navigation had introduced to English seamen as a whole the subject for the first time: Wright's work had improved and publicly explained Mercator's projection and had made possible the accurate plotting of a ship's position on a chart: Gunter's manuscript of 1606 or '07 opened up to many what was to all save a few an entirely new field, that of arithmetical navigation. It had been glimpsed by Dee, Borough and Davis, but only as a land that is very far off, it had been brilliantly explored by Hariat but with results kept secret from all save his patrons. Gunter's treatise brought it under foot to the many. Whether it was original in concept or derived from Dee's and Hariat's prior working, Gunter's exposition of finding a ship's position by calculation, since it was eventually published to the world, must be classed as one of the most influential scientific works on navigation. Discounting the later reprints of Cortes, Bourne, and Blundeville, all subsequent navigation manuals bear indelibly the stamp of its genius, for they are primarily treatises upon the solution of navigational problems by geometrical and trigonometrical methods. Gunter's De Sectore was just such a treatise. Its most important features were lucid descriptions of the nature of the trigonometrical functions, sines, chords, tangents, and secants, and their uses, a detailed description of his Sector, including the manner

1 See Pl. LXXX. DE SECTORE & RADIO. The description and vse of the Sector in three books. The description and vse of the Crosse-Staffe in other three books. For such as are studious of Mathematicall practise. LONDON. Printed by WILLIAM IONES and are to be sold by JOHN TOMSON at his house in Hosier-lane. 1623.

2 See Appendix 8.
of laying off the lines engraved upon it and their uses, and trigonometrical
formulae for solving on the Sector the course, distance, and difference of
longitude. The first traverse tables for eliminating tedious calculation in
the solution of certain navigational problems, an admirable treatise on the
resolution of spherical triangles, and clear descriptions of the drawing
of charts to various scales on Mercator’s projection and of the solution of
various problems on them are also included. Solutions found by plotting
and with the aid of the Sector were compared with the erroneous results of
similar workings on a plane chart. There can be little doubt that of Gunter’s
contributions to navigation the most outstanding was the enunciation to a
wide circle of friends and students of navigation of the various navigational
formulae known to Harriot and his circle and first formulated by Dee more
than thirty years before, and the explanation of how they could be used to
solve problems without tedious calculation, by means of the Sector and of	

How had Gunter made the Sector so practical? He had taken Hood’s
Sector and, except for the gnomon, had discarded everything extraneous
to the purposes of calculation. He had retained Hood’s Line of Equal
Parts and, because it was the measure of the Sector’s radius and thus the
basic line on it, had renamed it The Line of Lines. This was now drawn
on one face of each leg, so that each had his fellow, the instrument being
a simple wooden or brass ruler jointed in the middle like a carpenter’s
rule, from one to one and a half inches in width, and from one to two
feet in length. The Line of Lines on each leg was divided into tenths and
hundredths, and extended from the hinge centre almost to the end of
each leg. Thus the Line of Lines was equal to the radius of the Sector in
length and was divided upon the recently introduced decimal system. ‘The
Ground of the Sector’, the principle upon which it was based, was, like
Hood’s, that the sides of similar triangles are proportional. For instance,
if the legs of the Sector were opened to form an angle they also formed a
triangle consisting of The Line of Lines on each leg and the imaginary
chord or base line joining the two ends of the radii or legs. The sides of any
triangles formed by the Line of Lines and a base line parallel to the chord
or base of the Sector were proportional to the sides of this triangle. As
the Lines of Lines were sub-divided according to the decimal system it
followed that any problems of proportion which could be solved by the
Golden Rule, the Rule of Three referred to earlier in the chapter, could be
solved on the Sector quite simply without the labour of calculation, by
measuring linear distances off the Lines of Lines with the aid of the navi-
gator’s oldest plotting instrument, a pair of compasses. For instance, to take
Gunter’s example, to the question: ‘if 40 months give 50 pounds interest,
what will 60 months give?’ the Sector will provide the answer: ‘75 pounds’,
in a matter of seconds. For this problem, as for many others, there are
four methods of finding the answer, two by ‘Parallel Entrance’, and two

1 See Pl. LXXXI and Fig. 29.
I.XXX. Title-page of Edmund Gunter’s The Description and Use of the Sector (1624).
LXXXI. EDMUND GUNTER'S SECTOR OF 1605 OR 1606.
by 'Lateral Entrance'. To find the answer by 'entering by a parallel' one procedure is to open a pair of compasses to '40' on one of the Lines of Lines, then open the legs of the Sector until the compasses, still set to measure '40', span the space between '50' on the two now divergent Lines of Lines. The Sector has now been set for finding the fourth proportional, that is, the number that bears the same ratio to 60 as 50 does to 40. This number is found by now opening the compasses until they measure '60' on one of the Line of Lines and then, still set to span '60', sliding them along the two divergent Lines of Lines until each point falls upon identical divisions or numbers—in this example, '75'.

1 See Figs. 30 and 31.
If it had been decided to find the answer by an 'entrance by a lateral' the two similar known denominations, 40 months and 60 months, would have been measured in the Lines of Lines, the compasses being opened to '50' and the Sector then opened until the compasses' points, still set to span '50', fell upon '40' on each line. Then the parallel distance between the '60' marks on the Lines of Lines, on being spanned by the compasses

![Diagram](image)

AE : DE as AC : BC

and

DE : AE as BC : AC

**Fig. 30**

**THE PRINCIPLE AND USE OF THE SECTOR, PARALLEL ENTRANCE**

(now opened so as to span the distance between the two '60' divisions) would be found to measure '75' on the Lines of Lines.

Besides being used for the solution of such general questions involving proportion, as indicated above, the Line of Lines could be used to increase or diminish a line in a given proportion, to find the ratio of two or more
lines, to divide a line in the same manner as another line is divided, and so on.

In exploitation of the possibilities of the Sector Gunter added other lines of general use: a Line of Superficies and a Line of Solids, to enable areas and solids to be augmented or diminished proportionally, and lines of particular use: Lines of Quadrature, Segments, Inscribed Bodies, Equated Bodies and Metals. With them it was possible to find the sides of regular solids which could be inscribed in a given sphere, to find the proportion between various metals 'in their magnitude and weight', and so on. With these lines we are not concerned; Gunter made it clear that he himself regarded them as of quite subsidiary importance, and that he had added them only to fill up space 'without hindering the sight' of 'those which I
principally intended'. These were the lines designed to facilitate the solution of navigational problems and these, in addition to the Lines of Lines already described, included a Line of Sines and Chords, divided into 90°, a Line of Tangents for as many degrees as the length of the Sector permitted, a Line of Secants, divided into 60° and joined to the Line of Tangents, and 'a Meridian Line, or Line of Rums'. In order to waste no space, Gunter also incorporated a line of inches on one edge of the Sector, and on the other a Line of Tangents to which a gnomon, which folded into one of the legs when not in use, was the radius. Thus the Sector incorporated, for the ordinary navigator's use, something quite new, the trigonometrical functions and meridional parts on a linear scale. Here it must be remarked that once again Hariot had anticipated this development by setting his Canon Nauticus or table of meridional parts 'compendiously' upon the yard of his staff for the benefit of the esoteric circle to whom he taught navigation. This he had done by 1594. Now with supreme insight into the mind of the ordinary navigator of his day, and knowing his distrust of figures and of the intangible, this young man—Gunter was then only twenty-five or six—had reduced the mystery of 'cyphering' to the familiar process of taking off distances from scales, akin to those on the charts, with the oldest and most familiar plotting instrument in use, a pair of compasses.

The Line of Sines, which served also for cosines and chords, was engraved on the other face of the Sector from the Line of Lines. Like the latter the Line of Sines on one leg had its fellow on the other. As it was of the same length as the Line of Lines and graduated unequally in degrees from zero at the centre to 90 at the end, the value of the sine of any given angle up to 90° could be read off, if required, from the Line of Lines, with the aid of compasses. Sine 30°, for instance, came half-way down the sine scale, so that the points of a pair of compasses opened to this extent and transferred to the Line of Lines corresponded with the half-way point, 5, [0.5] on the Line of Lines (which was divided into 10). As the Line of Lines was its basis, advantage could be taken of the fact that the double sine of a half-arc is equal to the chord of the whole arc. For instance, the double sine of 30°, 0.5 or ½, is equal to the chord of 60°, 1.0. Thus if the chord of an angle was wanted it could be got by doubling the sine of the half-arc.

The Line of Tangents, because it was infinite, was on the side of the fully opened Sector. One leg was graduated from 0° at one end to 45°, at the hinge centre, the tangent of 45° being equal to the radius, 1.0; the other leg was graduated from 45° to 64°. The Line of Secants was drawn alongside the tangent scale between 45° and 64°, since secants are always greater than unity, and extended from 0° to 60°. The manner in which the scales of the Lines of Sines, Tangents, and Secants were projected on to the Sector can be followed from the diagrams based upon Gunter's. These diagrams of his, together with two illustrating his definitions of the trigonometrical functions, first placed before the English student a clear, graphic illustra-
tion of the nature of the functions, and of the meaning of the trigonometrical tables.¹

Before proceeding to describe the resolution of plane and spherical triangles Gunter introduced what at first sight appears to be a diversion in the form of a treatise upon four methods of projecting the celestial sphere *in plano* with the aid of the Sector. However, the examples which Gunter gave of the use of the various projections in finding the times of sunrise and sunset, the duration of twilight, and the azimuth of the sun go far to explain why the navigator who lacked a celestial globe or planispheric astrolabe needed such knowledge. In the continued absence of a universal nautical almanac which tabulated such information he could obtain it only graphically if it was beyond his powers to calculate it.

In order to simplify the finding of the time at night Gunter also included the description of a nocturnal which made use of all the constellations near the North Pole, and not merely those of Ursa Major and Ursa Minor. The base consisted of a disc divided equally into the twenty-four hours, though only the hours between 4 p.m. and 8 a.m. were marked; to it was fixed a smaller rotatable rundle for such stars as are near the North Pole, together with the twelve months, and the days of the twelve months fitted to the right ascension of the stars. By this arrangement the index pointer of the ordinary nocturnal was dispensed with and all that seamen had to do was to look up at the Pole, see what stars were near the meridian, ‘place the Rundle to the like situation’, and then look at the day of the month to find opposite it ‘the hour of the Night’. Such a nocturnal was easily made on a card but, because of the difficulty of engraving the constellations, was not easy to make in wood or brass. Moreover, it was necessary to have a light in order to set it and read it. It never ousted the older type which could be set and read by touch.

Having dealt with what may be termed the graphical methods of finding astronomical data Gunter now proceeded to explain how they could be found by calculation, but without the labour of computation, by the aid of his Sector. ‘In all triangles’, he explained, ‘there being six parts, viz., three Angles and three sides, any three of them being given, the rest may be found by the Sector.’ He then took the example of a right-angled triangle, which he broke down into four triangles—he included a line diagram—tabulating the lengths of all the sides and the sizes of all the angles so that the student could verify his results, and he explained how, given certain data, the rest, the various unknown sides and angles, could be found. From this he advanced to the resolution of spherical triangles, taking for his subject a triangle on the celestial sphere formed by an arc of the ecliptic and arcs of the sun’s declination and right ascension. In order to explain

¹ It is a simple matter to make a Sector. Take a jointed carpenter’s rule and paste strips of paper over it, draw the various lines upon them. A line on each leg, divided into tenths and hundredths, becomes the Line of Lines. From tables of sines, tangents, secants, and meridional parts the other lines can be pricked off using the Scale of Lines as the basic scale.
its solution he formulated the ‘sixteen Cases . . . that can fall out in a Rectangle Triangle’, and gave examples of their practical application—for instance, the finding of the time of sunrise and sunset and the length of day. He then proceeded to the description of the remaining twelve ‘Cases that can fall out in any Spherical Triangle’, and their practical application—the finding of the sun’s amplitude, of the time of day and such like astronomical data. He ended with words that ring as true today as they did three and a half centuries ago: ‘if any do not presently understand them, let them once more read over the use of the Globes, and they shall soon become easie unto them’.

Had Gunter done nothing else he would be notable for this alone, that he was the first mathematician to state for seamen the ‘28 Cases . . . that can fall out in any Spherical Triangles’ and their application to celestial navigation. But he did more for, by describing also how to avoid, by the use of the Sector, the tedious mathematical calculations involved in the solution of plane and spherical triangles in the period before logarithms were invented, he first made arithmetical navigation a practical proposition at sea.

Gunter’s genius was far from exhausted by these achievements. Indeed they did but pave the way towards the realization of his main objective, the general adoption of charts on Mercator’s projection and the application of the principles of plane trigonometry to problems of position-finding at sea. Just as he had prefaced the uses of spherical trigonometry in the solution of problems of celestial navigation with the description of their graphical solution on plane projections of the sphere, so Gunter prefaced his explanation of position-finding by mathematical methods with a description of the graphical method of plotting positions on a chart—Mercator’s as perfected by Wright. It was to facilitate this that Gunter had included the meridian line on the Sector, for it enabled a sea-chart to be divided by use of the Sector ‘according to Mercator’s Projection’.

True to his aim of facilitating the use of arithmetical navigation, Gunter also included in his treatise a Table of Meridional Parts on the basis of each degree in the equator being sub-divided into 1000 parts ‘By which Table’, he explained, ‘and the usual Table of Sines, Tangents, and Secants the Propositions’ might ‘be also resolved Arithmetically.’ However, this particular theme he pursued no further, the processes were too tedious for seamen.

Gunter’s preference for the decimal system, based on its simplification of calculation, is made apparent in his choice of sub-division of the degrees on the equator in order to obtain meridional parts.

Wright had made the traditional division of a degree into minutes the basis of his table of meridional parts of 1599, making a meridional part one-six-hundredth part of a degree on the equator. A part of a page of Wright’s work is as shown in Table 8 on page 367.
### TABLE 7

**Gunter's Table for the Division of the Meridian Line**

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</tbody>
</table>

**A Table for the true dividing of the Meridians in the Sea Chart**

*(Certaine Errors, 1599),

### TABLE 8

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<td>0</td>
<td>39682</td>
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</table>

See also Pl. LIX.
The first column of this table, Wright explained, contains degrees and
tens of minutes 'of the Meridian of the Nauticall planisphere, beginning
at the Aequinoctiall', the second column shows 'equal parts of the same

Meridional Parts
Wright's Gunter's

Meridian' also numbered from the equator, each part being equal to one-
tenth of one minute (1/600th part of a degree) on the equator, 'and sheweth how many of these parts are answerable to any degree or decade
of minutes of latitude, in the nauticall Planisphere, or Sea Chart'. Thus

POSITION ON A PLANE AND MERCATOR'S CHART COMPARED AND CONTRASTED,
AND GUNTER'S METHOD OF DRAWING A MERCATOR'S CHART
(After Gunter, De Sectore & Radio, 1623.)
Position on Mercator's Chart (M)
Position on Plane Chart (P)
in Wright's table 50 degrees of latitude from the equator are shown as containing 34746 meridional parts, and in Gunter's they are shown as containing 57°909. Both are correct, Wright's 34746 six-hundredth parts of a degree on the equator being equal to 57°54'6 (57°91) on the equator, and Gunter's 57°909 on the equator being the same as 57°54'5 on the equator. Custom overruled logic. Gunter's decimal system of navigation, despite its greater convenience, was never widely adopted, and quickly fell into disuse. Nevertheless, the method of drawing a Mercator's chart with the aid of Gunter's table of meridional parts merits description, particularly as in principle it differed not at all from the manner of drawing a chart using Wright's or other tables of meridional parts.

After the equator had been drawn on the intended chart and had been divided and crossed equally with parallel meridians, as in the common sea-chart, the distance between the equator and the parallels of latitude, in terms of degrees on the equator, was found by reference to the table of meridional parts. For instance the distance on a meridian between latitude 12° and the equator would be found to be 12°088 measured along the equator; between the equator and latitude 40° to be 43°711 measured along the equator; and between the equator and latitude 60° to be 75°451 measured along the equator. Gunter accompanied his explanation with a diagram of a chart covering an area measuring 60 degrees in longitude and 70 degrees in latitude.¹

¹ See Fig. 32. (a) The making of this Table [of Meridional Parts] is [explained Gunter] by addition of Secants. For the Parallel of Latitudes being less than the Equator or Meridian in such proportion as the Radius is to the Secant of the Parallel. For example, the Parallel of 60 degrees of Latitude is less than the Equator (and consequently, each degree of this Parallel of 60 degrees less than a degree of the Equator, or Meridian) in such proportion as 100000 the Radius, hath unto 200000 the Secant of 60 degrees.

Edward Wright, in Certaine Errors, 1599, gave the proof of the all-important statement that 'at everie point of latitude in this planisphere, a part of the meridian, keepeth the same proportion to the like part of the paralell; that the like parts of the meridian, and paralell have each to other in the globe, without explicable error' as follows:

Nowe because like partes of wholes keepe the same proportion that their wholes haue, therefore the like partes of any paralell, and meridian of the globe have the same proportion that the same paralell and meridian have.

For example sake, as the meridian is double to the paralell of 60. degrees, so a degree of the meridian is double to a degree of that paralell, or a minute to a minute &c. and what proportion the paralell hath to the meridian, the same proportion have their diameters and semi-diameters each to other . . .

But the sine of the complement of the paralells latitude, or distance from the equinoctiall, is the semidiameter of the paralell . . .

As here you see, a e the Sine of a h the complement of af the latitude or distance of the paralell a b c d, from the Equinoctiall, is the semidiameter of the same paralell a b c d.

And as the semidiameter of the Meridian (or the whole sine) is to the semidiameter of the paralell, so is the Secans, or Hypotenesa of the paralells latitude (or of the paralells distance from the aequinoctiall) to the semi-diameter of the
Gunter then proceeded to the description of the drawing of 'a particular Chart'. This covered the area between longitude 38° and 44° and latitude 50° and 55° which he pricked off on his general chart and then depicted on a larger scale on a separate diagram, reproduced here with explanatory additions.\(^1\) The method he used was to draw a meridian AB and, at a con-

meridian, or to the whole sine; as \(f\ k\) (that is) \(a\ k\), to \(a\ c\) [\(a\ e\)] (that is) \(g\ k\); so is \(j\ k\), to \(k\ f\).

Therefor in this nauticall planisphaere, the semidiameter of each parallel being aeuquall to the semidiameter of the aequinoctiall (that is) to the whole sine; the parts of the meridian at every point of latitude must needs increase with the same proportion wherewith the Secantes or hypotenuses of the arke, intercepted betweene those pointes of latitude and the aequinoctiall do increase.

Now then wee have an easie way layde open for the making of a table (by help of the Canon of triangles) whereby the meridians of the Mariners Chart may most easily and truely be divided into parts, in due proportion from the aequinoctiall towards either pole. [fos. C. iv. r & v.—D.1].

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**Fig. 33**

**WRIGHT’S PROOF OF THE MERCATOR’S CHART**

(b) To divide a chart with the Sector the procedure was take a pair of compasses and measure on the equator the angular distance to be converted into meridional parts. Let us suppose it to be 60°; with compasses still at this setting place one point of the compasses on the 60th division on one of the scale of lines (on the Sector); open the Sector until the other point falls on 60 on the other scale of lines. The Sector is now set for dividing the meridians into meridional parts proportional to the size of the degrees on the equator. This is done as follows. On the meridian line on the Sector measure off 20°. Lay it along each of the Lines of Lines noting where it falls there (20·5), measure the distance between these two points, (23·5), and prick it off on the meridian from the equator and mark it 20°; measure off 40° on the meridian line, lay this distance off along each of the Lines of Lines, measure the ‘parallel’ distance between them, prick this off on the meridian from the equator (43·7) and label it 40°, and so on.

\(^1\) See Fig. 32 and Table 7.
venient distance apart, two parallels of latitude, BC and AD, then to look in the table of meridional parts and find the meridional difference (d.m.p., or difference of meridional parts) between the two latitudes, thus:

<table>
<thead>
<tr>
<th>Latitude</th>
<th>Mer. Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>55°</td>
<td>66°.134</td>
</tr>
<tr>
<td>50°</td>
<td>57°.909</td>
</tr>
</tbody>
</table>

\[ \text{d. lat.} 5° \quad \text{d.m.p.} 8°.225 \]

Then, taking the length of the meridian line AB as determining the scale of the chart, that is to say, that AB was to measure 8.225 degrees in meridional parts, the equivalent of 5 degrees of latitude between latitude 50° and 55°, he divided each of the parallels into equal degrees, each divided into tenths, in such proportion that 8°.225 of longitude on the parallels equalled the length AB (5° of latitude). This was easily done with the Sector. It consisted in diminishing the line AB in the ratio 8.225 to 1000. To effect this the distance AB was measured off with compasses and the Sector opened until the compasses' points fell on 8.225 on each Line of Lines. Then the space between the 1, 2, 3, 4, 5, and 6 divisions on the two now divergent Lines of Lines, representing degrees of longitude on the equator, were successively measured off with the compasses and pricked off on the two parallels from the points A and B. The meridian lines were then drawn in through these points and numbered from 1 to 6 (Gunter drew in only 6 meridians; had he drawn in 8°.225 of longitude the width of the chart would have equalled the depth, AB). The degrees of longitude on the upper and lower parallels were then divided into tenths and the intervening parallels of latitude were then pricked off on the outer meridians, the difference of meridional parts separating them being found from the table, and taken off from the meridional part scales on either the upper or lower parallels that had just been drawn in. The intermediate parallels were then drawn in and the degrees of latitude were sub-divided into tenths. The result was an elongated chart. That is to say, where the plane chart would have shown 5 degrees of longitude as covering the same distance as 5 degrees of latitude, thus forming a square, Gunter’s showed the difference of latitude between, for instance, latitude 50° 0' and latitude 53° 10', as equal to 5 degrees of longitude, and if it had covered a larger area it would have shown 8°.225 degrees of longitude as equal to the difference of latitude between latitude 50° and latitude 55°.

The chart was completed by drawing six rhumbs from A to the top and right-hand edges. These, Gunter recommended, should be drawn with 'a Protractor', which he illustrated, 'such as is commonly used by Surveyors of Land', modified for nautical use. In addition to the degree scale on the surveyor’s semi-circular protractor Gunter, for the benefit of seamen, drew on an inner semi-circle the corresponding sixteen rhumbs and sixty-four quarter points. He added a rectangle to the base line, the
two sides and bottom edge of which he divided into equal parts, 'according to those on the Line of Lines on the Sector, or the Parallels upon this chart', so that they contained in effect a scale of meridional parts. The space between the base line (which he marked with a cosine scale) and the semi-circle he cut away and, on the back of the rectangle, he drew '6 lines of chords, or scales of several parts in the Inch'.

'So may the Meridian be divided by the [equal] parts . . .'. he explained, adding, 'the Angles of each rumb may readily be pricked down by the degrees in the semi-circle, and the Line of Chords and the other scales may serve to do the like with more variety.' It was the earliest version of what, when it had shed the protractor and become more elongated in length, became known as 'Gunter's Scale'. The protractor, as designed by him, it is to be remarked, was the logical development of Blundeville's 'fly', graduated with rhumbs of the winds, and Barlow's 'quadrant' with its peripheral scale of degrees. Indeed each quadrant of Gunter's protractor was divided into 90 degrees, starting with 0 degrees at the base; and the eighth rhumb, which of course coincided with 90°, was marked as in Blundeville's 'fly' with a +.

It was now that Gunter made what must ever count, in view of its later publication, as one of the great contributions to navigation; he explained and codified the trigonometrical relationships between the course and distance sailed by a ship and the resulting difference of latitude, departure, and difference of longitude. To what extent this work of Gunter was original and to what extent it was inspired by the researches of English mathematicians who had worked on the subject over the previous fifty years it is now hard to determine. Their surviving manuscripts are fragmentary and allusions in printed works to their contents are generally obscure. Recent researches upon scattered manuscripts by Dee and Hariot whose contents appear to have remained unexamined critically for close on four centuries show that, as early as 1575, Dr. Dee had compiled a manuscript which contained amongst other matters the trigonometrical solution of the nautical triangle. This manuscript, _The British Complement of Perfect Navigation_, evidently embodied the results of Dr. Dee's twenty-five years' research into the problems of navigation connected with northern exploration and trading which had proved too abstruse for Frobisher and Hall to apply successfully on their voyage of 1575 in search of the North-West Passage. It taught, for instance, it can be inferred, the solution of the nautical triangle by trigonometrical means for both great circle and paradoxic navigation, and the use of the circumpolar chart, of the complementary compass fly graduated in degrees instead of into rhumbs of the winds, and of the departure table for calculating and plotting position on such charts, known as _Canon Gubernaticus: An Arithmetical Resolution of the Paradoxicall Compass_.1 In the absence of suitable tables and of rapid processes of calculation, Dr. Dee's manuscript proved too advanced for the times to

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1 See Appendix 8B.
find a publisher and is now lost, though a manuscript, *Canon Gubernaticus*, of about 1556, does survive. Presumably Davis was cognisant of the contents of Dr. Dee's manual.

Another research worker on the same subject, but primarily in connexion with the colonizing ventures in the New World, was Thomas Hariot, a friend of Dr. Dee's. Working as mathematical adviser to Raleigh and his sea captains Hariot also elucidated, between 1583 and 1594, the solution of the nautical triangle by trigonometrical methods. Again, lack of appropriate tables and mathematical processes almost nullified the practical value of these researches. However, independently of Edward Wright, Hariot too solved the problem of Mercator's projection, and compiled tables of meridional parts, and drew a chart or charts with their use; he also devised improved astronomical instruments and tables for finding variation by observing the sun's amplitude. Although, through the publicity that Hakluyt gave it in his dedication of *De Orbo novo Petri Martyris . . . Decades octo* of 1587, the fact was well known that Hariot was employed by Raleigh 'to link theory with practice, not without almost incredible results', the practical details of Hariot's navigational researches were confined to the coterie of sea captains associated with Raleigh's colonizing ventures (even Davis, for instance, who had been associated with Raleigh through his sponsorship of Davis's voyages to the North-West, gives no hint in *The Seamans Secrets* that he knew of Hariot's 'Mercator' chart). Hariot's manuscript navigational manual of 1584, which he called *Arcticon* and wrote for Raleigh's and his sea captains' instruction, is now lost, but his manuscript, *The Doctrine of Nauticall Triangles Compendious*, completed in the latter part of 1594 and treating chiefly of the calculation of meridional parts, survives, as does the manuscript summary of his *Arcticon* prepared in 1595 to refresh the navigational knowledge of Raleigh and his sea-captains for the Guiana expedition.¹ It will be recalled that Hues in his *Tractatus de Globis* of 1594 had included a treatise entitled (in the first English translation) *Of the Rombes that are described in the Terrestrial Globe, and their use*, in which he had formulated six propositions for solving on the globe the several navigational problems involved in sailing between places which differ from one another both in longitude and latitude.² He had explained how, knowing two of the four differences involved—the difference of longitude, and of latitude, and the distance, and the course—the rest could be found instrumentally on the globe. Gunter took these same propositions and made of them twelve, for where Hues described the finding of two differences at one time Gunter described the finding of only one. Hues had introduced his propositions with a discussion on the manner of measuring the distance between places. He pointed out that unlike geographers, who measured the distance along the great circle, mariners, because they generally steered rhumb line courses, measured it along the longer, and spiral, rhumb lines. Next he explained,

¹ See Appendix 30. ² See Table 2 on page 195.
what indeed was well known, that places could differ in position either in longitude onely, or in latitude only, or in both'. Gunter adopted the same approach. For succinctness it is hard to beat his description of the navigator's problem of determining distance.

In sailing by the Compass, the Course [wrote Gunter], holds some time upon a Great Circle, sometime upon a Parallel to the Equator, but most commonly upon crooked Lines, winding towards one of the Poles, which Lines are well known by the Name of *Rumbs*.

If the Course hold upon a Great Circle, it is either North or South under some Meridian, or East or West under the Equator. And in these cases, every Degree requires an allowance of twenty Leagues, every twenty Leagues will make a Degree difference in sailing: so that there needs no further Precept than the Rule of Proportion . . .

Hues had been rather more explicit, explaining that, as a degree on the equator and on the meridian was sixty miles in length, the distance, measured in miles, sailed along a meridian, divided by sixty, gave the difference of latitude in degrees; conversely, that the difference of latitude in degrees multiplied by sixty, gave the distance in miles; and that the distance sailed along the equator, divided by sixty, gave the difference of longitude in degrees. It was when the navigator was not on the equator, but had to sail east or west along a parallel of latitude, that mathematics began to become less simple. This was because, like the equator, which is 21,600 miles in length, each parallel of latitude is divided into 360° yet each decreases in length 'proportionally till you come to the Pole'. The result, said Hues, is 'that there can be no one certaine determinate measure assigned to all the Parallels'. Indeed there are as many lengths as there are parallels. Provided the 'proportional change' of length is known these lengths can be calculated. Hues did not state the proportion but, like the authors of previous navigation manuals he contented himself with giving a table 'for those not so well acquainted with the Mathematiques', showing 'what portion a degree in every Parallel beareth to a degree in the Aequator'—Bourne, it will be recalled, had included a diagram for turning departure into difference of longitude. A part of Hues's table is given in Table 9 on page 375.

In other words this table gave the length of a degree of longitude in miles (minutes) and sixtieths of a mile (seconds) along the parallels measured at 1° intervals from the equator. Its purpose was to enable the navigator to determine his change of longitude when his ship's course lay east or west along a known parallel. For instance, suppose a ship, said Hues, to have sailed 600 miles west from Cape Geer, near Agadir, in latitude 30° 38' N (he called it Cape Dalguer) what was its difference of longitude? It was, he explained, 11° 1° 8' West because, in latitude 30°, as the table shows, one degree of longitude equals only 51' 57'' or 'suppose 52 full miles, because the difference is so small'. As 52 divides into 600 just 11° 1° 8' times this is the measure of the difference of longitude in degrees in this latitude.
TABLE 9

<table>
<thead>
<tr>
<th>Lat</th>
<th>M.</th>
<th>S.</th>
<th>Lat</th>
<th>M.</th>
<th>S.</th>
<th>Lat</th>
<th>M.</th>
<th>S.</th>
<th>Lat</th>
<th>M.</th>
<th>S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>[']</td>
<td>[']</td>
<td>[&quot;]</td>
<td>[']</td>
<td>[']</td>
<td>[']</td>
<td>[']</td>
<td>[']</td>
<td>[']</td>
<td>[']</td>
<td>[']</td>
<td>[']</td>
</tr>
<tr>
<td>1</td>
<td>59</td>
<td>59</td>
<td>27</td>
<td>53</td>
<td>27</td>
<td>50</td>
<td>38</td>
<td>34</td>
<td>71</td>
<td>19</td>
<td>31</td>
</tr>
<tr>
<td>2</td>
<td>59</td>
<td>57</td>
<td>28</td>
<td>52</td>
<td>58</td>
<td>51</td>
<td>37</td>
<td>46</td>
<td>72</td>
<td>18</td>
<td>31</td>
</tr>
<tr>
<td>3</td>
<td>59</td>
<td>55</td>
<td>29</td>
<td>52</td>
<td>28</td>
<td>52</td>
<td>36</td>
<td>56</td>
<td>73</td>
<td>17</td>
<td>31</td>
</tr>
<tr>
<td>4</td>
<td>59</td>
<td>51</td>
<td>30</td>
<td>51</td>
<td>57</td>
<td>53</td>
<td>36</td>
<td>6</td>
<td>74</td>
<td>16</td>
<td>31</td>
</tr>
</tbody>
</table>

[Length of a degree of Longitude in this latitude]

[Latitude in degrees] ↓

*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

10  | 59 | 5 | 36 | 48 | 32 | 60 | 29 | 59 | 81  | 9  | 18 |
11  | 58 | 53| 37 | 47 | 53 | 61 | 29 | 5  | 82  | 8  | 16 |

*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

Note. ['] = Degrees; M. = Minutes or Sea Miles [']; S. = Seconds ["].

Gunter too, gave a table showing the length of a degree of longitude in various latitudes but he, knowing the seaman's continued preference for working in leagues, gave it in the form of the parallels in which the length of a degree of longitude became progressively one league smaller as the pole is approached, thus:

TABLE 10

<table>
<thead>
<tr>
<th>Gr.</th>
<th>[']</th>
<th>Leag.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>18</td>
<td>12</td>
<td>19</td>
</tr>
<tr>
<td>25</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>31</td>
<td>48</td>
<td>17</td>
</tr>
</tbody>
</table>

[Length of a degree of longitude in leagues in this latitude] ↓

[Latitude in degrees and minutes] ↓

*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

36  | 52  | 16   |
41  | 25  | 15   |

*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

60  | 0   | 10   |
75  | 31  | 5    |

*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

| 87 | 8 | 1 |

Note. Gr. = Degrees; ['] = Minutes or Sea Miles; Leag. = Leagues.

It was Wright in Certaine Errors of 1599 who had first explained in print the mathematical relationship between departure and difference of longitude in different latitudes. He pointed out that 'it is manifest that the sine
of the complement [cosine] of the distance of any parallel from the Equinoctiall [latitude] is the semidiameter [radius] of the same parallel', and that, as 'semidiameters [radii], and like arks of circles have the same proportion', departure—the distance sailed along a parallel—is equal to the difference of longitude multiplied by the cosine of the angle of latitude. Today this formula is expressed in the form \( \text{dep.} = d. \text{long.} \cos (\text{lat}) \). In the particular case under consideration—the table of the length of a degree in different latitudes—this can be interpreted as signifying 'the length of a degree of longitude on a parallel of latitude is equal to the length of a degree of longitude on the equator multiplied by the cosine of the latitude' (see page 369, note 1(a)).

Gunter, like Hues, having dealt with the problems of distance along the meridians and distance along a parallel of latitude, turned to the problem of distance along a rhumb line. It is interesting to compare their introductions to the subject:

**Hues**

It remaineth now to speak of those places that differ both in Longitude and Latitude; wherein there is great variety and many kinds of differences. Of all which there are foure . . . especially to be considered; and these are the differences of longitude, and of latitude, and the distance, and Rumbe by which the voyage is performed. Two of which being knowne, the rest may easily be found out. Now the transmutation of the things to be granted for knowne, and to be enquired after in these four tearmes, may be proposed sixe manner of wayes . . . Now besides these things here already to be knowne, it is also necessary that we know the latitude of the place whence we set forth, and the quarter of the world to which our course is directed unto . . .

**Gunter**

. . . if the Course hold upon any of the Rumbs, between a Parallel of the Equator and the Meridian, we are to consider (besides the quarter of the World to which we tend, which must be always known),

1. The difference of longitude, at least in general.
2. The difference of Latitude, and that in particular.
3. The Rumb whereon the Course holds.
4. The distance upon the Rumb, which is the distance which we are here to consider, and is always somewhat greater than the like distance upon a greater Circle . . . This considered . . . and shew more particularly in twelve Propositions following, how of these four any two being given, the other two may be found, both by Mercator's Chart, and by this Sector . . .

Before discussing their several propositions further both authors dealt with the practical aspects of measuring off courses and distances, Hues on the globe, Gunter on the Mercator's chart. Hues explained how by means of the rhumb lines on the globe, the course between places in different latitudes and longitudes could be found—he chose Sierra Leone and St. Helena (S.S.E. rhumb), and Cape Contin and the Canary Is. (S.S.W.
De Zeeerusten van Laplande tusschen 't Cruys Cylande- en Warfaja en van Rusläd tot verby de Riviere van Archangel.

LXXXII. Chart Title, Scale of Distances and Ornament to a Chart in Blaeu's The Sea Mirrour (1625).
MEASURING RHUMB LINE DISTANCE

rhumb). He then pointed out that to measure distances accurately on the rhumb lines on the globe was no easy matter because, although near the equator they differ but little from great circles, as they get more remote from it; 'they are still more crooked and inclining' to the 'Meridian' from which they originated. Nuñez had advised measuring the distance on any rhumb, said Hues, 'by taking with your Compasses the space of 10 leagues, or halfe a degree. Others', he added, 'take 20 leagues, or a whole degree.' His own advice was that 'neare the Aequator . . . you may take a greater measure to go by and when far from it as small a distance as you can'. His personal preference, however, was for a table by means of which the distance, or rhumb, or even difference of latitude could be found by calculation:

<table>
<thead>
<tr>
<th>Rhumbs</th>
<th>Degr. [°]</th>
<th>Min. [']</th>
<th>Sec. [&quot;]</th>
</tr>
</thead>
<tbody>
<tr>
<td>First [111¼']</td>
<td>1</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Second [221½']</td>
<td>1</td>
<td>4</td>
<td>56</td>
</tr>
<tr>
<td>Third [333¼']</td>
<td>1</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Fourth [45']</td>
<td>1</td>
<td>24</td>
<td>51</td>
</tr>
<tr>
<td>Fifth [561¼']</td>
<td>1</td>
<td>47</td>
<td>59</td>
</tr>
<tr>
<td>Sixth [674¼']</td>
<td>2</td>
<td>36</td>
<td>47</td>
</tr>
<tr>
<td>Seventh [784°]</td>
<td>5</td>
<td>7</td>
<td>33</td>
</tr>
</tbody>
</table>

This was part of the 'Rule to raise or lay a degree of latitude in sailing by any point of the compass' evolved, probably in the fifteenth century, by Jewish mathematicians for the benefit of the Portuguese explorers, and already briefly referred to.\(^1\) Cortes had given a rectangular diagram showing the eight rhumbs in a quadrant of a circle marked with the distances that had to be sailed along each in order to raise or lay 1° of latitude. He had also given the resultant departure. He gave his distances in leagues on the basis of '17 leagues and a halfe for a degree of the greater circle', accounting four miles to the league, and also in degrees and minutes of a great circle. Bourne improved on Cortes's quadrant diagram by devising a circular one giving the distances involved in both Spanish leagues (corresponding to Cortes's) and English leagues of 3 miles to a league and 20 leagues to a degree. The two upper quadrants on his diagram gave the distance—the left-hand one in English, the right-hand one in Spanish leagues— to be sailed along each rhumb to raise or lay a degree; the lower quadrants gave the resultant departure from the meridian. Hues, it will be noticed, gave the distances on the rhumbs in terms of miles converted into the equivalent length of a degree on the equator or on a meridian, instead of in the customary leagues. Given, for the times, a fair amount of mathematical ability, this could be quite a useful table.

\(^1\) See Pls. XI, XL, and Fig. 16.  
28—A.O.N.
For instance, said Hues in effect, "suppose a ship takes departure from Cape Verde (which he gave as lying in lat. 14° 30' N) and makes for Cape St. Augustine, in Brazil (in lat. 8° 30' S) by following the third rhumb from this meridian—a course of S.W. by S.—how far has she to sail? The difference of latitude between Cape Verde and Cape St. Augustine is 23°. Table 11 shows that 1° of latitude is raised or laid by sailing 1° 12' 9" along the third rhumb, or \( \frac{72}{60} \) miles (taking sixty miles to the degree on the equator or meridian) and 9/60 of a mile, therefore the distance between Cape Verde and Cape St. Augustine is \( 23 \times \frac{72'}{9/60} = 1659\frac{1}{4} \) miles."

If it had been the distance and difference of latitude, and not the rhumb and difference of latitude, that had been known, the rhumb could have been found with the aid of the table. Knowing that the distance was 1660 miles and the difference of latitude 23°, the navigator would also have known that he had to lower (and after crossing the equator to raise) one degree of latitude in 1660 miles \( \div 23' \)—the distance divided by the difference of latitude. This he would have found by long division, to amount to 72' or 1° 12', taking 60' to a degree, the length of a degree on the equator or a meridian. Reference to the table would have shown him that this distance raised or laid a degree of latitude when following the third rhumb from the meridian. Or again, if the navigator had known only the distance and rhumb between Cape Verde and Cape St. Augustine he could have found the difference of latitude by calculation and reference to the table.

Gunter, too, included a table of 'rhumbs and distances' but unlike Hues he gave the distances in leagues (and hundredths parts of a league). A refinement was the inclusion of the distances on the quarter as well as the whole points, and their angular value in degrees and minutes of each point and quarter point. Since his object was to eliminate calculation in navigation Gunter gave no explanation of the use of the table; instead he gave the trigonometrical formula by means of which it was constructed. As before, he expressed the formula in terms best suited for its use on the Sector: namely,

\[
\text{difference of latitude} = \text{distance} \times \cos (\text{Course})
\]

or

\[
\text{distance} = \frac{\text{difference of latitude}}{\cos (\text{Course})}
\]

Today, when tables are used, this is generally expressed as 'the distance to raise or lower one degree of latitude is equal to the length of a degree of latitude multiplied by the Secant of the Course', or dist. = d. lat. sec (Co), a formula first published, as we shall see, in 1614.

Having explained how to find the distance on the Sector by the aid of his formula, Gunter followed Hariot in dealing with the question of laying off rhumbs between places and measuring the distance between them, but on charts of Mercator's projection. He held, like Wright, that
though the globe was commended by some navigators as perfect for all courses and latitudes yet its cost, 'troublesome carriage, stowage, and tedious vsage for the most part in navigation' made it unsuitable and unhandy 'and nothing so fit and ready for the mariners common use at sea as the nauticall planisphere truely made'. On such charts a rhumb could be laid off either by using a pair of compasses and the Line of Sines and Chords on the Sector; or by using the protractor Gunter had previously

<table>
<thead>
<tr>
<th>Navigational Problems &amp; Trigonometrical Formulæ</th>
<th><img src="image" alt="Diagram" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>TO FIND THE:</td>
<td>( R = \text{Radius} )</td>
</tr>
<tr>
<td><strong>COURSE</strong></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
<tr>
<td><img src="image" alt="Diagram" /></td>
<td></td>
</tr>
<tr>
<td><strong>DISTANCE</strong></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
<tr>
<td><img src="image" alt="Diagram" /></td>
<td></td>
</tr>
<tr>
<td><strong>DIFFERENCE</strong></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
<tr>
<td><strong>LATITUDE</strong></td>
<td></td>
</tr>
<tr>
<td><strong>DIFFERENCE</strong></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
<tr>
<td><strong>LONGITUDE</strong></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 34

GUNTER'S NAVIGATIONAL FORMULÆ, IN *De Sectore & Radio*, 1623, SHOWN PICTORIALLY

(The numbers refer to Gunter's propositions.)

described; or, having neither, 'I would have a Line of Chords set on the side of the Ruler which I am to use', he explained, and by this means lay off the appropriate arc. As this method was frequently practised in the seventeenth century, and was the one probably most generally used by hydrographers in the sixteenth century, it is worth knowing. It consisted of taking the chord of an arc of 60° as measured on the ruler, as this was equal to the radius of the circle of which the arc was a portion, and then,
from the desired point, through which a meridian was also drawn, striking an arc of this radius, and on it 'pricking down the chords of the other arks [measured on the ruler] from the Meridian'. The rhumbs were completed by drawing straight lines through the centre and these points with the ruler and a piece of lead.\(^1\)

Distance along a rhumb was measured by taking it off with a pair of compasses and, Gunter stressed, measuring it in the meridian scale 'as far above the greater Latitude as beneath the lesser'.\(^2\)

In the course of dealing with these general considerations of practical chart and Sector work, Gunter had so far stated three general formulae—that the latitude and distance scale at any part of a Mercator's chart is proportional to the secant of the latitude; that the length of a degree of longitude in miles (or leagues) on a parallel of latitude is equal to the length of a degree on the equator multiplied by the cosine of the latitude; and that the distance that has to be sailed along a rhumb in order to raise or lay a degree of latitude can be found by dividing the length of a degree of latitude by the cosine of the rhumb (course). It was now that he proceeded to explain how, any two of the four differences between places—the difference of latitude, difference of longitude, distance, and rhumb—being given, the other two could be found with the Sector and on a Mercator's chart. In order to find them with the Sector he gave nine formulae and three instrumental methods. The twelve propositions and his solutions are tabulated in Table 12, cross-referenced to Hues's propositions (see page 195). In addition, their explanation is shown diagrammatically, grouped so as to emphasize the various combinations of known and unknown differences (Fig. 34 on p. 379).

The first three propositions marked * can be found, Gunter pointed out, with the Sector, on a Mercator's chart, and 'as truly by the Common Sea Chart'. This is because they involve neither longitude nor departure. In order to solve on a chart the rest of the propositions (which do involve longitude) it is, however, essential, as he stressed, to use only a Mercator's chart, and to measure the longitude 'out of the Equator' scale, and the difference of latitude and distance 'out of the Meridian Line' scale. The reason for this, it will be recalled, is that the meridians being drawn parallel, the latitude scale, which is also the distance scale, increases continually as it recedes from the equator—until at the Pole it becomes infinite—being proportional to the secant of the latitude (the secant of an angle increases as the angle increases from 0° to 90°, at which point it becomes infinitely large). The consequence is that the latitude scale affords

---

\(^1\) See Fig. 32 on p. 368.

\(^2\) For if we open a pair of Compasses to the quantity of one Degree of Longitude in the Equator, or one of his Parallels, and measure it in the Meridian line, setting one Foot as much above the Latitude given, as the other falleth beneath it, so that the Latitude may be in the middle between the Feet of the Compasses, the number of Leagues intercepted shall be that which was required.

(Gunter, chapter VI, 3. (p. 100).)
no basis for comparison with the longitude scale. The latter, however, being
fixed, can be and is the basic scale for both, one minute or other con-
venient fractions of a degree of longitude on the equator being taken as
the basic unit, or meridional part. The latitude scale is accordingly drawn
in, as Gunter had explained, with the aid of the table of meridional parts
but, instead of meridional parts being shown the corresponding degrees
of latitude are marked on it.\(^1\)

**TABLE 12**

<table>
<thead>
<tr>
<th>Gunter’s Proposition</th>
<th>Hues’s (^2)</th>
<th>Knowing</th>
<th>How to find</th>
<th>Gunter’s Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1*</td>
<td>6b</td>
<td>the Rhumb and Distance, and one Latitude</td>
<td>the Difference of Latitude</td>
<td>d. lat. = dist. cos (Co)</td>
</tr>
<tr>
<td>2*</td>
<td>4b</td>
<td>the Rhumb and Both Latitudes</td>
<td>the Distance</td>
<td>dist. = d. lat. cos (Co)</td>
</tr>
<tr>
<td>3*</td>
<td>5a</td>
<td>the Distance and Both Latitudes</td>
<td>the Rhumb</td>
<td>cos (Co) = d. lat. dist.</td>
</tr>
<tr>
<td>4</td>
<td>1a</td>
<td>the Longitude and Latitude of Two Places</td>
<td>the Rhumb</td>
<td>tan (Co) = d. long. d.m.p.</td>
</tr>
<tr>
<td>5</td>
<td>4a</td>
<td>the Rhumb and Both Latitudes</td>
<td>the Difference of Longitude</td>
<td>d. long. = d.m.p. tan (Co)</td>
</tr>
<tr>
<td>6</td>
<td>2a</td>
<td>the Difference of Longitude, the Rhumb and one Latitude</td>
<td>the Difference of Latitude</td>
<td>d.m.p. = d. long. cot (Co)</td>
</tr>
<tr>
<td>7</td>
<td>6a</td>
<td>the Rhumb and Distance and one Latitude</td>
<td>the Difference of Longitude</td>
<td>d. long. = dist. sin (Co)</td>
</tr>
<tr>
<td>8</td>
<td>2b</td>
<td>The Rhumb and Difference of Longitude and one Latitude</td>
<td>the Distance</td>
<td>dist. = d. long. sin (Co)</td>
</tr>
<tr>
<td>9</td>
<td>3b</td>
<td>the Distance and Difference of Longitude and one Latitude</td>
<td>the Rhumb</td>
<td>sin (Co) = d. long. dist.</td>
</tr>
<tr>
<td>10</td>
<td>1b</td>
<td>The Longitude and the Latitude of Two Places</td>
<td>the Distance</td>
<td>By manipulation of the Sector</td>
</tr>
<tr>
<td>11</td>
<td>5b</td>
<td>The Latitude of Two Places, and the Distance</td>
<td>The Difference of Longitude</td>
<td>By manipulation of the Sector</td>
</tr>
<tr>
<td>12</td>
<td>3a</td>
<td>The Distance and Difference of Longitude and one Latitude</td>
<td>the Difference of Latitude</td>
<td>By manipulation of the Sector</td>
</tr>
</tbody>
</table>

\(^1\) See Fig. 32 on p. 368. \(^2\) See Table 2 on p. 195.
It was one thing for Gunter to recapitulate Hues's propositions in mathematical terms for use with the Sector and quite another to get seamen to make calculations with them without the aid of the Sector. Gunter realized this only too well. So he did no more at this stage than point out that his formulae could be used with the tables of meridional parts and of sines, tangents, and secants to solve navigational problems arithmetically. He then gave the method of using each one on the Sector and on the chart. For his examples he chose two places, 'A' and 'C', in latitude 50° and 55° respectively, on his 'particular chart'. Suppose, he said, referring to his first proposition, it is known that 'C' lies on the third rhumb, and is distant from 'A' 6° [that is 360°], and that it is desired to find in what latitude 'C' lies. Draw the rhumb from 'A', measure off 6° with compasses in the latitude scale on the meridian abreast the latitude of the two places, and transfer it to the rhumb. Place one point of the compasses on 'A', the other will fall on 'C' on the rhumb, and so the Degrees in the Meridian from "A" to "B" [on "A's" meridian in "C's" lat. (55°)] shall show the difference of Latitude to be 5 gr.1 While this was simplicity itself the method with the Sector was equally simple, yet to avoid any possibility of error and to reduce mental effort to the minimum Gunter provided 'A Table of Leagues, Rums, and Differences of Latitude'. It was for use with short distances, that is for such, as he put it, 'as fall within the compass of a days sailing'.2

This, rendered with modern navigational units and terms, is as shown in Tables 13 and 14 (see pages 384 and 385).

At first sight there does not appear to be much connexion between this table of Gunter's and the traditional 'Rule to Raise or Lay one Degree of Latitude' but, despite the greater complexity of Gunter's table, there is in fact a close connexion between the two. 'The Rule' had been based upon certain assumptions, namely, that the navigator knew his latitude, that he knew the latitude of his destination, that, in order to make his landfall he would 'run down' this latitude when he reached it, and that consequently what he wanted was a table that would tell him how far he had to sail on a given course in order to change his latitude by a degree. Its basis was therefore change of latitude. But, as we have seen, this was a very inconvenient basis because, to find the distance to sail to raise, or lay a lesser or greater difference of latitude than that tabulated, 1°, the navigator had to do a mathematical calculation and, if he knew how far he had sailed and wanted to know what the resultant difference of latitude was, unless it amounted to exactly 1°, he had again to do a mathematical calculation. In practice, in order to reach his desired latitude he had to work in distance sailed and not in degrees of latitude sailed. This was because he could find his latitude only once, or at most twice a day (by meridian altitudes of the sun, or by star sights), and frequently could not do so for days on end;

1 See Fig. 32 on. p. 368.  
2 See Tables 13 and 14.
consequently, in practice, what he wanted to know while he was approaching his desired latitude was the change of latitude resulting from his having sailed any given distance on a course. His need was for a table for converting distances sailed on a given course into change of latitude. It was this that Gunter’s table enabled him to do at a glance, or at most by some simple addition, for Gunter took the course and distance, instead of change of latitude, as the basis of his table, and tabulated the difference of latitude resulting from sailing any distance between one and one hundred leagues on any rhumb. He went further than this, for he gave the distances, and changes of latitude, on any quarter rhumb also. This was an advance in accordance with the needs of the times, for, by the seventeenth century, thanks to the improvements in compass design and the greater knowledge of and improved means of finding variation, navigators now commonly set course to the nearest quarter rhumb.

It will be remembered that Gunter had given the formula for making just such a table—difference of latitude = distance \times \cosine of the course and, as the interpretation of his table makes clear, what he had done was to take distances from 300’ down to 3’ and multiply them by the cosines of various angles between 0° and 90°. For instance, the cosine of 114° = 0.981, and therefore the difference of latitude resulting from sailing 300’ on a course 11° 15’ off the meridian is 300 \times 0.981 = 294.3’ = 4° 54.3’; on a course 22° 1’ from the meridian the change of latitude is 277’ = 4° 37’; because the cosine of 22° is 0.924 and 300 \times 0.924 = 277.2’.

Gunter’s traverse table, as such a table has come to be known, was the prototype of one of the most useful navigational tables ever devised: traverse tables are constantly used by navigators. The Royal Navy today uses traverse tables prepared by the Rev. James Inman and first published in 1821. A portion of Inman’s traverse tables in the revised ‘twentieth century’ edition of 1906 is shown in Table 15 (see page 386). It will be seen that it does no more than tabulate the difference of latitude for distances measured in miles along courses measured in degrees, and to tabulate also the departure. It is Gunter’s table in modern dress and, as a matter of interest, all editions of Inman’s Tables published between 1821 and 1906 included a traverse table for distances up to 296’ (almost 100 leagues) and on courses in points and quarter-points, as well as in degrees. Except for the ‘departure column’ it was thus almost pure ‘Gunter’. In addition to the departure column—a feature first introduced, as we shall see, by contemporaries of Gunter—Inman’s Table, it will be noticed, has a further refinement, also introduced by Gunter’s contemporaries. By incorporating a departure, or sine, column, it has been possible to give

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1 See Fig. 35 on p. 389. *Nautical Tables, designed for the use of British Seamen.* By the Rev. James Inman, D.D., Professor at the Royal Naval College Portsmouth. London: Printed, for C. and J. Rivington, St. Paul’s churchyard and Waterloo-Place. MDCCCXXIX and *Nautical Tables designed for the use of British Seamen by the Rev. James Inman, D.D. re-edited and adapted to modern needs by William Hall.* London, 1906. The edition of 1829 is the earliest in the Admiralty Library.


**TABLE 13**

**GUNTER'S TRAVERSE TABLE OF 1606 OR 1607:**

**A TABLE OF LEAGUES, RUMBS, AND DIFFERENCES OF LATITUDES**

<table>
<thead>
<tr>
<th>Lg.</th>
<th>100</th>
<th>80</th>
<th>60</th>
<th>40</th>
<th>20</th>
<th>19</th>
<th>etc.</th>
<th>11</th>
<th>10</th>
<th>9</th>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G.M.</td>
<td>G.M.</td>
<td>G.M.</td>
<td>G.M.</td>
<td>M.</td>
<td>M.</td>
<td>etc.</td>
<td>M.</td>
<td>M.</td>
<td>M.</td>
<td>M.</td>
<td>M.</td>
<td>M.</td>
<td>M.</td>
<td>M.</td>
<td>M.</td>
<td>M.</td>
<td>M.</td>
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<tr>
<td>Rum.</td>
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<tr>
<td>5°</td>
<td>4'59</td>
<td>3'59</td>
<td>2'55</td>
<td>1'59</td>
<td>60</td>
<td>57</td>
<td>etc.</td>
<td>33</td>
<td>30</td>
<td>27</td>
<td>24</td>
<td>21</td>
<td>18</td>
<td>15</td>
<td>12</td>
<td>9</td>
<td>6</td>
<td>3</td>
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<tr>
<td>6°</td>
<td>4'58</td>
<td>3'58</td>
<td>2'59</td>
<td>1'59</td>
<td>60</td>
<td>57</td>
<td>etc.</td>
<td>33</td>
<td>30</td>
<td>27</td>
<td>24</td>
<td>21</td>
<td>18</td>
<td>15</td>
<td>12</td>
<td>9</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>7°</td>
<td>4'56</td>
<td>3'58</td>
<td>2'58</td>
<td>1'58</td>
<td>59</td>
<td>56</td>
<td>etc.</td>
<td>33</td>
<td>29</td>
<td>27</td>
<td>24</td>
<td>21</td>
<td>18</td>
<td>15</td>
<td>12</td>
<td>9</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>8°</td>
<td>4'54</td>
<td>3'57</td>
<td>2'56</td>
<td>1'57</td>
<td>59</td>
<td>56</td>
<td></td>
<td>32</td>
<td>29</td>
<td>26</td>
<td>24</td>
<td>21</td>
<td>18</td>
<td>15</td>
<td>12</td>
<td>9</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>

**ARITHMETICAL NAVIGATION**

| Lg. | 100 | 80  | 60  | 40  | 20  | 19  | etc. | 11  | 10  | 9   | 8   | 7   | 6   | 5   | 4   | 3   | 2   | 1   |
|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|     | G.M. | G.M. | G.M. | G.M. | M.  | M.  | etc. | M.  | M.  | M.  | M.  | M.  | M.  | M.  | M.  | M.  | M.  | M.  |
| 9°  | 4'51| 3'53| 2'55| 1'56| 58  | 56  |      | 32  | 29  | 26  | 23  | 20  | 17  | 14  | 12  | 9   | 6   | 3   |
| 10° | 4'47| 3'50| 2'52| 1'55| 57  | 55  |      | 32  | 29  | 26  | 23  | 20  | 17  | 14  | 11  | 9   | 6   | 3   |
| 11° | 4'42| 3'46| 2'49| 1'53| 56  | 54  | etc. | 31  | 28  | 25  | 23  | 20  | 17  | 14  | 11  | 9   | 6   | 3   |
| 12° | 4'37| 3'42| 2'46| 1'51| 55  | 53  |      | 31  | 28  | 25  | 23  | 19  | 17  | 14  | 11  | 9   | 6   | 3   |

| Lg. | 100 | 80  | 60  | 40  | 20  | 19  | etc. | 11  | 10  | 9   | 8   | 7   | 6   | 5   | 4   | 3   | 2   | 1   |
|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|     | G.M. | G.M. | G.M. | G.M. | M.  | M.  | etc. | M.  | M.  | M.  | M.  | M.  | M.  | M.  | M.  | M.  | M.  | M.  |
| 13° | 4'37| 3'37| 2'43| 1'48| 54  | 52  |      | 30  | 27  | 24  | 22  | 19  | 16  | 14  | 11  | 8   | 5   | 3   |
| 14° | 4'25| 3'32| 2'39| 1'46| 53  | 50  |      | 29  | 26  | 24  | 21  | 19  | 16  | 14  | 11  | 8   | 5   | 3   |
| 15° | 4'17| 3'26| 2'34| 1'43| 51  | 49  | etc. | 28  | 26  | 23  | 21  | 18  | 15  | 13  | 10  | 8   | 5   | 3   |
| 16° | 4'10| 3'20| 2'30| 1'40| 50  | 47  |      | 27  | 25  | 22  | 20  | 17  | 15  | 13  | 10  | 7   | 5   | 2   |
TABLE 14
A Table of Distances, in Degrees and Miles, along Courses at 2° Intervals, and of the Resultant Differences of Latitude

<table>
<thead>
<tr>
<th>Distance</th>
<th>300'</th>
<th>240'</th>
<th>180'</th>
<th>120'</th>
<th>60'</th>
<th>57'</th>
<th>...</th>
<th>6'</th>
<th>3'</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Points)</td>
<td>(Degrees)</td>
<td>Difference of</td>
<td>d. lat.</td>
<td>d. lat.</td>
<td>d. lat.</td>
<td>d. lat.</td>
<td>...</td>
<td>d. lat.</td>
<td>d. lat.</td>
<td>(Points)</td>
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<tr>
<td>(Course)</td>
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<td>Latitude</td>
<td>[Cos. Co.]</td>
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<td>24°</td>
<td>4° 59'</td>
<td>3° 59'</td>
<td>2° 59'</td>
<td>1° 59'</td>
<td>60'</td>
<td>57'</td>
<td>...</td>
<td>6'</td>
<td>3'</td>
<td>24°</td>
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<tr>
<td>51°</td>
<td>4° 58'</td>
<td>3° 58'</td>
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<td>1° 59'</td>
<td>60'</td>
<td>57'</td>
<td>...</td>
<td>6'</td>
<td>3'</td>
<td>51°</td>
</tr>
<tr>
<td>81°</td>
<td>4° 56'</td>
<td>3° 58'</td>
<td>2° 58'</td>
<td>1° 58'</td>
<td>59'</td>
<td>56'</td>
<td>...</td>
<td>6'</td>
<td>3'</td>
<td>81°</td>
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<td>114°</td>
<td>4° 54'</td>
<td>3° 57'</td>
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<td>1° 57'</td>
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<td>56'</td>
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<td>6'</td>
<td>3'</td>
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<td>4° 51'</td>
<td>3° 53'</td>
<td>2° 55'</td>
<td>1° 56'</td>
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<td>163°</td>
<td>4° 47'</td>
<td>3° 50'</td>
<td>2° 52'</td>
<td>1° 55'</td>
<td>57'</td>
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<tr>
<td>191°</td>
<td>4° 42'</td>
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<td>2° 49'</td>
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<td>221°</td>
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<td>334°</td>
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<td>3° 20'</td>
<td>2° 30'</td>
<td>1° 40'</td>
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</tbody>
</table>
### TABLE 15

**PORTION OF A TRAVERSE TABLE FROM INMAN'S TABLES**

**TRAVERSE TABLE**

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</tbody>
</table>
angles from $1^\circ$ to $45^\circ$ on the left, reading from the top to the bottom, and from $45^\circ$ to $89^\circ$, on the right, reading from the bottom to the top. This takes advantage of the fact that the sine of $1^\circ$ = the cosine of $89^\circ$, and so on to $45^\circ$ at which angle sine and cosine are equal viz. 0.707.

Gunter explained the use of his Table with the example he had given for finding the difference of latitude by plotting—a navigator in latitude $50^\circ$ has to find his latitude after steering 120 leagues, or as he put it $6^\circ$, three points to the east of north, that is N $33\frac{1}{3}^\circ$ E or N.N.E. As the maximum distance column on the table was for 100 leagues, or $5^\circ$, the navigator ran his finger down the distance column headed,

\[
\begin{align*}
&\{ \text{100 [leagues]} \} \\
&\{ \text{G.M. ["']} \} \\
&\{ \text{5.0 ["]} \}
\end{align*}
\]

against it in the left-hand ‘Rum’ column. He read off ‘$4^\circ\ 10'$’—the difference of latitude—and noted it down. He had still to find the difference of latitude for the outstanding $1^\circ$, or 60 miles, so he looked down the column,

\[
\begin{align*}
&\{ \text{20 leagues} \} \\
&\{ \text{M} \} \\
&\{ \text{60} \}
\end{align*}
\]

where he found ‘$50'$’. He wrote this number (as $50'$) under the $4^\circ\ 10'$ noted earlier and added. The result, $5^\circ$, told him that his difference of latitude was $5^\circ$, and that his new latitude was therefore $55^\circ$.

**Problem**

<table>
<thead>
<tr>
<th>Latitude</th>
<th>Distance</th>
<th>Rhumb</th>
<th>Difference of Latitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>$50^\circ$</td>
<td>$6^\circ$</td>
<td>$3rd$</td>
<td>?</td>
</tr>
</tbody>
</table>

**From the Table**

On the line of the Third Rhumb, under the distance column for:— $5^\circ$, d. lat. $= 4^\circ\ 10'$

$d. \text{lat.} = 50'$

a distance of $6^\circ$ on the 3rd rhumb gives a d. lat. of $5^\circ\ 00'$

original lat. $50^\circ$

**Final lat.**

For a navigator who wanted to resolve the various traverses during the day it was clearly a very useful table.

Besides being suitable for finding difference of latitude, Gunter’s table could be used to find the distance to be sailed to effect a given change of latitude when following a certain rhumb. He pointed this out when explaining his second proposition. All that was necessary was to find the rhumb in the column at the side of the table and run a finger along to the difference of latitude in the same line. The distance, in leagues, was at the top of this column. Although Gunter did not mention the fact, the table
could also be used to solve his third proposition, namely, given the distance and difference of latitude, to find the rumb.

In solving the last nine of his propositions, those which could be done only on the Sector or on a Mercator’s chart because they involved difference of longitude, Gunter again emphasized that ‘the difference of latitude and distance upon the Rumb must alwaies be taken out of the Meridian line’, and to avoid confusion over the units being used in calculation he called them ‘the proper difference, and proper distance’.

‘Plane sailing’ deals with difference of latitude and departure—the linear distance sailed east or west, the latitude scale in the plane chart being a constant scale and the longitude scale being compressed into departure—Mercator’s sailing deals essentially with difference of meridional parts (d.m.p.) and difference of longitude—the angular distance sailed east or west. It is now the longitude scale which is constant, the latitude scale being stretched into meridional parts. The diagram (similar ones date from the latter half of the seventeenth century) illustrates the relationships between difference of latitude and departure, and difference of meridional parts and difference of longitude.¹

Gunter introduced Mercator sailing with the proposition ‘By the Longitude and Latitude of two places to find the Rumb’, and gave the formula, which is now expressed in the form of:

\[
\frac{\text{d. long}}{\text{d.m.p.}} = \tan. \ (\text{Co.})
\]

the ‘plane sailing’ formula being

\[
\frac{\text{dep}}{\text{d. lat.}} = \tan. \ (\text{Co.})
\]

He showed too that, if ‘A’ was in latitude 50°, and ‘C’ in latitude 55° and the difference of longitude between them was 5° 30′, they lay upon the third rhumb from the meridian (33° 45′) although if plotted in a plane chart they appeared to lie ‘above 47°’ from the meridian. In short the plane chart—and the Mariner’s Quadrant—induced a course error of 14° or 1 ¼ points! Gunter next demonstrated the error in difference of longitude caused by use of the plane sea chart. The formula, d. long = d.m.p. tan (Co.) gave a difference of longitude of 5° 30′ between ‘A’ and ‘C’ when applied to the Sector and this was confirmed by plotting on the Mercator’s chart. But plotting on a plane chart, Gunter pointed out, gave a result of only 3° 20′, or an error of longitude of 2° 10′. This was big enough in all conscience, ‘yet’ he stressed, (because what the plane chart actually showed was departure) ‘the error would be greater if either the latitudes concerned were higher or the course had lain farther from the Meridian’.²

¹ See Fig. 35. ² See Fig. 32 on p. 368.
Now, while Gunter had stated the formula for converting departure into difference of longitude when a ship's course lay east or west, i.e. dep. = d. long. cos. (lat.) not even he had been able to state the formula for converting departure into difference of longitude—in what was soon to become known as 'oblique sailing'—when a ship's course lay on an

A Traverse Table does no more than multiply a number by the sine or cosine of an angle.

Distances
(Radius) 364

<table>
<thead>
<tr>
<th>Co.</th>
<th>d. lat</th>
<th>dep.</th>
<th>Co.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Angle)</td>
<td>(Cosine)</td>
<td>(Sine)</td>
<td>(Angle)</td>
</tr>
<tr>
<td>1°</td>
<td>363.9</td>
<td>0.9</td>
<td>89°</td>
</tr>
<tr>
<td>30°</td>
<td>319.2</td>
<td>0.9</td>
<td>60°</td>
</tr>
<tr>
<td>45°</td>
<td>267.4</td>
<td>0.9</td>
<td>45°</td>
</tr>
</tbody>
</table>

Fig. 35

THE MERCATOR SAILING TRIANGLE, THE PLANE SAILING TRIANGLE, AND THE TRAVERSE TABLE

A Traverse Table does no more than multiply a number by the sine or cosine of an angle.

oblique rhumb, that is on any of the rhumbs above or below a parallel of latitude. The old ‘Rule to Raise or Lay A Degree of Latitude’ had included, as already pointed out, a table or diagram showing how far east or west a ship had sailed whilst sailing along the various rhumbs far enough to change her latitude by one degree. In explaining the
purpose of this ‘departure table’ it was stated, in Blundeville’s *Exercises*, for instance, that this distance, converted into degrees and multiplied by any difference of latitude in excess of one degree, showed how much the point of departure was ‘more Eastward (or Westward) than the place where you are’. The implication here, since the departure had been converted into degrees, was that the product was the difference of longitude. Gunter of course realized that this was not so. Being unable to provide a formula for effecting the necessary conversion he gave a ‘Table of Rumbs’ for finding the difference of longitude by ‘the Rumb and both Latitudes’. It was calculated for each rhumb and gave the distance from the equator along each rhumb at which each successive parallel was crossed, and the longitude of this point from that of the starting-point on the equator. The table for each of the first seven rhumbs had three columns. The first column listed the parallels of latitude at one-degree intervals, starting from the equator; the second gave the corresponding difference of longitude; the third the distance along the rhumb. The table gave, in effect, the mathematical solution to Hues’s problem of measuring rhumb line distances accurately on the globe. As on the eighth rhumb no difference of latitude was involved, this table showed ‘the difference of Longitude, belonging to one degree of distance and the distance belonging to one degree of Longitude’ in every parallel.\(^1\)

**TABLE 16**

**PART OF GUNTER’S TABLE OF RHUMBS FOR FINDING DIFFERENCE OF LONGITUDE**

<table>
<thead>
<tr>
<th>The third Rumb, from the Meridian</th>
<th>North-east by North, South-east by South</th>
<th>North-west by North, South-west by South</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>20</td>
<td>13</td>
<td>64</td>
</tr>
<tr>
<td>25</td>
<td>17</td>
<td>26</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Modernized, a typical extract reads as as shown in Table 17 on page 391. At first sight this table seems to provide the navigator with little information of practical value, merely, to take an example, that a ship, holding a

\(^1\) See Table 16 and Appendix 8.
course constantly on the third rhumb from the meridian from the time of leaving the equator to that of arriving in latitude 50° (say, 50° N), would have sailed 3308' (60°.13) and changed her longitude by 38°.41' (38°.69). Clearly it was useful for plotting rhumbs on globes or circumpolar charts, or indeed upon charts of any projection provided the meridians and parallels

**TABLE 17**

| Course 33°.45' (3 points) from Meridian | NE by N = 033°3' | NW by N = 326°4' |
| SE by S = 146°4' | SW by S = 213°4' |

<table>
<thead>
<tr>
<th>Latitude</th>
<th>Difference of Longitude from the Meridian at the Equator</th>
<th>Distance Sailed along the Rhumb</th>
</tr>
</thead>
<tbody>
<tr>
<td>In degrees</td>
<td>In degrees and 100ths of a degree (and in degrees and minutes)</td>
<td>In Units of 60 miles, i.e. in degrees and 100ths of a degree (and in miles)</td>
</tr>
<tr>
<td>50°</td>
<td>38°.69 (38°.41)</td>
<td>60°.13 = 3607.8</td>
</tr>
</tbody>
</table>

had been drawn in. In this respect it was akin to the Table of Rhumbs that Wright had included in *Certaine Errors* for: ‘shewing for every degree of longitude, by What degree and minute of latitude every rumbe is to be drawn till you come within a minute of the pole’, for ‘the true drawing of the rhumbs on the globe and the chart, which some call paradoxall’, a part of which ran as follows in the 1599 edition:

**TABLE 18**

**The First Rumbe from the Equinoctial**

The rhums of \{ East and by North, East and by South \{ West and by North, West and by South

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 11</td>
<td>31</td>
<td>6 9</td>
<td>etc.</td>
<td>195</td>
<td>89 57</td>
</tr>
<tr>
<td>2</td>
<td>0 23</td>
<td>32</td>
<td>6 21</td>
<td>etc.</td>
<td>210</td>
<td>89 57</td>
</tr>
<tr>
<td>etc.</td>
<td>etc.</td>
<td>etc.</td>
<td>etc.</td>
<td>etc.</td>
<td>etc.</td>
<td>etc.</td>
</tr>
<tr>
<td>29</td>
<td>5 45</td>
<td>59</td>
<td>11 39</td>
<td>etc.</td>
<td>340</td>
<td>89 59</td>
</tr>
<tr>
<td>30</td>
<td>5 57</td>
<td>60</td>
<td>11 50</td>
<td>etc.</td>
<td>360</td>
<td>89 59</td>
</tr>
</tbody>
</table>
We never use by the knoune Longitude to take the distance, Hues had written in *Tractatus de Globis*. Gunter had evidently taken his words to heart, for by making degrees of latitude instead of degrees of longitude the basis of his table of rhumbs and including distance along the rhumb, he had vastly improved upon Wright's table which, incidentally, confused matters by tabulating the rhumbs from the equator instead of from the meridian. Thus while both enabled rhumb lines to be drawn in on charts and globes, Gunter's enabled the navigator who knew either the rhumb and difference of latitude or the rhumb and distance between places to find their difference of longitude; or, knowing their rhumb and difference of longitude to find their distance apart as well as their difference of latitude. Provided any two of these factors were known the other two could be found directly by inspection. For instance, suppose, said Gunter, 'A' is in latitude 50°, 'C' in latitude 55° and the rhumb joining them is the third from the meridian, what is their difference of longitude and distance apart? Look, he directed, in the table of the third rhumb and there find the two latitudes, note both the longitude and the distance entered against them, subtract the lesser of each from the greater, and the result is the difference of longitude and distance, e.g.

\[
\begin{align*}
\text{Lat. } 55° \text{ N} &= \text{Long. } 44°19' \text{ Dist. } 66°15' (66°9' &= 3969') \\
\text{Lat. } 50° \text{ N} &= \text{Long. } 38°69' \text{ Dist. } 60°13' (60°8' &= 3608')
\end{align*}
\]

\[
\begin{align*}
d. \text{ lat. } 5° &= d. \text{ long. } = 5°5 \text{ dist. } 6°0 ( \quad &= 360°)
\end{align*}
\]

These tables of Gunter's, as they became known, were of fundamental importance in popularizing arithmetical navigation for they eliminated much dreary calculation in oblique sailing. But for most seamen as long as they were in manuscript they were no more accessible or comprehensible than Gunter's other great labour-saver, the Sector.

Although Gunter was the first man to make Dee's and Davis's revolutionary 'navigational arithmetical' a practical proposition for seamen by his invention of the Sector, the distinction of first publishing the formulae and methods of calculation involved goes to another, who also gave to the nautical world the formula most used in oblique sailing, that for converting the difference of longitude between places in different latitudes into departure in order to calculate the bearing and distance between them. As we have seen, while the tables still used for determining the distance to be sailed and the resultant departure and difference of longitude were adequate to effect changes of latitude of 1° they gave demonstrably incorrect answers to problems involving movements between places in widely separated latitudes, particularly in the higher latitudes. Wright's tables of meridional parts and 'showing for every degree of longitude through what degree and minute of latitude every rhumb was to be drawn', in his *Certaine Errors* of 1599, had offered solutions, but it is doubtful if they were grasped until Gunter showed to a limited circle of friends how the
difference of longitude resulting from oblique sailing could be obtained either by the use of meridional parts and formulae or from his improved table 'of Rhumbs for Finding Difference of Longitude'. Wright, it is true, improved his own table of rhumbs of 1599 in the second 1610 edition of *Certaine Errors* by tabulating the angles of the rhumbs from the meridian instead of from the equator, but even so the navigator who had no copy of the tables in *Certaine Errors* would still be unable to calculate his position in terms of latitude and longitude, or of accurate bearing and distance. The beauty of the Mercator's chart was that if positions were expressed either in terms of latitude and longitude or of bearing and distance from one another they could be plotted as accurately as on a globe, while the beauty of arithmetical navigation was precisely that it enabled positions to be found by calculation either in terms of bearing and distance from one another or in those very terms that enabled them to be plotted most expeditiously on a Mercator's chart, namely latitude and longitude. With the increased use of this chart the need for a general formula for calculating, in terms of latitude and longitude, the position resulting from sailing on any course for any given distance, grew. The solution, 'the mid-latitude formula' was published in 1614. The year could not have been more propitious for, as we shall see, in the same year was published the mathematical development which was to sweep away all the labour of calculation hitherto involved in arithmetical navigation. The mid-latitude formula together with its proof, first appeared in an appendix to an English translation of Pitiscus's later work of 1600 on trigonometry. Both were the work of an English mathematician called Ralph Handson who entitled his book *Trigonometry: or, The Doctrine of Triangles... Whereunto is added (for the Marriners use) certaine Nauticall Questions, together with the finding of the Variation of the Compassse. All performed Arithmetically, without Map, Sphaere, Globe, or Astrolabe.*

1 Bartholomaei Pitisci Grunbergensis Silesij
Trigonometriae

2 Ralph Handson, in his *Trigonometry*, 1614, reminds the student that the solution of the trigonometrical problems he gives can be greatly facilitated by 'prosthaphaeresis', a method of calculation devised for the solution of spherical triangles.

The method consists in the use of the formula
\[ \sin A \sin B = \frac{1}{2} (\cos (A - B) - \cos (A + B)) \]
by means of which the multiplication of two sines is reduced to the addition or subtraction of two tabular results taken from a table of cosines; and, as such products occur in the solution of spherical triangles, the method affords the solution of spherical triangles in certain cases by addition and subtraction only. It seems to be due to Wittich of 29—A.O.N.
Handson had studied mathematics under Briggs at Gresham College, he was a friend of Richard Hakluyt, and was associated with Sir Thomas Smith and John Wolstenholme. Indeed he dedicated his work to them as 'the sole Founders and Erectors of the Lecture of Navigation' in the City, and as 'two of the principall advancers of the North West discouerie'—1614, it will be recalled, was the year Captain Gibbons was embayed in Discovery on the coast of Labrador, having been dispatched by the North-West Passage Company, in which Sir Thomas Smith and Wolstenholme were prominent, to continue the exploration of Hudson’s Bay, begun by Hudson in 1610, and since carried on by Sir Thomas Button in search of the North-West Passage. Though Handson was no seaman, his studies at Gresham College and his discussions with Richard Hakluyt had enabled him to gain an excellent grasp of the current navigational practices and problems. He understood that only that man who combined practical experience in seamanship with 'the perfect knowledge of (this) Trigonometrie' could be termed an 'Absolute Marriner, fit to take charge in al voyages'. Accordingly, upon being pressed by Richard Hakluyt and other friends to publish for the advancement of the art of navigation the translation which he had already made of Pitiscus’s work, Handson perfected it for this purpose by showing in an appendix the practical application of its contents to some nautical problems. When, sixteen years later, he revived the work in a second edition and rededicated it to the Master, Wardens, and Assistants of Trinity House he assured them that the proof of its worth lay in the many mariners who by their own industry had

Breslau, who was assistant for a short time to Tycho Brahe; and it was used by them in their calculations of 1582. Wittich in 1584 made known at Cassel the calculation of one case by this prosthaphaeresis; and Justus Brygius proved it in such a manner that from his proof the extension to the solution of all triangles could be deduced. Clavius generalized the method in his treatise De astrolabio (1593), lib i, lemma iii. Wittich's prosthaphaeresis could not be a good method of practically effecting multiplications unless the quantities to be multiplied were sines. It satisfies the condition, however, equally with logarithms, of enabling multiplication to be performed by the aid of a table of single entry; and analytically considered, it is not very different in principle from the logarithmic method.

**Trigonometry:** OR THE DOCTRINE OF TRIANGLES. First written in Latine, by BARTHOLMEW [sic] PITISCVS of Grunberg in Silesia, and now Translated into English, By Ra: Handson. Whereunto is added (for the Marriners vse) certain Nauticall Questions, together with the finding of the variation of the Compasse.

All performed Arithmetically, without Mappe, Sphaere, Globe, or Astrolabe, by the said R.-H.

Printed for Io: Tappe.

**Imprint:**

LONDON.

Printed by Edw: Allde for John Tap, and are to be sold at his shop at St. Magnus corner. 1614.
benefited by studying the earlier edition,¹ and there can be little doubt that he spoke the truth, for until Gunter’s *De Sectore & Radio* was printed in 1623 no other published work gave so complete an explanation of the application of trigonometry to navigation. Indeed in some respects Handson’s *Trigonometry* was not superseded by Gunter’s book, for Handson gave fuller trigonometrical explanations and proofs than did Gunter.

The first five books or parts of the *Trigonometry* were translations of Pitiscus’s original work and treated respectively of the nature and quality of triangles, and of tables of sines, tangents, and secants; of the measuring of plane and of spherical triangles, and brief rules on trigonometrical calculation. Then followed Handson’s original contributions, ‘Questions of Navigation, performed Arithmetically by the Doctrine of Triangles, without Globe, Sphaere or Mappe’, and ‘Two most profitable propositions for the finding of the Variation of the Compass’. ‘A Canon of Triangles, or The Table of [Natural] Sines, Tangents and Secants’, from Pitiscus’s first tables, for every degree and minute completed the work. Handson’s ‘Questions of Navigation’ were designed especially to show the disagreement between the ordinary plane sea-chart and the globe and the agreement between the globe and ‘a true Sea-chart’ made on ‘Edw: Wright’s projection’, and consequently the benefit of working in arithmetical navigation. Having explained latitude and difference of latitude, longitude (measured ‘from some fixed Meridian into the East’ from ‘1. to 360 degrees’) and difference of longitude, Handson, like Gunter, gave the formulae for raising or laying one degree of latitude on any course and for converting departure—or distance between places on the same latitude—into difference of longitude. He then enunciated five of the six propositions formulated by Hues—all except the third—and thus ten of Gunter’s twelve—all except his ninth and twelfth (given the difference of longitude and the distance between two places, and one latitude, to find the rhumb and the difference of latitude)—and gave formulae appropriate to their solution. What were most important, because most helpful, were the accompanying examples illustrated with line diagrams and full mathematical solutions. Moreover, unlike Gunter, he expressed his formulae in terms best suited for use with trigonometrical tables; thus for instance, when explaining how to calculate how many miles had to be sailed on a given rhumb to raise or lay one degree of latitude, Handson gave as one of the formulae ‘distance = difference of latitude × secant of the course’ or ‘dist. = d. lat. sec. (Co.)’, whereas Gunter had given for use with his sector only ‘dist. = \( \frac{d. \text{ lat.}}{\cos (\text{Co})} \). Making the calculation with

¹ *Trigonometrie*: or, THE DOCTRINE OF TRIANGLES. First written in Latine, by BARTHOLOMEW PITISCVS of Grunberg in Silesia, and now Translated into English, By RA: HANDSON. Whereunto is added (for the Marriners vse) certaine Nauticall Questions, together with the finding of the Variation of the Compass. All performed Arithmetically, without Map, Sphaere, Globe, or Astrolabe; by the said R.H.

Printed by B. A. and T. Fawcet, for J. Tap. [1630].
tables it was easier to use Handson’s secant formula because it involved multiplication instead of division and this was an important consideration in the days before logarithms were used. Thus to find how many miles to raise or lay a degree of latitude on a course of 67° 30’ the working, explained Handson, is

\[
60 \times \sec 67° 30’ = 60 \times 26131
\]

\[
= 156\cdot78
\]

[ miles]

\[
\]

\[
\]

whereas using the cosine formula the working is:

\[
60 \div \cos 67° 30’ = \frac{60}{3827}
\]

which involves an awkward long division sum to produce the equivalent answer: 156\,298.8

Nor is the answer nearly so neat for 298.8 is not so convenient a fraction as 78.6.

If St. Mary’s Island in the Azores and Cape St. Vincent lie in the same latitude, 37° N, and if the longitude of the former is 351° 10’ and of the latter 007° 10’, wrote Handson, explaining how to find the distance of two places lying on one latitude, then although the plane chart shows the distance between them as being 960’ it is in fact 766.6’ and the plane chart is in error by 194’. In proof of this he gave two methods of determining the departure, using the formula ‘dep. = d. long. cos (lat.)’, on the following lines:

<table>
<thead>
<tr>
<th>St. Mary’s Island</th>
<th>37° N</th>
<th>351° 10’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cape St. Vincent</td>
<td>37° N</td>
<td>007° 10’</td>
</tr>
</tbody>
</table>

344° 0’
360° 0’

Difference of Longitude

16°
60’

960’

But in Latitude 37° N. Natural Cosine 37° = .7986

∴ Miles to a degree of longitude = 60 × .7986 = 47\,216.0

∴ Departure = 16° × 47\,216.0 = 766.6\,5.6

He then showed that the same answer was obtained by taking the d. long. in minutes and multiplying by cos (lat.), i.e. 960 × .7986 = 766.6’.

Unquestionably Handson’s most important personal contribution to the art of navigation was his trigonometrical solution of the next problem,
'The longitudes and latitudes of 2 places being given, both on one side of the Equinoctiall, to finde their bearing and distance'.

He illustrated the solution by considering the problem of finding the course and distance between 'the Lizard in Cornewall, and an Island lying in the mouth of Lumleys Inlet, in fretum Davis', which he placed respectively in latitude $50^\circ\ 10'\ N$, longitude $17^\circ$, and latitude $63^\circ\ 00'\ N$, longitude $309^\circ$, thus obtaining a difference of latitude of $12^\circ 50' = 770'$, and difference of longitude of $68^\circ = 4080'$. He then drew a right-angled triangle ABC in which AC represented the difference of longitude, BC the difference of latitude and AB the bearing and distance between the Lizard (A) and Lumley's Inlet (B). According to this triangle, which represented one drawn on the ordinary chart, i.e. a plane chart, the bearing of A from B was '79^\circ\ 19' East by South' [S 79^\circ\ 19' E] and the distance '4153\ 0\ 6\ 11\ 0$ miles', the (erroneous) formulae \[\frac{\text{d. long.}}{\text{d. lat.}} = \frac{AC}{BC} = \frac{4080}{770} = \tan B\] (bearing of the Lizard from Lumley's Inlet) being used. This gave an answer of '52987' which reference to the table of natural tangents showed to be equal to an angle of $79^\circ\ 19'$.

The complement of this angle, $10^\circ\ 41'$, was $\angle BAC$ in the triangle, the bearing of Lumley's Inlet from the Lizard expressed as an angle above the parallel. On this basis the distance of Lumley's Inlet from the Lizard was the difference of longitude $\times$ the secant of $10^\circ\ 41' = 4080 \times 1.01764 = 4153'$. But, pointed out Handson, the correct basic formula for finding the bearing between the two places is the Mercator formula, \[\frac{\text{d. long.}}{\text{d.m.p.}} = \tan B\], where d.m.p. = the difference of latitude between the Lizard and Lumley's Inlet expressed in difference of meridional parts. He therefore extended the line BC on his diagram to E so that the distance CE represented the difference in meridional parts between the latitudes of the Lizard and Lumley's Inlet as found from Wright's table of meridional parts. Then $\angle CEA = \angle CEA$ = the true bearing of the Lizard from Lumley's Inlet and EA represented the distance between them. On this basis the Lizard bore S $70^\circ\ 53'$ E from Lumley's Inlet and was distant from there only $2351'$. There was thus an error of $81^\circ$ in the bearing and of $1800'$ in the distance as given by the plane chart.

For those who had not got 'Mr. Wright's booke' with its table of meridional parts this was cold comfort; consequently what they wanted was a formula which enabled them to get the correct answers without having to work in meridional parts. It was for such that Handson stated the mid-latitude formula. If, he explained, you were working with a globe and you wanted to find the departure between Lumley's Inlet and the Lizard you would measure the distance in miles between the meridian of Lumley's Inlet and the meridian of the Lizard on the parallel of latitude lying midway between their parallels of latitude; in other words you would convert their difference of longitude into departure by foreshortening it in
proportion to the cosine 'of the middle parallel'. But how do you find the cosine of the middle latitude? That was the question whose answer no navigator knew. There are, explained Handson, three ways and, although the results are not precisely true because sines, tangents, and secants do not differ by equal proportion, the answers are sufficiently accurate for ordinary use at sea.¹ The navigator, he explained, can take either the mean of the departure along the higher and the lower parallels of latitude—this gives a mid-latitude departure of 2232½ miles between Lumley's Inlet and the Lizard—or he can take the mean of the cosines of the two angles of latitude as being equal to the cosine of the middle latitude, and multiply the difference of longitude by this—which gives a mid-latitude departure of 2232 miles between Lumley's Inlet and the Lizard; or he can multiply the difference of longitude by the cosine of the mean of the latitudes. This last solution, the 'mean-latitude', or as it is usually expressed 'mid-latitude' formula, besides being the easiest to work with, gives, as Handson rightly considered, an answer 'neere enough for the Marriners vse'. Indeed using his formula—dep. = d. long. cos (mid-lat.)—the distance between Lumley's Inlet and the Lizard was found to be 2361 miles, on a bearing of S 70° 58' E, a result differing only by five minutes in angle and ten miles in distance from the true bearing and distance on the Mercator's chart.² Handson concluded the subject by comparing the results of the various methods, taking the calculations based upon the tables of meridional parts, because they were calculated to every minute of the meridian, as true. The results are tabulated in Table 19 on page 399.

¹ Difference of longitude into departure.
² The mid-latitude solution: dep. = d. long. cos (mid-lat.)

(i) Take the mean of the departure along the upper and lower parallels.

\[
\begin{align*}
\text{d. long. 4080'} & = 1852' \text{ dep. in lat. 63'} \\
& = 2613' \text{ dep. in lat. 50'} 10' \\
\text{sum} & = 4465' \\
\text{mean} & = 22321/2
\end{align*}
\]

(ii) Take half the sum of the cosines of the two latitudes as the cosine of the middle latitude and multiply d. long by it.

\[
\begin{align*}
\cos 63' & = 4540 \\
\cos 50' 10' & = 6406 \\
\text{sum} & = 10946 \\
\text{mean} & = 5473 = \cos 56° 49' \\
\text{d. long} 4080' \times 5473 & = 2,232'
\end{align*}
\]

(iii) Take the cosine of the mean latitude and multiply the d. long by it:

\[
\begin{align*}
\text{lat. } 63° 00' \\
\text{lat. } 50° 10'
\end{align*}
\]

\[
\begin{align*}
\text{diff. lat.} & = 12° 50' \\
\frac{1}{2} \text{ lat.} & = 6° 25' \\
\therefore \text{ mean lat.} & = 56° 35' \\
\therefore \text{ dep.} & = 4080 \cos 56° 35' \\
& = 2247'
\end{align*}
\]

\[
\begin{align*}
d. \text{ lat.} & = \tan (\text{Co}) = \frac{22321/2}{770} = 70° 58'; \text{ dist.} = \text{ d. lat. sec(}\text{Co}) = 2361'.
\end{align*}
\]
<table>
<thead>
<tr>
<th>Bearing of Lizard from Lumley’s Inlet</th>
<th>By Plane Chart</th>
<th>True</th>
<th>Error of Plane Chart</th>
<th>By Cosine of Mid-Lat.</th>
<th>Mid-Lat. Formula Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>S 79° 19' E</td>
<td>4,153'</td>
<td>2,351'</td>
<td>8' 26' E</td>
<td>S 70° 58' E</td>
<td>5' E</td>
</tr>
<tr>
<td>Distance of Lizard from Lumley’s Inlet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10' too much</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In practice except when the difference of latitude is large, or the latitudes themselves are high (as in Handson’s example) no appreciable error results from using the mid-latitude formula given by Handson. To avoid error the formula is in practice not used where distances over 600’ are involved, problems involving greater distances being solved by working in meridional parts.

All the propositions explained and any other questions of right-angle spherical triangles may be performed, Handson concluded ‘by the Circular Scale without Arithmetick;’ adding tantalizingly, for he neither described nor illustrated it, ‘The use of which Instrument is facile and fitting for all practitioners in the Mathematics.’

When, in 1614, John Tapp brought out a new edition of Norman’s The Newe Attractive, together with Borough’s treatise on variation, he omitted from the former the declination and other tables that had been included in the second edition of 1585, probably because he was now regularly publishing an up-to-date edition of The Seamans Kalender. He also omitted Borough’s concluding comments on variation, putting in their place six and a half pages of examples of mathematical navigation, and ‘A Canon of Triangles’—tables of natural sines, tangents, and secants—so that the ‘Judicious’ might keep themselves up to date, for John Tapp had no doubts that ‘Arithmetickall Calculation’ was the most important navigational development of recent years.\(^1\) In his short treatise he briefly explained what Gunter’s manuscript of six or seven years earlier had pointed out, namely, that if any two of the difference of latitude, departure

---

\(^1\) See Appendix 20. THE NEWE ATTRACTIVE, shewing the nature, property and manifold virtues of the Loadstone, with the Declination of the Needle, touched therewith, under the plaine of the Horizon, Found out and discovered by Ro: Norman. WITH THE APPLICATION thereof, for finding the true Variation of the Compas: As also diuers profitable rules and Instruments, for the more perfection and exactness in the Art of Navigation.

By maister W: Burrowes.

LONDON, Printed by T.C. for John Tappe, and are to be sold at his shop at S. Magnus corner. 1614.

See also page 401, note 1.
(or difference of longitude), distance sailed, and true course be known "you
may by the tables of Sines, Tangents and Secants, find eyther of the other
two", and then gave, together with examples, six formulae for finding
the course, distance, difference of latitude or departure:

\[
\frac{\text{distance}}{\text{difference of latitude}} = \text{secant (Course)}
\]

(2) difference of latitude \times \text{tangent (Course)} = \text{departure}

(3) difference of latitude \times \text{secant (Course)} = \text{distance}

(4) departure \times \text{tangent (90°—Course)} \text{ i.e. cotangent (Course)} = \text{difference of latitude}

\[
\frac{\text{difference of latitude}}{\text{departure}} = \text{tangent (90°—Course) i.e. cotangent (Course)}
\]

(6) (difference of latitude)² + (departure)² = (distance)²

the quantities on the left being those known, those on the right being those
sought.

"These few Propositions", he explained, "are sufficient for the examining
and correcting of a dead reckoning upon any course or distance what so
ever", and to facilitate the calculation he included a table showing the
distance to raise or lay a degree of latitude on each point and half-point,
and the resultant departure; finally he included an original example of
"How to finde the angle of position vpon a Traverse of severall points" by
the resolution of various traverses "into one direct course, with the
difference of Latitude and Longitude".

Supposing you sail 8 leagues S.W., 10 leagues W.S.W., 11 leagues
S.S.E., and 9 leagues E.S.E., he said, find by means of the table to raise
or lay a degree of latitude the difference of latitude, and then the departure
resulting from following such course, and set them down one under the
other, thus:

\begin{align*}
\text{points} & & \text{Leags. of dist.} & & \text{Min. of Lat.} = & \text{departure from 3° Meri.} \\
S.W. & 8 & 17\frac{1}{2} & & 5\frac{5}{7} & \text{Westerly} \\
W.S.W. & 10 & 11\frac{7}{7} & & 9\frac{3}{7} & \text{Westerly} \\
S.S.E. & 11 & 30 & & 4 & \text{Easterly} \\
E.S.E. & 9 & 10\frac{4}{5} & & 8\frac{4}{3} & \text{Easterly} \\
\end{align*}

Add all the Southerly mins. of latitude together \(= 69\)
Add all westerly departures together \(= 14\frac{3}{7}\)
Add all easterly departures together \(= 12\frac{4}{3}\)
deduct one from the other \(= 2\frac{1}{2} \text{ L.W.} \)

In fact what had been found was that the resultant difference of latitude
was 69 leagues South, and the resultant departure was 2\(\frac{1}{2}\) leagues West.
As a result the ship's position could be quickly plotted and, by means of
the fifth proposition, the course made good could be calculated and by
either the third or the sixth, the distance made good.
Whoever wanted to know more about this kind of 'Arithmetical sailing', let him, concluded Tapp, study Handson's recent translation of Pitiscus's 'doctrine of Triangles', published 'for the benefit chiefly of our English Marriners'. There he would find of course the explanation and proof of the mid-latitude formula and a mathematical exposé of the errors of the plane chart. Although Tapp's short explanation of arithmetical navigation omitted these matters, it was unquestionably the clearest introduction to its subject, while his method of resolving several traverses was as admirable as it was novel. Although the source of Tapp's examples was probably Gunter's manuscript it is to be remarked that, like Handson, Tapp included formulæ not given by Gunter. As the publisher of Handson's Trigonometry of 1614 and of the 1614 edition of Borough's Variation of the Cumpas, and as the probable author of its mathematical additions, Tapp, to say nothing of his other publications, ranks high amongst the men who, in the early seventeenth century, went far towards transforming the art of navigation into a science by bringing into use the methods of 'arithmetical navigation'. Nevertheless, it is doubtful whether arithmetical navigation would have come into such rapid and widespread use as it did had not other mathematical developments of a novel, indeed revolutionary, nature by a coincidence been made and published at the same time.¹

¹ In his third edition of The Seamans Kalender, which he published in 1608, Tapp included a table of sines 'for Arithmetical calculatio'. He preceded it with fifteen propositions which, he stated, could be solved with its aid. Eleven concerned the solution by calculation of astronomical problems, such as finding the sun's amplitude and meridional altitude. Four concerned the sailing triangle. The first two were correct, namely, that, given the latitude, the length of a degree of longitude in it could be found by multiplying 60 miles by the cosine of the latitude; and that given the course and distance sailed the difference of latitude equalled the distance sailed multiplied by the cosine of the course. Two of his propositions, however, were incorrect because, although they involved difference of longitude or departure, he did not work in meridional parts. Given the course and distance sailed in miles you can find the difference of longitude, stated Tapp, by multiplying the distance by the sine of the course and dividing the resultant departure by the number of miles in a degree in the latitude arrived at; and, given the distance and departure sailed in miles you can find the sine of the course by dividing the departure by the distance. Tapp was clearly ignorant at this time of the mid-latitude formula as well as of the significance of meridional parts.
Chapter Five

LOGARITHMICAL NAVIGATION

'This new course of Logarithmes doth cleane take away all the difficultie
that heretofore hath beene in mathematicall calculations.'
John Napier, Mirifici Logarithmorum Canonis Descriptio, Edinburgh,
1614.

It was in 1614 that John Napier, laird of Merchiston, a property then
on the outskirts of Edinburgh, published in that city a small quarto
volume of one hundred and forty-seven pages entitled Mirifici Logarithmorum
Canonis Descriptio. It consisted of ninety pages of mathematical
tables and fifty-seven pages of explanatory text written, as became a work
intended for scholars in all lands, in Latin.1 Probably no work has ever
influenced science as a whole, and mathematics in particular, so pro-
foundly as this modest little book. It opened the way for the abolition,
one and for all, of the infinitely laborious, nay, nightmarish, processes
of long division and multiplication, of finding the power and the root of
numbers, that had hitherto been the inescapable lot of every mathema-
tician in every walk of life. It described and tabulated Napier’s invention
of logarithms—the rare and exquisite Invention of the Logarithmes’
as it was soon called—and ‘gaue directions how to resolue all the Propositions
of Trigonometrie by Addition, and Subtraction, which were never
performed before without Multiplication, and Division . . .’.

Napier, born in 1550 of a father aged fifteen, had been educated at St.
Andrews University, whither he had gone at the age of thirteen, and after-
wards apparently abroad. Returning to Scotland after some years he had
married and settled down in Stirlingshire as a landed proprietor in 1573.
In the house which he built at Gartner he lived for over thirty years
paying special attention to the fertility of the soil, becoming embroiled
for a time in religious controversy, and pursuing as a hobby investiga-
tions into the problem of facilitating mathematical calculation. He was in fact
a mathematical genius who set his mind to the business of simplifying the
processes. He found at length, in about 1594, a way of replacing multi-
plication and division by addition and subtraction. Twenty years of calcu-
lation followed.

The tables which Napier eventually published were for sines for every
minute to seven figures.

1 MIRIFICI Logarithmorum Canonis descriptio, Eiusque usus, in utraque
Trigonometria; ut etiam in omni Logistica Mathematica, Amplissimi, Facillimi,
& expeditissimi explicatio Authore ac Inventore IOANNE NEPERO, Barone
Merchistonii, &c. Scoto. EDINBURGI, Ex officina ANDREAE HART Bibliopola,
CIO.DC.XIV.

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NAPIER AND BRIGGS

Napier’s logarithms were not what are now termed Naperian or hyperbolic logarithms—logarithms to base $e$. These were first computed for the trigonometrical functions, and published under the title of *New Logarithmes* by John Speidell, a teacher of mathematics in London of some dozen years’ standing.¹ *New Logarithmes* consisted of a ‘Canon for Sphaerical Triangles, made with Sines, Tangents, and Secants . . .’ but without any explanation of their use except for a statement on the title-page that they could ‘be used by every one that can onely adde and Subtract, in whole numbers according to the common or vulgar Arithmetike’, which Napier’s could not. Despite the brevity of his instructions Speidell’s work was sufficiently in demand for a sixth impression to appear by 1624.

For the logarithms in most common use to-day, the world is chiefly indebted to Henry Briggs. He had been Gresham Professor of Astronomy since the foundation of the College, and by 1614 was already noted in the mathematical and navigational world for his ‘Table to find the Height of the Pole, the Magnetical Declination or Dip being given’, published in Blundeville’s work of 1602 on the planets, and for his ‘Tables for the Improvement of Navigation’, included in the second (1610) edition of Wright’s *Certaine Errors*. Briggs must have got a copy of Napier’s *Descriprio* upon publication and have at once grasped the profound significance of the logarithms. Conscious of the charge laid upon him by the founder of his College he had, we are told, promptly ‘explained, and highly extolled the same *Invention* in his ordinary *lectures* at Gresham Colledge’. He was particularly struck by their possibilities for expediting calculations of all kinds, besides trigonometrical

¹ NEW LOGARITHMES. The First intusion whereof, was, by the Honourable Lo: IOHN NEPAIR Baron of Marchiston, and Printed at Edinburg in Scotland, Anno: 1614. In whose vse was and is required the knowledge of Albraicall Addition and Subtraction, according to + and —.

These being Extracted from and out of them (they being first ouer scene, corrected, and amended) require not at all any skill in Algebra, or Cossicke numbers, But may be vsed by euer one that can onely adde and Substract, in whole numbers, according to the Common or vulgar Arithmetike, without any consideration or respect of + and —

By IOHN SPEIDELL, professor of the Mathematickes, and are to bee solde at his dwelling house in the Fields, on the backe side of Drury Lane, between Princes streete and the new Play-house. *The first Impression*. 1619.

The tables were arranged in this manner:

<table>
<thead>
<tr>
<th>Deg. 0</th>
<th>Numbers for the</th>
<th>M.</th>
<th>Sine</th>
<th>Comp.</th>
<th>Tangent</th>
<th>Comp.</th>
<th>Secant.</th>
<th>Comp.</th>
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<tr>
<td>0</td>
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<td>oooooo</td>
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<tr>
<td>Comp.</td>
<td>Sine</td>
<td>Comp.</td>
<td>Tangent</td>
<td>Comp.</td>
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</tr>
</tbody>
</table>

Nombers for the Deg. 89
ones, provided the necessary tables could be calculated. He gave expression to his views in his lectures, and wrote of them also to Napier.

Briggs was now a man of fifty-four or five, a bachelor accustomed to a collegiate life, of a mild disposition and studious bent, but the spirit of scientific invention and of public service burned so bright within him that he could not rest until he had discussed his projects with the inventor of logarithms himself. Accordingly, at the earliest opportunity, in the following summer of 1615, the summer being the only suitable season of the year for such long journeys, Henry Briggs travelled to Edinburgh. He took with him examples of his proposed logarithms and spent a month in the society of Napier. Napier confessed that, like Briggs, he had thought of making a change but gout, age, and his duties as Laird of Merchiston, had combined to prevent him from undertaking the task. That he must leave to younger men, and men freed from the cares of public office and private property. Upon further conference between them ‘it was conceived most convenient that 000 000, etc. should be appointed the Logarithme of the Radius’. It was Napier who suggested 0 as the logarithm of unity and 10 000 000 000 as the logarithm of the whole sine, it was Briggs who gracefully acknowledged it to be by far the most convenient system and who gladly undertook to compute the logarithms.

Meanwhile, Wright, like Briggs, had also perceived the importance of Napier’s work. Moreover, with his strong navigational bent he had seen that, if the Latin text was put into plain English, it would prove to be ‘of very great use for Mariners . . . a booke of more than ordinary worth, especially for Sea-men’. Accordingly, with the encouragement and, through his lectureship, the financial support of the East India Company, he had undertaken the task of translation. He had submitted the result, together with a diagram for finding proportional parts which he had devised to simplify interpolation, to Napier for his approval. This Napier conceded, but unfortunately Wright died before he could complete the work, apparently in December 1615.

On the news of Wright’s death the indefatigable Briggs immediately undertook to complete his work and, with Wright’s son Samuel, to see it through the press. It appeared the next year, A Description of the Admirable Table of Logarithmes.

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1 A DESCRIPTION OF THE ADMIRABLE TABLE OF LOGARITHMES: with A DECLARATION OF THE MOST PLENTIFUL, EASY, and speedy use thereof in both kindes of Trigonometrie, as also in all Mathematicall calculations. INVENTED AND PUBLISHED IN LATIN BY THAT Honorable L. IOHN NEPAIR, baron of Marchiston, and translated into English by the late learned and famous Mathematician Edward Wright. With an Addition of an Instrumentall Table to finde the part proportionall, inuented by the Translator, and described in the end of the Booke by HENRY BRIGS Geometry-reader at Gresham house in London. All perused and approvvd by the Author, & published since the death of the Translator. LONDON, Printed by NICHOLAS OKES. 1616.
Samuel Wright dedicated the translation 'to the Right Honourable and Right Worshipful Company of Merchants of London trading to the East Indies', and it is important to note that he did so not so much for 'their favours towards his deceased Father and their imployment of him', as for 'their continuall imployment of so many Mariners in so many goodly and costly ships, in long and dangerous voyages', and because it was for the use of these men, '(though many other ways profitable)', that his father had believed that the 'little booke' would be 'chiefly behooueful'. Thus, and it is probably not generally realized today, logarithms were first brought into popular use primarily in the interests of easier and more accurate navigation.¹

In his day Edward Wright was a man most highly esteemed. His death brought a loss to his friends and to his countrymen, and to the mariners of England most of all. He it was who had answered the prayers of their forefathers for a chart upon which they could plot the way of a ship through the sea. Even in death he had greatly eased the burden of finding their place in great waters.

Today Wright's name is remembered by few. His greatest work—his chart projection—bears the name of another. He was a modest man, yet one, indubitably, who held John Aspley's creed faithfully unto death, that 'we are not born for ourselves onely, but our friends challenge a part in us, and our Countries...' and

especially... *those that traffique in the deepe, and have their businesse in the great waters*, those that are unto this Island as a woodden wall, the Sea-chariots, and the horses of *England*: these, I say, may claime justly to the fruits of our labours, whatsoever they be which have not altogether been abhorrent from the Mathematicall studies...to further that so much deserving Science of Navigation...²

The preface of Wright's *Description* of Napier's tables of logarithms is a translation of Napier's own preface in his *Descriptio*, with the addition

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¹ The following lines by Richard Lever, 'In the last praise of this Booke, Author, and Translator', sums up its use:

*The toylesome Rules of due Proportion*

*Done here by Addition and Subtraction,*

*By Bi partition and Tripartition,*

*The Square and cubicle rootes extraction:*

*And so, all questions Geometricall,*

*But with most ease Triangles-sphaerical.*

*The use is great in all true Measuring...*

*Geography and Navigation...*

*In Latine to the world it first appear'd*

*Strange unto them to whom that tongue is strange:*

*But he who eart our Navigation clear'd,*

*From that strange tongue to English did it change,*

*That famous, learned, Errors true Corrector,*

*Englands great Pilot, Mariners Director. Ri. Lever.*

of some sentences by Napier commending the translation as accurate and as conformable to his mind and original work. There was, however, a second preface and a description by Briggs of the 'Instrumental Table to find the Part Proportional' devised by Wright. In his preface Briggs pointed out that in the past much time, effort and money had been spent on 'the making of the Tables of Sines, Tangents, and Secants, that by the helpe of them we may attaine to the knowledge and vse of the Mathematices, and especially of Astronomic and Navigation ...'. We have only to think of the monumental labours of Peuerbach and Regiomontanus, of Rhaeticus, Clavius, and Piticus, the last of whom had completed the ultimate version of the tables only two years before Napier's *Descriptio* appeared, to realize the truth of Brigg's observation and to appreciate the marvellous nature of Napier's invention for, to use Brigg's words, 'this little Table of Logarithmes', prepared by an elderly man in his leisure hours from family cares and the responsibilities of a progressive landlord, 'may for exactnesse and certainty compare with all those Tables, and for ease and expedition go very farre beyond them for all Trigonometrical operations especially Sphaerical'. Briggs added that, seeing that he himself had publicly taught the meaning and use of the book at Gresham College it was only right that he should write 'of the excellent use of it to those who ... cannot come to heare me ...'. The tables that follow are unchanged from Napier's, except for having the seventh figure omitted, a small error having been found in the last figure of Napier's logarithms. Marvellous as was Napier's invention, he owed a debt to those mathematicians of the last two centuries who had laboured to compile tables of the natural trigonometrical functions—tables which, though the latest of a long series had only just been published, his little book had rendered obsolescent.

In the summer of 1616, probably after completing his work on Wright's translation of the *Descriptio*, Briggs paid a second visit to Napier to show him and to discuss with him his progress on the project of producing logarithms of whole numbers. Napier was then busy on a book describing his invention for speeding up calculation mechanically by means of 'little rods', a calculating device later known, from the ivory of which the rods were made, as 'Napier's bones'. In the same book, *Rabdologiae seu numerationis per virgulas libri duo*, which was published in Edinburgh early in 1617, Napier also described a calculating machine which was in fact the prototype of modern office calculating machines.¹ It was his last work, though not the last to be published. Worn out by his labours and his sufferings from gout he died on the first day of April, in 1617, before Briggs could pay him a third visit as he had intended to do. The probability

¹ *RABDOLOGIAE, SEV NUMERATIONIS PER VIRGULAS LIBRI DVO: Cum APPENDICE de expeditissimo MULTIPLICATIONIS PROMPTVARIO. Quibus accessit & ARITHMETICAES LOCALIS LIBER VNVS. Authore & Inventore IOANNNE NEPERO, Barone MERCHISTONII, &c. SCOTO, EDINKGBORGI, Excudebat Andreas Hart, 1617.*
therefore is that Napier never saw the slim table of logarithms, *Logarithmorum chilias prima* that some time in 1617 Briggs had printed, probably privately, 'for the sake of his friends and hearers at Gresham College'.

It is a small octavo volume of sixteen pages and contains the first table of common logarithms ever calculated. The numerals run from unity to 1000—the title means 'The First Thousand Logarithms'—and the logarithms are calculated to fourteen places of decimals. Briggs’s system of decimal notation consisted in underlining the decimal figures, so that 2312 signified 23.12, this being his abbreviated way of writing $23\frac{12}{10^0}$.

This was of course only a preliminary work. To his dying day he was henceforth to devote his energies primarily to the compilation of definitive logarithmic tables. However, from a scholar’s point of view a most important task had still to be carried out. This was the publication of Napier's explanation of his method of constructing logarithmic tables. Kepler had urged this upon Napier, particularly as Napier had already composed the description; indeed he had done so before he had calculated the tables or thought of the word 'logarithm' ($= \text{ratio number}$) for describing his 'artificial numbers'. As Napier died before his description of the construction of logarithms was published, his son Robert forwarded the manuscript to Briggs, asking him to edit and publish it. This Briggs did, and the work, entitled *Mirifici Logarithmorum Canonis Constructio*, came out in 1619, the same year that John Speidell published his *New Logarithmes*. Besides explaining the construction of his logarithms Napier’s *Constructio* contained ‘some very remarkable propositions for the solution of spherical triangles with wonderful ease’ without dividing them into two quadrants.

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1. **LOGARITHMORVM CHILIAS PRIMA:**
   
   Quam autor typis excudendum curavit, non eo concilio, ut publici iuris fieret; sed, partim, ut quorundam suorum necessarium desiderium priuatim satisfaceret: partim, ut eius adiumento, non solum Chilias aliquot inequivalentes; sed etiam integrum Logarithmorum Canonem, omnium Triangulorum calculo inseruientem commodius absolueat. Habet enim Canonem Sinuum, a seipso, ante Deoconium, per aequationes Algebraicas, & differentias, ipsis Sinubus proportionales, pro singulis Gradibus & gradu centesimis, Â primis fundamentis accuratissimae extruere: quem vna cum Logarithmum adiunctis, volente Deo, in lucem se daturum sperat, quam primum commode licuerit.

   Quod autem hi Logarithmi, diversi sint ab ijs, quos Clarissimus inuentor, memoriae semper colendae, in suo edidit Canone Mirifico; sperandum eius librum posthumum, abunde nobis propediem satisfacimur. Qui autori (cum eum domi suae, Edinburgi, bis inuisseret, & apud eum humanissime exceptus, per aliquot septimanas libentissime mansisset; eique horum partem praecipuam quam tum absoluerat ostendisset) suadere non desitut, ut hinc in se laborem susiceret. Cui ille non inuitus morem gessit.

   In tenui; sed non tenuis, fructusse laborve.

   The date is established as being between April 1617, the date of Napier's death, (through Briggs's reference to Napier's 'librum posthumum') and December 1617 (when Sir Henry Bourchier wrote to Ussher mentioning the book).


or rectangular triangles, as had been necessary hitherto, and this completed the development of the modern formulae for the solution of spherical triangles. An important treatise on the use of versed sines, or versines as they are termed today, and amplifying or explanatory notes by Briggs completed the work.

Meanwhile, in 1618 a second edition of Wright's translation of Napier's *Descriptio*, with additional matter, had appeared. As yet, however, no tables of common logarithms of the trigonometrical functions had been published. It was these that the navigational world awaited if it was to use logarithms. It had not to wait long, for the business of preparing the tables was already in hand. At Gresham College there had been changes in the professorial staff. Someone in the City, or some of the city fathers, had at heart the interests of scientific developments, particularly those that could improve navigation, and thus commerce overseas. The first move had been the preferment of Edmund Gunter to the living of St. George's, Southwark, in 1615. Since becoming an M.A. in 1606 Gunter had taken holy orders and had proceeded to take his B.D. Perhaps it was on this account that, when Brerewood, the first Professor of Astronomy at Gresham, had died in 1613, the chair had not gone to Gunter but to Williams. However that may be, it was on taking his B.D. in 1615 that Gunter had been preferred to this London parish that lay only just across the Thames from Gresham College, easily accessible by way of London Bridge. The arrangement brought England's three most productive mathematicians—for Wright did not die till the end of the year—into close consultation. Perhaps Briggs was the moving spirit behind the scenes. He certainly was a close friend of Gunter's, and lost no opportunity of introducing him to his own mathematical friends. For instance, when, in 1610, William Oughtred, the rector of Albury in Surrey, and one of the most gifted mathematicians of the age, called on Briggs he was introduced to Gunter and the two quickly fell into conversation over mathematical instruments. Briggs certainly interested Gunter in the preparation of logarithmic tables and must early have enlisted his help for, when Williams resigned from his Gresham chair in 1619, Gunter, in the March of that year, was elected to take his place, and only a year later published tables of common logarithms of the trigonometrical functions. Gunter's *Canon Triangulorum sive Tabulæ Sineum et Tangentium artificialium ad Radium 1000,0000*, of which another edition, *Canon of Triangles or Table of Artificial Sines and Tangents*, to a radius of 1000,0000 parts to each minute of the quadrant appeared in the same year, was one of the fundamental books of arithmetical, or modern, navigation. It did for the trigonometrical functions what Briggs had done for numerals from 1 to 1000. Like Briggs's *Logarithmorum Chilias Prima*,

1 CANON TRIANGVLORUM, SIVE Tabulæ Sineum et Tangentium artificialium ad Radium 1000,0000. & ad scrupula prima quadrantis, Per EDM: GUNTER, Professorem Astronomiae in Collegio Greshamensi. LONDINI, Excudebat Gulielmus Iones. MDCXX.
which besides tables had contained only a single page of text in Latin on
their value, Gunter’s Canon contained no explanation of its use. A single
page at the front described the method of taking out sines, secants, and
tangents, cosines, and cotangents (the last two words first coined by Gun-
ter in this work) giving as an example the latitude of London—$51^\circ \, 32'$ (N).
Briggs’s logarithms and Gunter’s were laid out as below:

**TABLE 20**

**PART OF THE SECOND PAGE OF BRIGGS’ LOGARITHMORUM CHILIAS PRIMA, 1616, THE FIRST PAGE OF LOGARITHMS OF NUMERALS TO BASE 10:**

<table>
<thead>
<tr>
<th>2</th>
<th>Logarithmi</th>
<th>Logarithmi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0000,000000,00000</td>
<td>34</td>
</tr>
<tr>
<td>2</td>
<td>3010,29995,66398</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>34</td>
<td>15314,78917,04226</td>
<td>67</td>
</tr>
</tbody>
</table>

**TABLE 21**

**PART OF A PAGE OF GUNTER’S CANON TRIANGULORUM, 1620, THE FIRST LOGARITHMS TO BASE 10 OF THE TRIGONOMETRICAL FUNCTIONS**

<table>
<thead>
<tr>
<th>$M$</th>
<th>Sin. 38</th>
<th>Cosine 38°</th>
<th>Tan. 38</th>
<th>Cot. 38°</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>9789</td>
<td>3419</td>
<td>9896</td>
<td>5321</td>
</tr>
<tr>
<td>1</td>
<td>9</td>
<td>5036</td>
<td>4334</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>6651</td>
<td>3346</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>9793</td>
<td>8317</td>
<td>7452</td>
<td>9900</td>
</tr>
<tr>
<td>29</td>
<td>3</td>
<td>9907</td>
<td>6448</td>
<td>0</td>
</tr>
<tr>
<td>30</td>
<td>4</td>
<td>1495</td>
<td>5443</td>
<td>0</td>
</tr>
</tbody>
</table>

Today these are tabulated typically, in Inman’s Nautical Tables, for instance, as follows:

**TABLE 22**

<table>
<thead>
<tr>
<th>Log. Sine 38°</th>
<th>Log Sine 51°</th>
<th>Log Tangent 38°</th>
<th>Log Tangent 51°</th>
</tr>
</thead>
<tbody>
<tr>
<td>0’</td>
<td>9.78934</td>
<td>60’</td>
<td>60’</td>
</tr>
<tr>
<td>30’</td>
<td>9.79415</td>
<td>30’</td>
<td>30’</td>
</tr>
<tr>
<td>60’</td>
<td>9.79887</td>
<td>0’</td>
<td>0’</td>
</tr>
</tbody>
</table>

Log. Cosine 51° Log Cosine 38° Log Cotangent 51° Log Cotangent 38°

30—A.O.N.
Gunter’s tables followed immediately after his explanatory note, and it
will be noticed that in the tables he omitted cosine and cotangent captions
(added in brackets here) from the columns. In a half-page at the end of the
book he stated, in Latin, that the tables were valuable for the solution of
spherical triangles and, with the logarithms of his friend and colleague,
Briggs, for the solution of plane triangles. Another edition of Gunter’s
Canon of Triangles, appeared in 1623.1

Gunter’s reference to Briggs is a reminder that the latter was still
Gresham Professor of Geometry, and that he first published his logarithms
while he held that chair. Fate has decreed, however, that that distinction
be credited to him as Savilian Professor of Geometry at Oxford. This is
because, four years after the period of which we are speaking, and several
after the publication of his Chilias, when he was Savilian Professor of
Geometry, Briggs published a much larger work than the Chilias, con-
taining logarithms from 1 to 20,000 and from 90,000 to 100,000 (in some
copies to 101,000) to fourteen places of decimals, and with an eighty-
eight page introduction, in Latin. This explained, for the first time for
common logarithms, their general application. It did not, however, deal
with their particular application to navigation. Briggs’s Arithmetica
Logarithmica of 1624, a folio work was thus, since his Chilias was most
probably printed privately, the first of his works to come before the
public, and for this reason the logarithmic honours have been awarded
him as ‘Henricus Briggius in celeberrima Academia Oxoniensi geo-
metriae professor Savilianus’, as the title-page of his Arithmetica
Logarithmica expressed it, and not as Gresham Professor of Geometry at
London.2

It was in 1619 that Sir Henry Savile, who had for long lectured at Oxford
on mathematics, established there chairs of Astronomy and Geometry,
or as we would say today, of Mathematics. Doubtless he perceived the
lead that Gresham College was gaining in scientific matters. It is certain

1 Canon Triangulorum, Or Tables of Artificial Sines and Tangents, to a Radius
of 1000,000 parts, and each minute of the quadrant. By Edm. Gunter Professor of
Astronomie in Gresham College. London, Printed by William Iones, and are to be
sold by Edmund Weauer. 1623.

2 ARITHMETICA LOGARITHMICA

SIVE LOGARITHMORVM CHILIADES TRIGINTA, PRO numeris
naturali serie crescentibus ab unitate ad 20,000: et a 90,000 ad 100,000. Quorum
ipse multa perficiuntur Arithmetica problemata et Geometrica. HOS NVMEROS
PRIMVS INVENIT CLARISSIMVS VIR IOHANNES NEPERVS Baro
Marchistonij: eos autem ex ejusdem sententia mutavit, eorumque ortum et vsum
illustravit HENRICVS BRIGGIVS, in celeberrima Academia Oxoniensi
Geometriae professor SAVILIANVS.

DEUS NOBIS VSVRAM VITAE DEDIT ET INGENII, TANQVAM
PECVNIAE, NVLLA PRAESTITVTA DIE.

[‘I.R.’ and royal arms follow here.]

LONDINI, Excudebat GVLIELMVS IONES. 1624.
that like Gresham himself he was deeply conscious of the contribution that research on these subjects could make to human knowledge, wealth, and skill. He munificently endowed his chairs, then invited one, Bainbridge, who has been described as 'a respectable character interested in comets', to be the first Professor of Astronomy.¹ The chair of Geometry he offered to Briggs. Briggs accepted, but he did not relinquish his Gresham post until July 1620 so that he and Gunter worked together there for over a year.² Meanwhile Savile acted in Briggs's capacity at Oxford.

The establishment of the Savilian chairs of Geometry and Astronomy meant that from henceforth the lead in scientific research that Gresham College had established was to be challenged. It also meant that the facilities for which Hakluyt had pleaded so earnestly nearly forty years before—for higher research into mathematics and astronomy at one of the older universities, and instruction in the heart of the country’s greatest port, London, in its application to navigation—had been brought into being. During the course of the seventeenth century Oxford and, when similar chairs were established there, Cambridge, were to strip the laurels of scientific research from Gresham's brow—largely with the aid of men from Gresham. But this casts no adverse reflection upon the College. Rather does it mean that Gresham College had long more than fulfilled its founder's hopes. Thus, as the century wore on, astronomy and mathematics became established at both the older universities; a Royal Observatory for the solution of the navigator's most intractable problem—longitude-finding—was functioning at Greenwich; at Christ's Hospital young scholars were being taught mathematics and navigation from text-books written especially for them; and, throughout the realm there was a quickening of the spirit of scientific inquiry and observation typified by the Royal Society which systematized the results.

Just as Gunter lectured at Gresham on the application of logarithms to navigation, so, it is clear, did Briggs. Indeed it would appear that he even used the same examples. So lucid are his explanations and so clear his examples that we can follow them with pleasure, for he had the art of presenting subjects that repel many even to this day because of their supposed difficulty, with a clarity that disarms antipathy. However, before we sample Briggs’s work we must follow the completion of logarithmic tables. While Briggs at Oxfordlaboured to fill the gap in his tables in *Arithmetica Logarithmica*, Adrian Vlacq on the Continent was equally hard at work. In 1628, having copied only 30,000 logarithms and calculated 70,000 he published at Gouda in Holland tables of logarithms from unity to 100,000, to ten places of logarithms and, using the tables of natural sines, tangents, and secants in Pitiscus's *Thesaurus Mathematicus* of 1613, the logarithms of sines, tangents, and secants for every minute of the quad-

¹ *The Times*, 30 November 1949. 'A Promoter of Learning.'
rant to ten places of decimals.\textsuperscript{1} He called the work \textit{Arithmetica logarithmica sive Logarithmorum Chiliaedes centum . . . editio secunda aucta per Adrianum Vlacq . . . thus paying a graceful tribute to Briggs’s pioneer labours.\textsuperscript{2} Briggs expressed only gratitude to Vlacq, although the latter had in fact forestalled the publication of his own definitive work on logarithms. This Briggs did not live long enough to complete. When he died in January 1631 Henry Gellibrand as Professor of Astronomy at Gresham continued his calculations, and in 1633 Vlacq published the resultant work at Gouda under the title of \textit{Trigonometria Britannica}.\textsuperscript{3} It embodied

\textsuperscript{1} \textit{THESAVRVS MATHEMATICVS}

\textit{Sive CANON SINUUM AD RADIUS 1.00000.00000.00000. ET ADDENDA QVAEVE SCRVPVLA secunda Quadrantis: UNA CUM SINIBUS PRIMI ET POSTREMII GRADUS, AD EVNDEM RADIVM, ET AD SINGVLA scrupula secunda Quadrantis: ADIVNTIS VBIQVE DIFFERENTIIS PRIMIS ET SEcundis; atq[ue], vii res tulti, etiam, tertiii. IAM OLIM QVIDEM INCREDIBILI LABORE & sumptu à GEORGIJO JOACHIMO RHETICO supputatus: AT NVNC PRIMVM IN LVCEM EDITVS, & cum viris doctis communicatus A BARTHOLOMAEO PITYSCO GRUNBERGENSI SILESIO. CVIVS ETIAM ACCESSERVNT:}

I. Principia Sinuum, ad radium, 1.00000.00000. 00000. 00000. 00000. quàm accuratissimè supputata.

II. Sinus decimorum, tricesimorum & quinquagesimorum quotumq[ue]; scrupulum secundorum per prima & postrema 35. scrupula prima, ad radium, 1.00000. 00000. 00000. 00000. 00.

FRANCOFURTII Excudebat Nicolaus Hoffmannus, sumptibus JONAE ROSAE ANNO CII. IC. XIII.

\[\text{[Sic., for 1613].}\]

\textsuperscript{2} \textit{ARITHMETICA LOGARITHMICA,}

\textit{SIVE LOGARITHMORVM CHILIADES CENTVM, PRO Numeris natural serie crescentibus ab Vnitate ad 100000. VNA CVM CANONE TRIANGVlorvm, SEV TABVLA ARTIFICIALIVM Sinuum- Tangentium & Secantium, Ad Radium 10,00000,00000. & ad singula Scrupula Prima Quadrantis, QVIBVS NOVVM TRADITVR COMPENDIVM- QVO NVLium nec admirabilis, nec utilius solvendi pleraque Problematra Arithmetica & Geometrica. HOS NVMVEROS PRIMVS INVENIT Clarissimus Vir IOHANNES NEPERVS. Baro Merchistonij; eos autem ex ejusdem sententiæ mutavit, eorumque ortum & usum illustravit HENRICVS BRIGGIVS, in celeberrimâ Academiâ Oxoniensi Geometriae Professor Savilianus. Editio Secunda aucta per ADRIANVM VLACQ Goudanum. DEVS NOBIS VSVRAM VITAE DEDIT ET INGENII, TANQVAM PECVIAE, NVLLA PRAESTITVTA DIE. GOVDÆ, Excudebat Petrus Rammassienius. M.DC.XXXVIII. Cum Privilegio Illust. Ord. Generalium.}

\textsuperscript{3} \textit{TRIGONOMETRIA BRITANNICA:}

\textit{SIVE DE DOCTRINA TRIANGVlorvm LIBRI Dvo.}

Quorum PRIOR continet Constructionem Canonis Sinuum Tangentium & Secantium, unà cum Logarithmis Sinuum Tangentium et Secantium, ad Gradus & Graduum Centesimas & ad Minuta & Secunda Centesimis respondentia: A Clarissimo Doctissimo Interregnoque Viro Domino HENRICO BRIGGIO Geometriae in Celeberrima Academia Oxoniensi Professore SAVILIANO Dignissimo, paulo ante inopinatum Ipsius e terris emigrationem compositus. POSTERIOR verò usum sive Applicationem Canonis in Resolutione Triangulorum tam Planorum quam Sphaericorum e Geometricis fundamentis petitæ,
the Herculean labours involved in computing log sines to fourteen places and log tangents to ten places of decimals, and natural sines, tangents, and secants, at intervals of a hundredth of a degree. Meanwhile, shortly after Briggs's death, friends in England had done what lay nearest to his heart, translated the *Arithmetica Logarithmica* into English and published it. This folio work came out in 1631 as *Logarithmicae Arithmetice or Tables of Logarithmes for Absolute Numbers from an unit to 100000; as also for Sines, Tangentes and Secantes for every Minute of a Quadrant with a plaine description of their use in Arithmetike, Geometric, Geographic, Astronomic, Navigation, &c. . . .* Thus the student ignorant of Latin could learn from the printed word *Of the Nature and Properties of the Logarithmes.*

Logarithmes [Briggs had written], are Numbers invented for the more easie working of questions in Arithmetike and Geometric. The name is derived of *Logos,* which signifies *Reason,* and *Arithmos,* signifying *Numbers;* so the whole word signifies rationall or proportionall numbers. By them all troublesome Multiplications and Divisions in Arithmetike are avoided, and performed onely by Addition in stead of Multiplication, and by Subtraction instead of Division. The curious and laborious extraction of roots are also performed with great ease . . . All proportions continued, disjunct, double, triple, and what els are hereby most easily performed. All Triangles of what kind soever, are with much facility resolved. And in a word, all questions, not onely in Arithmetike and Geometrie, but in Astronomic also are thereby most plainly and easily answered, as hereafter will appeare.

Now seeing all these things are done by numbers, it is requisite that for every number, as, 1, 2, 3, 4. and so infinitely a Logarithme be fitted. Onely an unitie which neither multiplies nor divides, needs no Logarithme. Thereupon a Table is made, beginning with 2, and so forward calculo facillimo, eximiusque compendiiis exhibet: Ab HENRICO GELLIBRAND Astronomiae in Collegio Greshamensi apud Londinenses Professore constructus. *Ex angulis latera, vel ex lateribus angulos, & mixtim in Triangulis tam planis quam Sphaericis, assequi, summa gloria Mathematici est: Sic enim Coelum & Terras & Maria faelici & admirando calculo mensurat.* Franc: Vieta. GOVDAE, Excudebat Petrus Rammaseniis M.DC.XXXIII. Cum Pravilegio [sic].

1 LOGARITHMICAL ARITHMETIKE, OR TABLES OF LOGARITHMES FOR ABSOLUTVE NUMBERS FROM AN unite to 100000; as also for Sines, Tangentes and Secantes for every Minute of a Quadrant: with a plaine description of their use in Arithmetike, Geometric, Geographic, Astronomic, Navigation, &c. These Numbers were first invented by the most excellent JOHN NEPER Baron of Marchiston, and the same were transformed, and the foundation and use of them illustrated with his approbation by HENRY BRIGGS Sir HENRY SAVILS Professor of Geometric in the Universitie of Oxford. The uses whereof were written in Latin by the Author himselfe, and since his death published in English by diverse of his friends according to his mind, for the benefit of such as understand not the Latin tongue.

DEVS NOBIS VSVRAM VITAE DEDIT, ET INGENII, TANQVAM PECVNIAR, NVLLA PRAESTITVTA DIE.

LONDON, Printed by GEORGE MILLER. 1631.
to 100,000 of all whole numbers, which may serve for any use, although they might be made for many more numbers . . .

The Logar. of 1 is 0, of 10 is 1 with cyphers: of 100 is 2 with cyphers: of 1000 is 3 with cyphers: of 10,000 is 4 with cyphers: of 100,000 is 5 with cyphers, and so infinitely.

Every Logar. has his absolute number placed afore it . . . [in the following table]. The differences also of 2 Logarithmes next adjoyning, are added for the easier finding out of the Logarithme of any number, or the absolute number of any Logarithme which is not there expressed.

Every thousand of the numbers is distinguished by a Grecce word *Chilias*, which signifies a thousand. So in the whole booke there be 100 *Chiliads*, which is 100 thousand.

Every Logarithme hath a figure placed afore it on the left hand called *Characteristicke* or an Index, showing of how many places the absolute number thereof is: As in whole Numbers all under 10 the Indexes onely 0. the rest all vnder 100 is 1. Betweene 100 and 1000 is 2: . . . so then every Index is an unite less than the place of the absolute number thereof . . . *To find a logarithme . . . seeke the number . . . in the Chiliad in the Columnne under the title of Num. and on the right hand thereof you shall find the Logar. answering thereto . . . Of Multiplication . . .* If you would know the product of 654 and 27.

\[
\begin{align*}
2,81557,77 & \text{ the Log. of 654 the Multiplicand.} \\
1,43136,38 & \text{ the Log. of 27 the Multiplicator.} \\
4,24694,15 & \text{ the Log. of 17658 the Product.'}
\end{align*}
\]

Examples of the tables appear in Table 23 on page 415.

In the explanations of 'the Resolution of Spherical Triangles' and of 'Questions in Navigation' the examples and accompanying illustrations are identical with Gunter's in *De Sectore & Radio* except, of course, that they exemplify the logarithmic solutions. For instance, Briggs proposed:

*To finde the distance of Latitude of two places, by the Rhumb and distance . . . Let the Rumb be the third from the Meridian, viz. 33 gr. 45 min. and the distance betweene two place 120 leagues, or 360 miles,  
\[
\begin{align*}
2,55630,25 & \text{ the Log. of 360 miles the distance.} \\
9,9[1]984,63 & \text{ the Cosine of 33 gr. 45 min. the Rumb form the Meridian.} \\
12,47614,88 & \text{ the Log. of 299 minutes or 4 gr. 59 min. the diff. of Latitude.}
\end{align*}
\]

This will be recognized as the logarithmic solution of Gunter's proposition, \(d. \text{ lat.} = \text{ dist cos. (Co.)}\) and his example of two places in latitudes 50\(^\circ\) and 55\(^\circ\), distant from one another 6\(^\circ\), or 360', along the third rhumb from the meridian or 33\(^\circ\) 45'.

It was such explanations of the use of logarithms in navigation—using
### TABLE 23

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0,000000,00000</td>
<td></td>
<td>51</td>
<td>1,70757,01761</td>
<td>843,31675</td>
<td>101</td>
<td>2,00432,13738</td>
<td>427,87980</td>
</tr>
<tr>
<td>2</td>
<td>0,30102,99957</td>
<td></td>
<td>52</td>
<td>1,71600,33436</td>
<td></td>
<td>102</td>
<td>2,00860,01718</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td></td>
<td>...</td>
<td>...</td>
<td></td>
<td>...</td>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>

and so on to 100,000

### TABLE 24

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>9,69897,00043</td>
<td>9,93753,06317</td>
<td>9,76143,93726</td>
<td>10,23856,06274</td>
<td>10,06246,93683</td>
<td>10,30102,99957</td>
</tr>
<tr>
<td></td>
<td>21,87385</td>
<td>7,29619</td>
<td>29,17004</td>
<td>29,17004</td>
<td>7,29619</td>
<td>21,87385</td>
</tr>
<tr>
<td>1</td>
<td>9,69918,87428</td>
<td>9,93745,76698</td>
<td>9,76173,10730</td>
<td>10,23826,89270</td>
<td>10,06254,43302</td>
<td>10,30081,12572</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sin. Compl.</th>
<th>SINVS.</th>
<th>Tang. Compl.</th>
<th>TANG.</th>
<th>Sec. Compl.</th>
<th>SECAN.</th>
</tr>
</thead>
</table>

Note: The trigonometrical functions are for angles from 0° to 90°.
at first Napier’s logarithms—that Briggs (we can be sure) delivered at Gresham in the seven fruitful years, 1614–20 during which he lectured there on logarithms.

Gunter had been Professor of Astronomy at Gresham for over three years when he finally gave way to the importunity of his friends and students, and consented to the publication of his lectures, with illustrations of the various navigational instruments he had invented. As we have seen it was his early manuscripts on the projection of the sphere and on the Sector which formed the major part of the first half of De Sectore & Radio of 1623—The Sector in Three Books.1 It was his latest inventions and most recent lectures which formed the second half, The Cross-staff in Three Books, with an appendix on a small portable quadrant, ‘for the more easie finding of the Hour and Azimuth, and other Astronomical and Geometrical Conclusions’. These books contained his counterpart to Briggs’s Arithmetica Logarithmica of 1624; for while Briggs, after the publication of Gunter’s Canon Triangulorum in 1620, had busied himself at Oxford with furthering the simplification of calculation by preparing more logarithmic tables, Gunter, with his powerful practical bent, had approached the problem quite differently. Briggs was pre-eminently the scholar, a man with all the scholar’s passion for precision. His tables typify him. They were intended primarily for precision work: speed in calculation was subordinated to accuracy. They were designed for the astronomer, surveyor, engineer and financier. Size, weight, and to some extent cost, were therefore unimportant compared with the need for comprehensiveness. Gunter was quite different from Briggs. While Gunter, too, was capable of meticulous and protracted calculation—his traverse and logarithmic trigonometrical tables are evidence of that—he was essentially an inventor, a man who saw that the need of most men busy about their daily tasks was primarily for a speedy and easy means of getting answers to their particular problems accurate enough for all practical purposes. Seamen in particular needed something that incorporated logarithms in a simple, robust, and durable form, which was easy to use, cheap to buy, and impervious to the wind, the rain, and the salt spray encountered at sea. Books had none of these qualities, particularly books like Briggs’s folio tables. Gunter’s solution was an instrument—of the simplest possible sort—a straight ruler. It could be of wood, ivory, or brass and, unless modified to form the

1 DE SECTORE & RADIO

The description and use of the Sector in three books. The description and use of the Cross-Staffe in other three books. For such as are studious of Mathematicall practise. LONDON, Printed by WILLIAM IONES. and are to be sold by JOHN TOMSON at his house in Hosier-lane. 1623.

This title-page is preceded in the B.M. copy by another, as follows:

THE DESCRIPTION and use of the SECTOR. The Cross-staffe and other instruments. For such as are studious of Mathematicall practise. AT LONDON. Printed by Willià Jones. and are to be sold by: Edmund Weauer. 1624.
staff of a cross-staff, measured about two feet in length and two to three inches in width. On it he engraved a logarithmic ‘line of numbers’. The logarithms he took ‘out of the first Chilaid of Mr. Briggs Logarithms’, and the line he ‘noted with the letter N’. He engraved other straight lines upon the ruler, a ‘Line of Artificial Tangents . . . noted with the letter T’, divided unequally into 45 degrees, and numbered bothways, for the Tangent and the Complement; a ‘Line of Artificial Sines noted with the letter S’, divided unequally into 90 degrees, and numbered with 1, 2, 3, 4, unto 90, and a Line of Versed Sines for more ease finding the hour and Azimuth, noted with V . . .; a Line of Inches . . . each Inch subdivided into ten parts . . .; A Line of Several Chords, one answerable to a Circle of twelve Inches semidiameter . . . another a semidiameter of a Circle of six Inches; and a third of a circle of three inches’; and a Meridian Line ‘of a Sea-chart, according to Mercator’s Projection . . . known by the Letter M . . .’. The ‘lines of Proportion’, as he called the logarithmic lines of the trigonometrical functions, he took ‘out of my Canon of Artificial Sines and Tangents’.

Gunter’s Scale was the logical development of his Sector. This, it will be recalled, was based upon the characteristics of proportional triangles and enabled problems involving proportion to be solved instrumentally. Its basic features were the identical jointed legs that could be opened 180° to form a straight ruler; the Line of Lines, divided into equal parts; and the lines of the natural trigonometrical functions and of meridional parts. It was to be used with a pair of compasses. Just as problems involving proportion were solvable on the Sector with the aid of compasses, so were they on the Scale. Indeed, in his description of it, it was this that Gunter emphasized. For instance, he gave five different problems involving proportion, such as ‘having two extreme Numbers given, to find a mean proportional between them’, before dealing with multiplication and division. Napier, Briggs and other later mathematicians of the period always observed that logarithms facilitated ‘the working of Proportions in several

1 See Appendix 30 and Figs. 36 and 37.
kinds'. Gunter's Scale was, in fact, no more than his Sector fully opened and with a logarithmic line of [unequally spaced] numbers substituted for a Line of Lines of equal parts [equally spaced numbers]; logarithmic lines of sines and tangents substituted for lines of natural sines and tangents, and a logarithmic line of versed sines substituted for a line of natural secants. Gunter, with his grasp of the characteristics of logarithms and the possibilities of the Sector, must early have appreciated that, as the addition of logarithms amounts to multiplication of the numbers for which they stand and subtraction to division, it should be possible to perform the processes by measuring the logarithms of the quantities concerned on a line graduated in logarithms, and to add or subtract them on this scale with a pair of compasses in order to obtain the products or quotients.

1 We see the admirable use of these Logarithmes, not only in the doctrine of triangles (which I account to bee farre the most excellent part, and which may by other Tables be performed as exactly but nothing so speedily, or with the like ease) but also in all our common accounts of ordinary proportionall numbers. [Briggs's Preface in Wright's translation of Napier's Descriptio, 1616.]
This was indeed how the scale was used. For instance, take Gunter's explanation of multiplication and division (which can be followed on Fig. 36 with the aid of a pair of dividers):

_To multiply one number by another_

Extend the Compasses from 1 to the Multiplier; the same extent applied the same way, shall reach from the Multiplier to the Product.
As if the Numbers to be multiplied were 25 and 30: either extend the Compasses from 1 to 25, and the same extent will give the distance from 30 to 750; or extend them from 1 to 30, and the same extent shall reach from 25 to 750.

_To divide one Number by another_

Extend the compasses from the Divisor to 1, the same extent shall reach from the Dividend to the Quotient.
So if 750 were to be divided by 25, the quotient would be found to be 30.

With the invention of Gunter's Scale the solution of navigational problems by logarithms was reduced to the simplest of instrumental manipulations. Writing of logarithms in later years William Oughtred declared, 'The honour of the invention next to the lord of Merchiston, and our master Briggs belong[s] . . . to master Gunter, who exposed these numbers upon a straight line.'

1 This is indeed true, for Gunter's Scale was the immediate ancestor of the slide-rule. Except that distances were measured by a pair of compasses and not by another rule, it was a slide-rule. It performed all that a slide-rule does. Remove the sliding scale from a modern slide-rule and you have Gunter's logarithmic scale.

Gunter explained his Scale in De Sectore & Radio in the course of describing a cross-staff, of which the staff was a yard long ('so it may serve for measure'), and was inscribed with four sorts of lines: one served 'for Measure and Protraction; One for observation of Angles: One for the Sea-Chart; and the [four] other for working of Proportions in several kinds'. The only lines additional to those already mentioned as being on the Scale in ruler-form were 'the Lines for observation of Angles', or the tangent lines on staff and cross 'inscribed out of the ordinary Table of Tangents'. These were for use in measuring 'perpendicular heights and distances and angles', chiefly in survey work.

The first published description of Gunter's Scale in plain rule form appeared in Paris in 1624. It was written by a thirty-year-old English mathematician of great enthusiasm, Edmund Wingate, then tutor to Princess Henrietta, and was entitled L'Usage de la Reigle de Proportion en l'Aritmetique & Geometrie. 2 It contained a folding, full-scale copper-

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1 See Ward, J., Lives of the Professors of Gresham College (1740) Vol. 1, p. 79.
In tenui, sed nō tenuis vsusve, laboruc.
A PARIS, Chez MELCHIOR MONDIERE, demeurant en l'Isle du Palais, à la rue de Harlay aux deux Viperes.
M.DC. XXIV. *Auce Privilège du Roy.*
plate engraving, 25 inches long and 1·6 inches wide, consisting of a single logarithmic line of numbers; a logarithmic line of tangents; another of sines; and a line of equal parts. Two years later there came out an English edition of Wingate's book; a second edition was soon called for, and it appeared in 1628 as The Construction and Use of the Line of Proportion. ¹

Three further revised editions were published in the succeeding fifty-five years.² Wingate explained that 'The Line of Proportion' or Gunter's Scale was 'nothing else but a mechanickall Table of Logarithms', which is as good a description as any, and he referred students wishing 'to understand the nature of Logarithmes ... to Master Briggs his learned Worke, intituled Arithmetica Logarithmica', which had just been published.

Gunter, in describing the use of the scales on his cross-staff followed the system he had adopted for the Sector. That is to say, he went from the general to the particular. In the 'first book of the cross-staff' he described the scales on the cross-staff—which otherwise was like any other cross-staff of the period—and explained their general use for finding heights, distances and angles, for solving spherical and plane triangles, and for finding proportional numbers. In the second book he described their more particular use 'in several kinds', that is to say in measuring places and solids, 'in gauging of vessels', i.e. casks; in 'resolving such Astronomical Propositions as are of ordinary use in the practice of Navigation'; and 'such nautical questions as are of ordinary use concerning Longitude, Latitude, Rumb and distance'. The third book dealt with dialling, a science in which Gunter, since the death of Wright who had also published a work on the subject, had become the acknowledged expert.

Because those not fully conversant with 'the Rule of Three, and the doctrine of Triangles', would find it difficult to solve 'proportions of

¹ THE CONSTRUCTION, And Use of the Line of PROPORTION. By helpe whereof the hardest Questions of Arithmetique & Geometry, as well in broken as whole numbers, are resolved by Addition and Subtraction.
By EDM. WINGATE, Gent. Nulla dies sine Linea.
LONDON Printed by John Dawson, 1628.

² THE USE OF THE RULE OF PROPORTION: In Arithmetique and Geometric. First published at Paris in the French tongue, and dedicated to Monsieur, the then Kings only brother, (now Duke of Orleans, [sic: bracket not closed]
By Edm: Wingate an English Gent.

And now translated into English by the same Author:
Whereinto is now also inserted the Construction of the same Rule, and a farther use thereof, in questions that concern

Astronomie, 
Dialling, 
Geographie, 
Navigation,

Gaging of Vessell,
Military Orders,
Interest and
Annuities.

Ecclesiasticus 39. 17. None may say, What is this? wherefore is that? for at time convenient they shall all be sought out.

LONDON, Printed by M.F. for P. Stephens at the gilded Lion in Pauls Churchyard, 1645. Preface is dated Grays Inne Jan. 20.

164$
ordinary use, without 'the particular proportions by which such propositions are to be wrought', Gunter codified the various problems which he explained in the second book. It was in the fifth chapter that he dealt with astronomical problems. He did so by formulating seventeen propositions 'useful to Seamen', in such a form that they could also be easily applied to the Sector or resolved 'by Arithmetick ... by the Tables of Sines and Tangents', both natural and 'Artificial'. The first two propositions concerned the sun's altitude and declination and so could 'help them to find their Latitude; the third to find the sun's rising and setting'; the next eight explained how to calculate the sun's amplitude or azimuth in various ways and thus how to find 'the variation of their Compass'; while 'the 11 and 12 Prop', explained how to find the hour of the day; the rest ... the finding of the hour of the night'.

One example will suffice to show Gunter's method of explaining their application to his Scale. 'Having', he postulated, 'the latitude of the place, and the Declination of the Sun, to find his Amplitude ... Extend the compasses from the Co-sine of the Latitude to the sine of 90 gr. the same extent will reach from the Sine of the Suns Declination to the Sine of the Amplitude', because as he expressed it,

'As the co-sine of the latitude
is to the Radius:
So the Sine of the Declination,
to the Sine of the Amplitude.'

Clearly these astronomical propositions of Gunter's were similar in form to his navigational ones in the second book of the Sector. They have an economy of expression that is admirable, and for the seaman, almost heaven-sent. There was only one danger, they might be learnt easily by heart and then applied by rule of thumb, without any knowledge of astronomy. Although this meant that the fruits of astronomical research were made available to men deficient in astronomical learning for the solution of practical problems, the danger was that a generation of navigators might arise who were ignorant of the basis of their art. Such indeed was to happen, a process accelerated by the disappearance of celestial globes from the navigator's store of instruments.

In astronomical propositions Gunter gave special consideration to the calculations of the sun's azimuth—the arc of the horizon, or the angle at the zenith, between the north or south point and a vertical circle through the sun—when the ship's latitude, and the sun's altitude and declination were known. He did so partly 'because they are thought to be harder than the rest, and require three operations'; partly in order that he 'might shew the agreement between the Staffe and the Canon', and partly because 'Having these means to find the Suns Azimuth, we may compare it with the Magnetical Azimuth, and so find the variation of the Needle'. He supported this declaration with a linear diagram, familiar to every modern navigator, of the PZX triangle (Pole-Zenith-Celestial Object)
on the plane parallel to the horizon, showing the difference between the true and observed azimuths. Except that he used the symbol for the sun, $\odot$, instead of $X$, Gunter’s diagram might be from a text-book of today.

If, [he commented], the Magneticall Azimuth $AZM$ [the bearing of the sun observed with the compass] shall be $84\,gr.\,7\,m.$ and the Suns [calculated] Azimuth $AZM\ 72\,gr.\ 52\ m.$ then must NZM the difference between the two Meridians, give the variation to be $11\,gr.\ 15\ m.$ as Mr. Borough heretofore found by his observations at Limehouse in the year 1580.

Borough it will be remembered had included his 1580 observations and calculations of the variation at Limehouse in his *Variation of the Cumpas* of 1581. Gunter then remarked that, if the observed azimuth were only $79^\circ\ 7\ ',$ and the calculated $72^\circ\ 52\ ',$ the variation would be only $6^\circ\ 15\ 'E$ and further, that of late he had sometimes found it to be of this order. Indeed he had been so intrigued by this discovery that he had inquired as to the exact place where, in Limehouse, William Borough had made his observations and then, with ‘a Quadrant of three foot Semidiameter, and two Needles, the one above 6 inches, and the other 10 inches long’, had proceeded to the spot. Towards the night of 13 June 1622 he had made observations of the sun’s azimuth from several parts of the ground and, he stated, had obtained the following results:

**TABLE 25**

<table>
<thead>
<tr>
<th>Alt. $\odot$</th>
<th>$AZM$</th>
<th>$AZN$</th>
<th>Variat.</th>
</tr>
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<td>$M.$</td>
<td>$Gr.$</td>
<td>$M.$</td>
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<td>19</td>
<td>0</td>
<td>82</td>
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<td>18</td>
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<td>80</td>
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<tr>
<td>17</td>
<td>34</td>
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</tr>
<tr>
<td>17</td>
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<td>79</td>
<td>15</td>
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<td>16</td>
<td>18</td>
<td>78</td>
<td>12</td>
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<td>16</td>
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<td>77</td>
<td>50</td>
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<tr>
<td>10</td>
<td>20</td>
<td>71</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>25</td>
<td>70</td>
<td>12</td>
</tr>
</tbody>
</table>

The mean of these observations, $5^\circ\ 55\ 'E,$ is less by $20\ '$ than Gunter’s previous observations and it is almost half that of Borough’s of 1580. Upon these differences Gunter made no comment. He left it for others to draw their own conclusions. When he died in December, 1626, it fell to his successor at Gresham, Henry Gellibrand, to publish the implication
of these, and his own later, observations that variation, far from being immutable at any place, as hitherto believed, changes with the passage of time. This discovery of 'the secular change of variation' was to give an added urgency to the problem of finding longitude astronomically. Not only did it show all earlier observations of variation in all parts of the world to be thoroughly unreliable for longitude-finding, but it showed how imperative it was to check the steering-compass frequently for variation, either by azimuth or amplitude observations (amplitude of the sun being the arc of the horizon between the east point and the sun when rising, or the west point, and the sun when setting). Gunter's celestial propositions of 1623 for calculating the azimuth were thus particularly opportune.

Gunter approached the subject of the use of his Scale in 'nautical questions' in a typically scientific manner. One of the basic things that a navigator is concerned with is distance—the distance between places, the distance he has sailed, the distance he has to sail. Gunter—correctly—considered that the first essential was to establish clearly the relationship between the basic unit customarily used to express distances in lengths and the basic unit used to describe angular distance on the globe. This, of course, is of fundamental importance when a ship's position is fixed astronomically. As we have seen, the difficulty hitherto had been to determine this relationship accurately. It depends, as Hues and before him Cumingham had pointed out, upon measuring the length of a degree along a meridian on the earth's surface. Hues, it will be recalled, had discussed the question of the length of a degree in his Tractatus de Globis. He had given the various measurements of the classical geographers and Arabs, all of which differed, concluding, rather helpfully, that although English seamen followed the measurement of Ptolemy, and counted 5,000 feet to the mile, the actual choice of the number of such miles to a degree was a matter of personal preference. Gunter, writing thirty years later, was equally definite as to the length of a degree in the opinion of English seamen. 'They say', he wrote, 'that there are 5 feet in a pace, 1000 paces in a Mile, and 60 miles in a degree, and there fore 300000 feet in a degree.' However, he was not content to leave such an important matter either to custom or personal preference. 'Comparing several observations, and their measure with our feet usual about London, I find', he announced, 'that we may allow 352,000 feet to a degree', and, confident in his greater accuracy, from then on used this measure. It gives a mile of 5,866 feet instead of 5,000, and so was a sixth greater than that commonly used hitherto, and was in error on the length used today by only about one twenty-eighth

(the standard nautical mile is taken to be 6080 feet, the length of a degree having been found to vary between 6046 feet on the equator and 6108 feet at the pole.) In taking a length of 352,000 feet to the degree Gunter was adopting, in round figures, the length computed from the very latest measurement of an arc of the earth's surface. This had been made by Willebrord Snell (or Snellius) in 1615. Snell was a Dutchman, the son of a Dutch philosopher, Rudolph Snell, who held the chair of mathematics at Leyden University for thirty-four years, until his death in 1613. It was his brilliant, twenty-two-year-old-son, Willebrord, who succeeded him in the same chair. The Dutch, with their now flourishing oceanic commerce, were extremely interested in determining as accurately as possible the length of a degree. Willebrord Snell undertook the task. Accordingly he measured the distance between Alkmaar and Bergen-op-Zoom, taking the difference of latitude between these two places as 1° 11' 30". He also measured the distance between the parallels of Alkmar and Leyden and, from the mean of these two measurements, and after comparisons with former measurements of the length of a degree, made the degree to consist of 352,347 feet. He described his operation in a book appropriately entitled Eratosthenes Batavus, published in 1617.1 Gunter must have been impressed with his work to accept his measurement in the face of the long-established one. Snell was indeed in many ways the Dutch counterpart of Gunter. Not only was he a young professor of mathematics, but he wrote a number of mathematical works dealing in particular with geometry and the solution of plane and spherical triangles, and in 1624 he was to publish a treatise on navigation, Tiphys Batavus.2 He is also credited with the discovery of the law of the refraction of light.

Although the amended estimate of the length of a degree does not lie to the credit of Gunter, the use of it by English seamen does, for Gunter was the first man to draw their attention to it in their own language, and to explain the greater accuracy that would result from its use. It was indeed a most important innovation, for it meant that the greater accuracy of plotting made possible by the use of charts on Wright's Mercator projection was now more nearly attainable.

One of the chief tasks of the Gresham mathematical professors was to explain to ordinary citizens the way in which mathematics could help to solve everyday problems 'and to explain', it will be recalled, 'the use of common instruments for the capacity of mariners'. There is no doubt, from the evidence of their contemporaries as well as from that of their writings,

1 ERATOSTHENES BATAVVS
De Terrae ambitus vera quantitata, A WILLEBRORDO SNELLIO, Διὰ τῶν ἐκ ἀποστημάτων μετρουμένων διοπτρῶν Suscitatus.
O quam contempta res est homo, nisi supra humana se erexerit.
LVGDVNI BATAVORUM, Apud IODOCVM à COLSTER Ann. Cl ci ιο CXVII.

2 WILLEBRORDI SNELLII à Royen. R.F. TIPHYS BATAVVS, SIVE HISTIODROMICÉ, De navium cursibus, ET RE NAVALI. LVGDVNI BATAVORUM, Ex officinâ ELZEVIRIANA, Anno Cl ci ιο CXXIV.
that the professors of early Stuart times took their responsibilities seriously and applied themselves whole-heartedly to the business of making mathematics and instruments both intelligible and useful to their fellow-men. The improvement of the log and line in use at sea provides an excellent example of the practical importance of their work. Though simple enough in appearance, the log and line described by Bourne was in practice too simple for popular use for it did not give a direct answer to the navigator’s question: ‘How many miles or leagues have I sailed in the last hour?’ However, when Sir Henry Mainwaring, the one-time pupil in navigation of Richard Norwood, wrote a personal dictionary of sea-terms for the newly appointed Lord High Admiral, the Marquis of Buckingham—probably in 1620, certainly not later than February, 1623—he wrote of the log and line, thus:

A Log-Line. Some call this a minute-line. It is a small line, with a little piece of a board at the end, with a little lead to it to keep it edge long in the water. The use of it is that by judging how many fathom this runs out in a minute, to give a judgment how many leagues the ship will run in a watch; for if in a minute there run out 14 fathom of line, then they conclude that the ship doth run a mile in an hour, for 60 [the number of minutes in an hour] being multiplied by 14 [the number of fathoms run out in a minute] make just so many paces [fathoms] as there are in a mile; so accordingly as in a minute there runs out more or less, they do by judgment allow for the ship’s way. But this is a way of no certainty unless the wind and seas and the course would continue all one, beside the error of turning the glass and stopping the line, both at an instant; so that it is rather to be esteemed as a trick for a conclusion, than any solid way to ground upon. The manner of doing it is: one stands by with a minute glass, whilst another out of the gallery lets fall the log; just as the log falls into the water the other turns the glass, and just when the glass is even out he cries ‘stop’; then he stops and reckons how many fathom are run out, so gives his judgment.1

It is true that Mainwaring omitted mention of the stray line to ensure that the log drew clear of the dead water under the ship’s counter before it began to be timed, but in all other essentials his description differs but little from Bourne’s of fifty years before of the then newly invented log and log-line. However, he indicates an improvement in the method of calculating the distance run. It was now based upon the number of fathoms sailed in a minute which is proportional to a distance of one mile per hour, since one mile of 5000 feet per hour = 84 feet (approximately) per minute = 14 fathoms per minute. The practical value of this improvement was amongst the matters that Gunter explained, thereby helping to popularize the use of the log and log-line amongst English seamen.

It is in the journals of the first quarter of the seventeenth century that we first come across entries recording the use of the log and line. When

31—A.O.N.
Captain Keeling, in the course of the third voyage of the East India Company's ships to the East Indies, missed his intended landfall at the Ile de Fernando de Noronha off the coast of Brazil, in June 1607, he was at a loss what to do. Strange currents, contrary winds and the tropic heat dismayed his men, and sickness also broke out. Then he bethought himself of Sierra Leone and 'having formerly read well of the place, sent for the Booke, and shewed it my Master . . .', he recorded in his journal, referring to Hakluyt's *Voyages*. The master agreeing that it seemed best to turn back and call at Sierra Leone for fresh water and victuals, Keeling ordered him to shape course accordingly. Weeks later Keeling noted in his Journal:

This morning the fourth of August we saw many Floures, a signe of Land, and this evening we had ground from twentie eight to sixteene fathome Ozy, but no sight of land.

I hoysted out my Skiffe, and sent her to ride neere us to prove the set of the Current: she found by the Log-line, the Current to set South-east by East two miles a watch, howbeit the Skiffe roade wind-road . . .

that is to say while the skiff rowed to windward.

In *Purchas his Pilgrimes* we also find extracts from the journal 'written by Nathaniel Marten, Masters Mate', on the East India Company's seventh voyage made under the command of Captain Anthony Hippon. When off Java in March 1612, Marten entered in his journal:

From the one and twentieth at noone, till the two and twentieth at noone we had the wind all Northerly, we steered away South and ran fifteene leagues by the logge, and then wee were in the latitude of one degree, thirte foure minutes: at night I observed the variation: . . . From the two and twentieth, to the three and twentieth at noone, wee . . . ran eight leagues: at night I observed the variation and, made it to bee ten degrees. The Magneticall Azimuth is fifteene degrees fifteene minutes, the Amplitude is five degrees thirteene minutes. From the three and twentieth at noone till the foure and twentieth at noone, wee . . . ranne three and twentie leagues by the logge, and then we were under the Line by our observation.

We have seen how Gunter discussed the length of the unit of length that should be used for measuring distance at sea. Now let us see how he dealt with the problem of measuring a ship's way. 'The way that the Ship maketh, may be knoun to an old Sea man', he conceded, 'by experience', and then immediately continued, 'by others it may be found for some small proportion of time, either by the Log-Line, or by the distance of two knoun marks on the Ships side'. This latter statement is the earliest reference in nautical writings to a method of using a log without a log-line, in fact to the type of

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log which, because of its popularity with the Dutch later in the century and in the eighteenth century, became known as 'the Dutchman's log'.

The time in which it maketh this way, [he continued], may be measured by a Watch, or by a Glass, or by the Pulse, or by repeating a certain number of words. Then as long as the wind continueth in the same stay, it followeth by proportion,

As the time given, is to an hour
So the way made, to an hours way.

Here we have Gunter clarifying the mathematical basis of the log—of any log—for seamen with a proposition expressed in general terms yet capable of application in particular forms. For instance this proposition not only made rational the division of the log-line into proportional parts of fixed length but also the employment of a log based, not upon a fixed interval of time in which the distance sailed was measured, but upon measuring how long it took to sail a fixed distance—the timing of an object in the water past 'two known marks on the Ships side', the Dutchman's log.¹

If all other references to the 'Dutchman's log' were not subsequent to Gunter's it might be supposed, from its seeming simplicity, that the Dutchman's is the older of the two forms of log, and that its name reflects its country of origin. Let us consider these points. This log—which is given no name—is first mentioned in print in 1623, by an English professor of mathematics in the course of explaining particular applications of a general proposition which he has just enunciated. Up till that time there had been no such general proposition; the only formulae known to have been used were based on measuring with a log-line the distance run in 1/120th or 1/60th of an hour. By the 1/120th of an hour method the fathoms of log-line veered in half a minute were measured and multiplied by 120 to find the number of the fathoms sailed in an hour, this total then being compared with the number of fathoms in a league to find the distance sailed in leagues. By the 1/60th of an hour method the number of fourteen-fathom lengths of line veered in a minute was estimated and taken to indicate the distance sailed in miles each hour. It was an advance on the earlier method but still laborious and liable to considerable error. The 'Dutchman's log' depended upon both a known distance and a known proportional time-interval that varied with the speed of the ship. We know the log and log-line had been invented by the 1570s, probably by an Englishman. We also know that in 1632 Champlain described it as a device he had seen used by several skilful English navigators. In the same year Adrian Metius described the log and log-line in his Astronomische en Geographische Onderwijsinghe and stated that its invention was ascribed to the English. The 'Dutchman's log', however, is not mentioned in any Dutch work until 1662. Indeed half a

¹ Or a log-line of fixed length as described in somewhat obscure terms by Snell, Tiphys Batavus (1624).
century later the students of the Mathematical School, founded by King Charles II, in Christ's Hospital, London, were taught that the log and log-line was an English invention. In *The Seaman's Tutor* of 1682, the text-book written for their particular use by Mr. P. Perkins and completed, after his premature death, by his brother Eysum Perkins, they read

of the Estimation of a Ships way at Sea [that] there's hardly any thing more necessary than to be able to make a good Estimate of the Ships way with any wind, according to all Circumstances, [and that of] the Nations now of Fame and Experience at Sea [some made it by] only guessing by the sail born, and running of the Froth or Water by the ship's side, as the Spaniards and Portuguese; others by flinging into the water a Chip, or the like; and counting how many equal timed paces they can make on the Deck, while the said Chip drives between any two Bolt-Heads or Marks on the Side, which is usual amongst the Dutch, (instead of paces you may number the Pulses while the Chip drives), but the most approved way, and now most followed is by our English Log, and Log-Line.¹

Thus the available evidence suggests strongly that the English log and log-line preceded the Dutchman's log in use at sea.

The Dutchman's log may well have been Gunter's invention. It was based upon the Rule of Proportion and reflects the genius of a mathematician interested, not merely in navigation and problems of proportion but, above all, in the solution of problems of proportion by mechanical or instrumental means. Gunter was such a man. In the second book of the cross-staff he introduced his log inventions methodically, so that they developed naturally out of his reasoning and seem so obvious that it at once appears as though all former generations were stupid not to think of them. As Gunter showed, what made his inventions demonstrably correct and helpful was his prior invention of the Line of Proportion—the Line of Numbers—the Logarithmic Scale of numbers. As we have seen, to convert the number of fathoms of log-line run out in a minute or half-minute into leagues or miles sailed in an hour was no simple process for most seamen before Gunter invented his Scale. Before that, when the answer was wanted in miles, it could be obtained by dividing the number


Compiled for the Use of the Mathematical School in *Christ's Hospital-London*, His Majesty *Charles II*, his Royal Foundation.

By Mr. P. Perkins, late Master of that Mathematical School.

*LONDON*, Printed for *Obadiah Blagrave*, at the *Bear* in *S. Paul's* Church Yard. 1682.
of fathoms run out in a minute by 14, but this generally left an awkward fraction or one of the new-fangled decimals. With a Gunter's Scale, finding the answer was simplicity itself. Listen to Gunter:

Suppose the time to be 15 seconds, which make a quarter of a minute, and the way of the Ship 88 feet: then because there are 3600 seconds in an hour, I may extend the compasses in the Line of Numbers, from 15 unto 3600, and the same extent will reach from 88 unto 21120 [This can easily be checked with a pair of compasses and a slide-rule] Or I may extend them from 15 unto 88, and this extent will reach from 3600 unto 21120, according to the ordinary work in Arithmetick,

As 15, unto 3600:
So 88, unto 21120.

Which shows that an hour's way came to 21120 feet.

As the navigator never worked in feet for long distances this, of course, had to be converted into miles or leagues. It was easily done on the scale by taking the length of a degree in feet and finding the proportion between this distance and the distance, in feet, sailed in an hour. This was converted into leagues or miles by extending the compasses from 21,120 [the distance sailed in an hour] on the Line of Numbers to 300,000 [the number of feet customarily considered to be in a degree]. Then with this setting, if the navigator placed one point on 20, the number of leagues in a degree, the other would fall on 1.4—the number of leagues sailed in an hour; or if he put one point on the number of miles in a degree, 60, then the other point would fall on the number of miles sailed in an hour—4.2. If he took Gunter's advice and counted 352,000 feet to the degree he would find the answers to be 1.2 leagues or 3.6 nautical miles, or as Gunter expressed it:

...if I extend the compasses in the Line of Numbers from 352000 unto 21120, I shall find the same extent to reach from 20 Leagues, the measure of one degree, to 1, 2, [1.2] and from 60 miles to 03,6, [3.6] according to Arithmetick...

In other words, using the amended length of a degree the distance sailed in an hour would be found 'to be 1 league, and 2 tenths of a league, or 3 miles and 6 tenths of a mile' because,

As 352000 [is] unto 21120; [No. of feet in a degree, to ]
[No. of feet sailed in the hour]  
So [is] 20,00 unto 1,20. [No. of leagues in a degree, to]
[No. of leagues sailed in the hour]
And 60,00 unto 3,60. [No. of miles in a degree, to]
[No. of miles sailed in the hour]

Incidentally this example of the use of the old plain log-line illustrates the improvement in navigational accuracy made possible by using the length
of a degree advocated by Gunter, particularly when comparison is made
with the same problem resolved in terms of the correct length of a degree:

<table>
<thead>
<tr>
<th>Measure</th>
<th>Miles/Hour</th>
<th>Leagues/Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old measure</td>
<td>300,000' to a degree</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>5,000' to the mile</td>
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</tr>
<tr>
<td>Gunter’s measure</td>
<td>352,000' to a degree</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>5,870' to the mile</td>
<td></td>
</tr>
<tr>
<td>Modern measure</td>
<td>364,800' to a degree</td>
<td>3.45</td>
</tr>
<tr>
<td></td>
<td>6,080' to the mile</td>
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</tbody>
</table>

It has already been remarked that when using the log and log-line as
originally designed the process of computing the distance sailed in leagues
or miles in an hour was not the simple, straightforward process that it was
with a Gunter’s Scale, particularly when the ship’s speed varied in the
course of a few hours. Take Bourne’s example, in his second edition of A
Regiment for the Sea, of ‘a good order in the keeping your account’. Either,
his said, knowing the number of hours in which the wind’s force has not
changed and ‘how many fadames that the Shippe hath gone in an hour’
multiply the fathoms by the hours sailed and divide by 2500 [fathoms] in
order to find the distance in leagues

or else it is better to add per hour, your numbers of fadames as long as
the Shippe hath gone one course without altering: as for ensemble this.
The shippe hath gone foure hours. 25. fadome, in the time of 120.
parte of an houre, that is in four hours. 12000. fadame, and the
Winde encreasing, she went three hours 34 fadames. In 120. parte of
an houre, that is in 3 hours 1224. fadames, and the Winde decreasing,
the Shippe went five hours, but 16. fadames, in the 120. part of an
hour, that is. 9600 fadame in five hours, nowe add all the numbers
of fadames together, that is 12000. and 12240. and 9600. and all these
make 33840. So that the shippe hath gone in 12. hours. 33840 fadams,
and now divide this summe by 2500. which is a league [number of
fathoms in a league], and then there will stande 13. in the quantitie
lyne, and 1340. remaineth ouer. So that you maye conclude, that the
Shippe hath gone 13. leagues and a halfe, and 90. fadames: and by this
order you may keepe a verie good order in your reckoning, and so note
it in your Booke, and make a mark in your Cart, etc. . . .

In the second book of the Sector Gunter, it has already been remarked,
had advocated a decimal system for the degrees of latitude and longitude,
dividing every degree into hundredths instead of into the customary
sixtieths. In this second book of the Cross-staff he also recommended
the system as being a ‘much better’ one in which to keep the account of
the ship’s way, coining the word Centesims for the units of one hundredth
of a degree. He pointed out that not only would the account be more
exact in degrees and centesms than in degrees and minutes—because a
centesm was smaller than a minute—but it would render 'the addition, subtraction, multiplication [and] division of them more eacie', particularly as a ship usually sailed about a degree in a day—a statement he based upon examination of ships' 'Journals to the East and West Indies', the former showing that the 90° passage from the Lizard to the Cape now took 'about 3 months'. Gunter supported his argument by showing how the answer to the problem of the ship's speed which he had just given—88 feet in 15 seconds—came to a whole number, 6 centesms per hour.

It was now that Gunter described the principle of the Dutchman's log and the first important modification to the log and line that lead to the term 'knots' being used as the measure of a ship's speed. A vessel's speed, he pointed out, could be found in 'one operation' on the Line of Numbers on the Scale if you 'divide 44 feet in 45 lengths, and set as many of them as you may conveniently between two marks on the ships side, and note the seconds of the time in which the ship goeth these lengths3 for,

As the seconds, to the lengths.  
So 1 hour, unto the Centesms. 
The lengths divided by the time, shall give the Cent.  
which the ship goeth in an hour.

It must be admitted that for once Gunter's pronouncement is oracular. What it means is this. If it be agreed that the length of a degree is 352,000 feet and that there are 100 centesms in a degree, then 1 cent = 3,520 feet (\(\frac{1}{100}\)th of 352,000 feet). If it be also agreed that there are 3,600 seconds in 1 hour then \(\frac{1}{1\text{ hour}} = \frac{3520}{3600}\text{ secs.} = \frac{58.7}{60}\text{ secs.} = 44\text{ feet}\). Therefore at a speed of 1 cent. per hour the ship sails \(\frac{44}{45}\)ths of a foot in one second, 44 feet in 45 seconds, and \((60 \times \frac{44}{45})\) feet or 58 feet 8 inches in 60 seconds. If marks be placed on the ship's side at this distance—60 lengths—apart, then, Gunter pointed out, the time taken in seconds to traverse this distance divided into 60 would give the speed in centesms per hour.

Suppose . . . the time be 12 seconds, [said Gunter] extend the Compasses from 12 to 1, in the Line of Numbers, so the same extent will reach from 60 unto 5. Or extend them from 12 unto 60, and the same extent will reach from 1 unto 5. This shows the ship's way is according to 5 Cent. in the hour.

(It will not escape the modern reader that 12 seconds are one-fifth of a minute). So much for the Dutchman's log for which, Gunter made it clear, though he may be termed its inventor, since he first described its mathematical basis, he had little use. He preferred the log and line for, he pointed out, the speed could be found

yet more easily, if the Log-line shall be fitted to the time. As if the time be 45 seconds, the Log-line may have a knot at the end of every 44 feet; then doth the ship run so many Cent. in an hour as there are knots veered out in the space of 45 seconds.
If 30 seconds were thought a more convenient interval of time then, he explained,

the Log-line may have a knot at the end of every 29 feet and 4 inches, and then also the Cent. will be as many as the knots . . . If there be 5 knots veered out in a Glass, then 5 Cent. if 6 knots, then the ship goeth 6 Cent. in the space of an hour . . . For upon this supposition, [he added], the proportion between the time and the feet will be as 45 unto 44.

In the 1620s, there can be little doubt, the log and line came into far more general use amongst English navigators. It is probable that it did so because it had been made more useful than hitherto. By the addition of knots to mark proportional lengths on it, the log-line was turned into a direct reading instrument that could be used by any seaman capable of simple addition and subtraction. The development, of which Gunter gave the first clear explanation, came at a very important juncture in English overseas voyaging—the colonization of the New England states and the West Indies in the 1620s and 1630s. It is Richard Norwood who intimates why it was so important. It will be recalled that since 1617 he had been settled in London as a teacher of mathematics and navigation. In 1637 he published a book, The Sea-mans Practice, a large part of which he devoted to a discussion of the length of a degree; to a description of the manner in which, between 1633 and 1635, he measured the length of a degree along the meridian between London and York; and to the correct spacing of the knots on the log-line so as to take advantage of his amended length of the nautical mile.1 It is perfectly clear from his text that he bases his description of dividing the log-line into knots upon Gunter’s in De Sectore et Radio; he actually gives examples of dividing ‘the Log-line so as it might give the ships way in Centesmes, or the hundredth part of a Degree, and fit it [as in Gunter’s description] to an half Minute-glasse’. But it is Norwood’s opening remarks on the log and log-line that immediately concern us.

There are four things, upon which the Practice of Navigation is especially grounded, [he wrote], namely, the knowledge of the Longitude, Latitude, Course, and Distance. Touching the Longitude, though it may be found by the other three, yet hitherto there hath not been

1 THE SEA-MANS PRACTICE, Contayning A FVNDAMENTALL PROBLEME in Navigation, experimentally verified:

Namely, Touching the Compass of the Earth and Sea, and the quantity of a Degree in our English measures. Also an exact method or forme of keeping a Reckoning at Sea, in any kinde or manner of saying. With certayne Tables and other Rules usefull in Navigation, As also in the Plotting and Surveying of places. The LAtitude of the principall places in England. The finding of Currents at Sea; and what allowance is to bee given in respect of them.

By RICHARD NORWOOD, Reader of the Mathematicks. LONDON, Printed for George Hurlock, and are to be sold at his Shop at Saint Magnus Corner, 1637.
delivered any general Rule true and practicable, whereby the Longitudes of places might be immediately and ordinarily found of themselves. The Latitude of places may immediately be found by Observation of the Sun and Stars . . . the Course by the Compasse, the Variation being dueely Observed, wherein we have many good Mariners very expert . . .

The distance run is found by it self by the Log-line . . . he that runs any course neer the Meridian Southerly or Northerly, hath a more certain way of reckoning; namely, his Latitude, which he findes daily by Observation of the Sun and Starres, upon which he will depend, either neglecting or at least not regarding his dead reckoning yea, (may be) never casting the Log so much as once in such a Voyage, having a more sure ground for his reckoning. But in a Course that is neer East and West (for as much as there is no way discovered for finding the Longitude) he is driven of necessity to make use of his dead reckoning.

The 1620s saw the great westward surge of English colonists to America. They sailed in ships that ‘made good’ passages on largely easterly or westerly courses and made their land-falls off coasts where visibility was often poor. The log became an indispensable instrument for checking the distance run and the longitude on charts of Mercator’s projection now increasingly used for oceanic sailing, particularly in the higher latitudes where its improvements were greatest.

Although the advantages of Gunter’s decimal system of navigation could not be denied, and just as custom continued to prove too strong for its general adoption, so, despite Gunter’s advocacy of the 352,000-foot length of a degree, the length of a degree continued to be counted by most navigators as 300,000 feet. This was why Richard Norwood went to the trouble and expense of remeasuring it. As a result, when he wrote The Sea-mans Practice he had to explain how, if ‘a man sailing between any to Places, which lie neer East and West one from another, have kept his reckoning by Course and Distance, using a Log-line so divided that it have a knot at every 7 Fathomes (as many do)’ he could convert his readings into miles of 6000 feet, the figure he himself recommended. Seven fathoms equals 42 feet, and was commonly chosen as the spacing of the knots on the log-line used with a half-minute glass because, as has been shown, the length of a mile in feet divided by one hundred and twenty gave the distance sailed in one hour when a half-minute glass was used because 

\[
\left(\frac{5,000' \times 30'}{60 \times 60}\right)
\]

\[= 41\frac{3}{3} \text{ feet.}\]

Norwood had little respect for people who thought ‘that the way which the ship maketh may be knoun to an old Sea-man by experience (as they say)’. He called it correctly, if unkindly, ‘conjecture’, and added that, as often as not, it was pride which prevented the use of the log by experienced seamen because they were fearful of being ‘accounted young sea-men’ if observed to use it. As for finding the ship’s way ‘by two marks on the ship’s side’, he considered it ‘very uncertain both by reason of the shortnesse
of the time, and in respect of the dead water (as they called it) by the ships side'. And he explained how 'the water which is neer the ship, is drawn along with the ship in her motion, as so much the more, by how much it is neerer'. He therefore preferred the use 'of the Log-line, according to the half minute-glasse', and he recommended fitting it with a stray line by leaving 'half a score fathom, or more from the Log, that so it may be out of the Eddy of the ships wake, before you begin to account or turn the glasse', and to make there 'a mark for the beginning, and so 51 [or 41\3] feet from thence a mark of one knot, and 51 [or 41\3] feet further a mark of two knots, and 51 [or 41\3] feet further (that is, 153 [or 125] feet from your first mark) another mark of three knots, and so proceeding'. Then, he continued, 'Look how many knots are veered out in half a minute, so many miles is the ships way for an hour.' Gunter, it has been pointed out, had recommended dividing the log-line by 'a knot at the end of every 44 feet' [for the distance in centesms]; Norwood, it will be noticed, recommended the further refinement of dividing the log-line by 'a mark for the beginning . . . thence a mark of one knot, . . . a mark of two knots, . . . another mark of three knots, and so proceeding'. The mark at the beginning of the log-line—the end of the stray-line—was probably, as later, a piece of white bunting; similarly from the time of the innovation of knots they must have been spliced into the line in the form of pieces of knotted leather, for the system of knotting the line itself, illustrated by Champlain, while practicable with single knots was not with more. From Metius's description of 1632 of the English log and log-line it is clear that, as mentioned in later English descriptions, the practice of marking half-knots by the insertion of a piece of leather with a single knot in it, had already been adopted, and that he was aware of the system of progressive knotting of the line.

We can conclude then that the log and line was an English invention probably of the late 1560s for measuring distance sailed; that it then consisted of a log chip, a 3-fathom stray-line, and a plain log-line; that the distance run was measured by the number of fathoms veered in a minute or half-minute converted into fathoms in an hour; that by early Jacobean days the distance run was found by measuring how many 14-fathom lengths were veered in a minute; that Gunter, probably as a result of his invention of the line of proportion—the logarithmic scale of numbers—pointed out in his lectures at Gresham College, between 1619 and 1623 (when they were published), that the log-line could also be made into a line of proportion to give a direct reading in miles of distance run in an hour by marking the log-line off into fixed lengths with a succession of single knots for use with a known interval of time. He recommended using a time basis of half a minute and marking the log-line by a knot at every 1/120th of a nautical mile. The system was quickly adopted and was illustrated by Champlain in a work of 1632 and described by Metius in the same year. Richard Norwood described in detail the refinement of using one knot to indicate a distance run of 1 mile in an hour, two knots a distance of 2 miles and so on, Metius distances of fractions of a mile. Finally,
we can conclude that log-line knots led Gunter logically to explain the complementary method of measuring the distance run by a ship namely, that of measuring the time taken to sail a fixed distance, representing 1 mile, marked on the ship's side, with the aid of a chip or Dutchman's log.

To sum up, the log and log-line was an instrument of navigation developed by English seamen, probably in the middle of the sixteenth century. It was designed to assist the navigator to assess more accurately than by the unaided eye the distance his ship had sailed in a given time.

In the fifteenth century the English seamen did not work in units of distances. As the surviving rutter of the period shows he sailed from land-mark to land-mark, ignorant of the distances between them, and, when he was out of sight of land, assisted by his soundings, his knowledge of the sea-bed and his running-glass, by guessing his relative progress. Thus his sailing directions advised him, when bound from Spain to Bristol, 'at capfenister [Cape Finisterre] go your cours north north est. And ye gesse you ij. parties ovir the sec and be bound into sebarne [the Severn] ye must north and by est till ye come into Sowdying [the Soundings, the 100-fathom line]', the directions then told him to go north till in seventy fathoms he found 'feir grey sonde' on the 'Rigge' [the Nymph Bank], and to continue on that course till he came into soundings of ooze, when he should alter course to east-north-east or east by north on which course he could not then 'faile much' of Steepholm. Elsewhere he was directed—if he were sailing from the Orwell, in Suffolk, to the Downs—that his course should be east-south-east to take him clear of the Ridge and the Rocks and the northern end of the Longsands shoal, until he was in fifteen fathoms when he could go south-south-east until he was in 7 or 8 fathoms when, he was warned, 'ye must go south a glass or two', to avoid the Kentish Knock, after which 'ye goo south south west, and seke up Tenet [the Isle of Thanet]' off which he was told, in 6 fathoms on the Brake Sand, 'go your cours south it is your fairway'.

When, in the early sixteenth century, distances began to be recorded in sailing directions they were given in kennings—the distance a man could see—and days of sail, both very variable units. Thus the seaman still estimated by eye his relative speed (from the foam slipping past his vessel), namely, that he was making fast or slow progress along his customary coastal or short sea route.

When Englishmen began to learn and to practise the art of oceanic navigation they had to work consistently in fixed units of angular distance used to express position in terms of latitude and, using a globe, of longitude. They had then to learn to estimate by eye the speed of their ship, and to express it, in units of distance sailed in a given time. This was because they had to correlate their estimate of distance sailed, expressed in leagues and miles, with the angular distance, expressed in degrees and minutes.

Although they estimated their speed and distance run daily these navigators, as Medina, Cortes and other authorities make clear, fixed their position as much as possible by their observed latitude and estimated course
made good. In other words, they rejected their estimate of distance sailed if there was any difference, in favour of the distance which, on the basis of their table of 'distance to raise or lay a degree' accorded with their observed difference of latitude and their course made good. However, as on easterly or westerly courses latitude observations afforded no such check on distance sailed, the navigator following such courses was forced to rely on his estimate of it, and this estimate the Iberian navigator of the sixteenth and seventeenth centuries continued to make after judging his speed by eye. The English, however, developed the log and log-line and used it, in conjunction with a minute or half-minute glass, to measure distance sailed. It was a mathematical instrument.

Another mathematical way of measuring distance sailed, perhaps developed at this time or perhaps later, by Gunter, was the Dutchman's log. Because with this log the time-interval to be measured was variable (it varied with the distance apart of the marks and the speed of the ship) it was not practicable to use a sand-glass directly as a time-piece (as will be recounted a Dutchman's log sand-glass was devised in the 1620s by an English navigator but it was not a satisfactory time-piece). The navigator had therefore to learn to count rhythmically so that he reached the same number every time a minute- or half-minute-sand-glass ran out. Thereafter he could gauge the time taken for a log chip to pass between two marks. The Dutchman's log was deceptively simple. Not only was there large scope for error in the timing through incorrect counting, but also the faster the speed of the ship, the shorter was the interval of time over which her progress was measured, consequently a slight error when the ship was sailing fast produced a large error in the estimated distance sailed. For example, assume two marks 60 feet apart, a sea-mile of 6000 feet, and a speed of one mile an hour, then the log chip will pass between the marks in 36 seconds; at two miles an hour it will take only 18 seconds; at four miles an hour only 9 seconds; and at six miles an hour only 6 seconds. Thus an error of only minus 2 seconds at a speed of six miles an hour results in an underestimation of distance run of 1½ miles in an hour. This goes far towards explaining the English preference for the log and log-line for it suffered from none of the defects; its accuracy was not affected by the speed of the vessel through the water, and the unit of time measured was constant. As originally conceived the log-line was a plain line, by the 1630s it had been developed into a progressively-knotted line directly registering the speed of the ship in knots and half knots as soon as it was checked on the log-glass running out.

A certain amount of judgment and skill was always necessary in arriving at a correct reading of the log. When veering the log-line great care had to be taken to 'overhale it so slack that it might not draw forwards the Log'. Despite this precaution the log undoubtedly did follow the ship a little, being 'drawn by the Line, and withal by the Eddy of the ships wake'. Sometimes also, when the ship was running before the wind, or reaching, the log was 'cast forwards by the winde and waves'. The result was that
due allowance for such occurrences had to be made 'as a man in his experience and discretion' found it necessary—generally by allowing 'three or foure fathomes more' than was veered out.

The log was commonly thrown every two hours, but some navigators preferred to throw it every hour. Every noon, in a well-regulated ship, the master and his mates, whether they had made an observation or not, called for the log-board and added up the knots and fathoms run since the previous noon. If the log had been cast only every two hours, they doubled the sum in order to find the day's run. The result was entered into the traverse-book or log-book and, after the traverse from the last noon had been worked out, and the difference of latitude and departure had been found, corrected by the observation if it had been made, the fair entry was made in the journal.

Having dealt with the application of his Scale to the problems of measuring distance sailed by log-chips and log-lines Gunter turned to the solution on his Scale of some of the navigational problems which he had formulated earlier for solution with the Sector. He explained, for instance how to convert difference of longitude on a parallel into departure, and departure along a parallel into difference of longitude, and the solution of the first five propositions contained in Table 12, p. 381. The fourth and fifth of these propositions, namely 'given the longitude and latitude of two places, find the rhumb between them', and 'given the latitude of two places and the rhumb between them, find their difference of longitude', involved two operations on the scale. The first operation gave the answer according to plane sailing, the second corrected this result, bringing it into conformity with Mercator sailing. In the course of his explanation Gunter pointed out that if the mid-latitude formula were used with the canon or tables of logarithmic sines, tangents and secants the answer to each of his problems could be found in a single simple calculation. He did not, however, explain the proof of the formula. He contented himself with stating it and with explaining the logarithmic solution of various navigational problems by use of the line of meridional parts and the logarithmic lines of numbers, sines, and tangents on his Scale.

Before ending his chapter on nautical questions he gave the formulæ for finding 'the distance between the ship and the land' by methods that are now called a 'running fix' and a 'cross-bearing fix'. Bourne had first described them. The first method consists in fixing the ship's position by plotting two separate bearings of one conspicuous object on shore, and the distance run by the ship—on a steady course—in the interval between taking the bearings; the second consists in the simultaneous observations of the bearing of two conspicuous objects on shore, the distance apart of which is known. A fix 'by cross-bearings' is usually taken when running past a well-charted coast, or when coming to an anchor, a 'running fix' is most useful on first making a landfall, or on taking departure from a headland when the flanking coasts are obscured. Their results are usually obtained by plotting and almost certainly were in Stuart days, so that Gunter's
formulae were chiefly valuable for showing the mathematical basis of the
fixes.

Gunter added an Appendix to this chapter in which he described—with a woodcut—‘an Instrument made in form of a Cross-bow, for the more easie finding of the Latitude at Sea’. This instrument has already been referred to in the previous chapters. His object was to facilitate the observation of celestial objects for latitude-finding by incorporating their various declinations in linear scales on the instrument itself. By setting the upper sight vane to the celestial body’s declination before making the observation the observed meridian altitude when taken was read off as the latitude (uncorrected for height of eye and refraction). The design reflected Gunter’s passion for reproducing, in the form of scales, the contents of tables prepared for (but so much disliked by) seamen. Although his description of the graduation of the scales on the cross-bow is perfectly clear, and the manner of using the cross-bow is shown equally clearly on the title-page of De Sectore & Radio, the cross-bow does not seem to have come into general use. The fact of the matter is that Davis’s back-staff was far easier to manipulate.

The solid brass or wooden astronomical quadrant (astrolabe-quadrant) which Gunter described in the Appendix to De Sectore & Radio can rarely have been useful to deep-sea mariners away from their home port, because the lines had to be engraved for a particular latitude. However, Captain Smith included one in his lists of necessary instruments. Gunter’s description of the engraving of the lines and of the various uses to which his quadrant could be put were such models of clear exposition, and its size—it was specially designed for the pocket—was so convenient that Gunter’s quadrant, as it came to be called, came rapidly into popular use on shore, and continued so for close on a century as a handy time-piece and almanac.

De Sectore & Radio was Gunter’s last work. As already stated, he died in 1626, and was succeeded at Gresham by Henry Briggs’s friend, Henry Gellibrand, who was in due course to publish the results of studying and comparing Gunter’s observations on variation.

In 1624, the year following the publication of De Sectore & Radio and the year that saw the publication of Briggs’s Arithmetica Logarithmica, there appeared on the bookstalls and in the bookshops specializing in scientific, mathematical, and navigational works a book entitled Speculum Nauticum. A Looking Glasse for Sea-men.1 It was written by John Aspley, who described himself as a ‘Student in Physick, & Practitioner of the Mathematicks’. Aspley had practised himself ‘in the Mathematicall

1 Speculum Nauticum: A LOOKING GLASSE FOR SEA-MEN: WHEREIN THEY MAY behold a small instrument called the Plaine Scale: whereby all questions Nauticall, and propositions Astronomicall are very easily and demonstratively wrought. Lately penned, and now published for the use and benefit of such as will make good use of it. By JOHN ASPLEY Student in Physicke, and Practitioner of the Mathematicks, in the City of LONDON.

LONDON, Printed by THOMAS HARPER, M.DC.XXIV.
studies', he informed the reader, ever since he 'came to understanding'. That Aspley held strong views upon the ends to which a man's talents should be devoted, and upon the call of the sea upon patriotic men in particular, has already been indicated in considering Edward Wright's achievements, when part of Aspley's preface from Speculum Nauticum was quoted. It can be said at once that, while little appears to be known of John Aspley, his work ('this yong sonne of my studies, this little handfull of paper'), 'published for the use and benefit of such as will make good use of it', proved of immediate and real benefit to the seamen of England occupying 'their businesse in the great waters'. As their author had hoped, it did indeed 'further that so much deserving Science of Navigation'.

The work set out to describe and illustrate the use of

a small instrument called the plain Scale . . . which though it be in use with very few, yet is most necessary with Sea-men, because all questions in Navigation are thereby easily and plainly wrought. And also all questions of Astronomy (belonging unto the expert and industrious Sea-men) may both easily and speedily be wrought by the same Scale:

Aspley dedicated Speculum Nauticum, as became a work of navigation, 'To the Worshipfull The Master, Wardens, And Assistants, of the Trinity House in Deptford Strand'. To the reader he wrote a note hoping the book, 'the first fruit of my labours', would be well received, and promised another from his pen should it be so. Like a good teacher he introduced his subject with a few essential definitions of geometrical terms such as 'point', 'angle', 'circle', etc. He then gave clear descriptions, helped out with line drawings, of the few geometrical constructions essential to the navigator —how to raise or drop a perpendicular on to a line, and how to draw an angle, etc. Next he proceeded to describe the plain scale.

The plain scale was a ruler, usually with three parallel straight lines drawn longitudinally on one face and two on the other. The bottom line on the front face was 'a Scale of Equall Leagues', a line divided into equal divisions from 0 to 100 or any convenient figure upwards: the mid-line was a Line of Chords, a line divided into ninety unequal divisions, marked 10, 20, 30, etc., representing the chords of the 90° in a quadrant or quarter of a circle of radius equal to the distance between 0 and 60 on the league scale; thus 60 on the line of chords—the length of the chord of an angle of 60°—coincided with 60 on the Line of Equal Leagues. This distance was known as the Radius of the Scale, and all arcs or circles drawn in connexion with the use of the plain scale were drawn to this radius; the top line, known as the line of rhumbs, was divided into eight unequal parts representing the chords of 'the eight winds of the compass in one quadrant'. The circle on which these chords were based was of the same radius as that used for marking the line of chords. The end of the line of rhumbs, marking the eighth rhumb, was therefore co-terminal with the 90° division on the line of chords.

The line of equal leagues was really a distance scale. It was used to
measure off 'the distance run by a ship on any course or the amount she had raised or laid the pole or had departed from the meridian', in other words, distance, difference of latitude and departure. The line of chords was for measuring 'any arc of a circle not exceeding 90°', in modern speech, any angle up to 90°; the line of rhumbs was for measuring the arc [angle] of any rhumb (or point of the compass) up to eight [90°], and was provided in addition to the line of chords merely for the convenience of navigators who preferred working in rhumbs of the winds or compass to working in degrees of the quadrant or circle. Both these lines thus served in the place of the degree graduations, which had not yet been introduced, on the top and side edges of rectangular protractors.¹

These three lines enabled a navigator, armed with a pair of compasses and a piece of lead, to lay off on a plotting board the courses sailed and the distances run during any given time, or the difference of latitude and the mean course between observations, and thus to find his position by plotting. Together they were equivalent to the scale of equal parts, and the degree and rhumb scales on Gunter's protractor. Aspley capped his description of these lines with a drawing of the front face of 'the Plaine Scale' showing the graduation of the lines, and a pair of compasses measuring a chord on the line of rhumbs. He then stepped straight into their use in the solution of particular and typical navigational problems. His explanations were perfectly clear and were illustrated by linear diagrams. These diagrams—there was one to most of the propositions—are of particular interest and importance, for they are the earliest printed ones showing the geometrical solution of typical navigational problems. Aspley did not necessarily orientate his diagrams so that the north was at the top. As a result some are at first glance confusing. This practice of marking the north end of a meridian line at the top of a diagram did not become general until later in the century, when the practice was advocated in a later edition of Speculum Nauticum, together with an improved method of correcting the dead reckoning position geometrically by the observed latitude.

Aspley posed as the first problem: 'To finde how much any ship hath raised or depressed the Pole, knowing the course she hath made, and the leagues she hath sayled'—in other words how to find the difference of latitude resulting from sailing a given distance upon a particular course. He gave the distance sailed as 100 leagues [300 miles] on a course of S.W. by S. [three points west of south].² The procedure was first to open the compasses to the radius of the plain scale by extending them from 0 to 60° on the line of leagues or of chords, and then with the compasses set to this radius to draw a quadrant KAB with centre A. The line AK then represented the meridian and AB the parallel of latitude through the point of departure A. As the course followed had lain along the third rhumb from the meridian, the length of the chord of this rhumb was next measured on the line of rhumbs with the compasses and transferred to the quadrant

¹ See Fig. 37 on p. 418. ² See Fig. 38.
KCB so that with one point in K the other point of the compasses fell on the arc of the quadrant at C. A line drawn from A through C and extended to D then represented the ship’s track along the third rhumb. The distance sailed, measured off with the compasses on the line of leagues and transferred to the line ACD, gave the ship’s position at D relative to A. A line DF drawn through D parallel to AB so as to cut the meridian line AK in F

\[ \text{(dep} = 56 \text{L} = 188') \]

\[ \text{d. lat} \]
\[ 4^\circ 09' \]
\[ 83 \text{L} \]
\[ 249' \left(\text{chord of 3 pts or} \right) \]

\[ \text{(Chord of 3 pts or 33.2')} \]

\[ \text{dem. prim:} \]

\[ \text{Radius of the scale, 60).} \]

\[ \text{(Lat. 51°54'N)} \]

\[ \text{(Lat 56°05'N)} \]

Fig. 38

ASPLEY'S DIAGRAM TO SHOW HOW TO FIND THE D. LAT. AND DEP., GIVEN THE COURSE AND DISTANCE, USING THE PLAIN SCALE

(Figures in [ ] are added for clarity.)

completed the construction. DF, measured with the compasses and transferred to the line of leagues, gave the departure west of A’s meridian [56 leagues], while AF gave the difference of latitude south of A [4°09’]. The solution of all the other problems of plane sailing followed similar constructions. In addition to these straightforward ones involving only one course and distance Aspley explained and illustrated the method of resolving geometrically several traverses in succession, a very necessary business in the course of a day’s sailing with contrary or changeable winds.

1 See Fig. 39 on p. 442.
Besides facilitating the geometrical solution of problems involving traverses in plane sailing, the plain scale could be used in problems of parallel sailing—sailing along a parallel. Aspley explained the simple preliminary construction involved—that of finding 'how many miles or minutes of any Parallel doth answer unto one degree of the Equinoctiall.'¹ This was to strike a quadrant BDC of the radius [AB] of the scale, measure the chord of the angle of latitude on the line of chords, transfer this to the quadrant so that BD equalled the chord of the angle of latitude, draw a parallel from

\[
\begin{align*}
\angle DAB &= 58°56' \\
\therefore \angle DF &= 31' \\
\angle EAB &= 52' \\
\therefore \angle EG &= 36°56' \text{ or } 36\frac{56}{60}
\end{align*}
\]

Fig. 39

Aspley's diagram of the solution of the problem, given the difference of latitude and departure, to find the rhumb with the aid of the plain scale

Fig. 40

Aspley's demonstration of: 'To find how many miles or minutes of any parallel doth answer to the degree of the equinoctiall.'

D through the meridian AC cutting it at F, and measuring the distance DF on the line of leagues. He gave the example for latitude 58° 56', and the answer as 30 miles, which for all practical purposes was accurate enough. The underlying principle was, of course, that dep. = d. long. cos (lat.). As the radius of the scale AB was made 60 equal parts in length, that is 60' in length, equal to the length of a degree of longitude on the equator, and as the angle of latitude was equal to DAB = 58° 56', as also DF was by construction the cosine of DAB, so the length of DF on the scale of equal parts was the equivalent of the d. long. × cos (lat.) when the d. long. = 60' and the latitude = 58° 56'. While this construction was perfectly

¹ See Fig. 40.
simple and straightforward it was a rather laborious method of finding the
length of a degree of longitude, nor did it particularly help the navigator
desirous of converting departure into difference of longitude or the reverse.
It was to make these processes possible by rapid reference to the plain scale

![Diagram of longitude calculation]

This radius is to
the same scale as
Aspley’s repro-
duction of a Plain
Scale

**Fig. 41**

**METHOD OF PROJECTING THE FIRST LINE OF LONGITUDE UPON
ASPLEY’S PLAIN SCALE OF 1624**

Principle — dep. = d.long . . cos (Lat.) where d.long. = 60°
Example — 30° = 60° × \(\frac{1}{2}\)

= 60° cos 60°

∴ in latitude 60°, 30 miles = 60° of longitude,

= 1° of longitude

that Aspley ‘caused two other lines to be placed up on the backside of the
Scale’, and which he named ‘the first and second lines of Longitudes’.
The first line of longitude was nothing more in effect than the projection,
upon the 90° chord of a circle of the radius of the scale, of the length of a
degree in every several latitude.\(^1\) Actually Aspley did not graduate the resultant scale with degrees of latitude and the corresponding number of leagues
and miles in a degree of longitude. Instead he divided the scale into leagues
and miles only, the resultant unequal divisions being marked 0, 5, 10, 15 and
20 [leagues], 0 being in latitude 90°, 10 in latitude 60°, 20 on the equator
(lat. 0°), and the line of chords on the front face of the scale was used
as the corresponding latitude scale. In order to find how many leagues [or
miles] there are in a degree of longitude in any latitude, all that was neces-
sary was to extend the compasses from the centre in the line of chords to

\(^1\) See Fig. 41.
the degree of latitude of the place. Then the same extent transferred to the first line of longitude reached from the centre at 20 (or 60) to the number of leagues (or miles) answering to a degree of longitude in that latitude.

Asley's second line of longitude was for converting departure into difference of longitude in parallel sailing and also in oblique sailing. Curiously enough he explained the construction of neither the first line of longitude nor of the second, nor did he illustrate either line. Nevertheless he did describe the second line of longitude as being 'divided into 100 proportionable parts, or unto 100 unequall Leagues, and . . . miles. . . .' It was, in fact, Gunter's logarithmic line of numbers.

Although in a later example Asley showed the use of the mid-latitude formula for converting departure between two places in different latitudes into difference of longitude, in the first of such problems he wrote, on 'sayling from 56° 05' N, 100 L(eagues) between S & W until d. lat. = 4° 9', to find the difference of longitude make the construction already described for finding departure, found to be 56 leagues or 168 miles west. As the latitude of the point of departure was 56° 05' N, and the difference of latitude was 4° 9' S, the final latitude was 51° 56' N. This was correct. But he then said use this latitude to convert the departure into difference of longitude; whereas a more accurate answer would have been obtained by taking the mid-latitude between the two places—latitude 54° N.

The method of converting the departure into difference of longitude was to open the compasses to the chord of the latitude, in this case 51° 56', on the line of chords and then apply them to the first line of longitude. This showed that a change of longitude of 1° in latitude 51° 56' involves a departure of 12 leagues 1 mile (37 miles). The compasses were then used on the logarithmic second line of longitude to find the quotient of the total departure, 56 leagues, divided by 12 leagues 1 mile (37 miles), for this gave the difference of longitude which was found to be 4° 33' W.

In the second part of Speculum Nauticum Asley described the way to find, by means of the plain scale and dividers, astronomical data useful to the navigator, but hitherto most easily found on the celestial sphere or an astrolabe or planisphere. He gave the various definitions of the sphere and of the lines and circles relating to it in astronomy, and then the solution of problems such as: 'The true place of the sun being given [in terms of the Zodiac] find his declination', or 'The amplitude of the sun being found, find the variation of the compass'. In defining the lines of the sphere he discussed the question of the sun's declination, concluding that 'in these our daies (by the observation of Ticho de Brahe, and that late famous Mathematician, Master Edward Right) it is found distant from the Equinoctiall 23 degrees 31 minutes 30 seconds'.

Asley concluded his book with 'A general Table for the Tides in all places', and a short explanation of the Ptolemaic theory of the movement of 'the Moon and all the rest of the Stars and Planets', and of the reason for the '48 minutes difference of every full Sea'. It was quite irrelevant to the rest of the subject-matter of the book, but he presumably included
it on the grounds of its universal value, for he listed the thirty days of the moon's age and opposite each day the number of hours and minutes that had to be added to the time that the moon, at full and change, made a 'full Sea'. It thus showed the time of high-water on any day of the moon's age. Therefore all that was necessary to 'know the full Sea at any place in the World' was to find out the establishment of the place and the age of the moon and to add to the establishment the appropriate hours and minutes listed against the moon's age in Aspley's table. He gave a well-known example, high-water at London Bridge. The establishment of London Bridge was 'full sea at 3 hours' on days of full and change. Therefore on the 13 July 1624 when the age of the moon was 8 days, full sea or high-water occurred at 3 hours + (and here one referred to Aspley's table) 6 hours 24 minutes, that is, at 9.24.

The *Speculum Nauticum* was several times reprinted—with improvements—during the course of the century, and Aspley's plain scale became a deservedly popular instrument with navigators. It was simpler than Gunter's Scale and it combined ease of manufacture and of manipulation with cheapness. The ordinary navigator could see and understand the geometrical constructions used with the plain scale—he was far less confident using the lines of meridional parts and of the trigonometrical functions on Gunter's Scale. The latter was for the use of his more mathematically-minded brethren.

While the plain scale was undoubtedly brought into general use amongst seamen through the publication of Aspley's *Speculum Nauticum*, Aspley was not, and did not claim to be, the inventor of the original plain scale. This, it seems clear, was John Speidell, the 'professor of mathematics' whose *New Logarithmes* of 1619 has already been mentioned. It will be recalled that Aspley wrote of the plain scale that it was an instrument 'in use with very few', which showed that it had already been invented. Now John Speidell, writing eight years before Aspley, pointed out in his *A Geometricall Extraction* (a book, incidentally, recommended in later years by the author of a book on navigation) that

... not only these Problems contained in this booke ... but much more viz. in Arithmetike, Geometrie, Astronomie, Navigation, Surveighing ... may be performed by a Mathematical Scale. now newly (this present yeare) by me invented, farre beyond my former Scale made in Anno, 1607. the which with all other Mathematicall instruments, are made by my loving friends Mr. Elias Allen ... in Brasse ... and Mr. John Tomson ... (in Wood) and may also ... be had, with the instructions thereof by me at my house.¹

¹ A GEOMETRICALL EXTRACTION, OR A COMPENDIOUS COLLEC-
TION of the Chiefe and choyse Problemes, Collected out of the best, and latest Writers. WHEREVNTO IS ADDED, about 30. Problemes of the Authors Inven-
tion, being for the most part, performed by a better and briefer way, then by any former Writer. By JOHN SPEIDELL, practitioner in the Mathematicks, and
In fact Speidell invented a scale as early as 1607—which was about the year Gunter invented his Sector. Except for the probability that both were first made and sold by Elias Allen there appears, however, to be no connecting link between the two inventions. It is unlikely that one of Speidell's early scales will come to light. What lines the instrument contained—since Speidell did not describe it—is therefore likely to remain a mystery; it is possible that this scale was the 'circular scale' referred to by Handson, but again we are ignorant of its details; nor do we know precisely what lines Speidell's 'Scale' of 1616 had engraved on it. We do know, however, that Allen manufactured it—as he did Gunter's Sector, so it may have been the prototype of Gunter's Scale—and that it probably contained the lines on the front of Aspley's plain scale, because Aspley in his description of the plain scale, after describing the lines on the front specifically states that he 'caused two other Lines to be placed on the backside of the Scale', clearly by its maker, Elias Allen. Thus the genesis of instruments designed to facilitate navigational calculation occurred in the 1600s, that is to say in the decade immediately following the establishment of Gresham College.

Aspley's *Speculum Nauticum* was the last Jacobean navigational book. King James I died in March 1625, and was succeeded by his second son, Charles I. The accession of Charles coincided with the renewal of hostilities with Spain. Since 1618 what was to become known as the Thirty Years' War had been raging on the continent of Europe. Its ramifications had now embroiled England. It was therefore with the old strategic aim animating them as much as anything else that the English at this time began to colonize the coasts and lesser islands of the Caribbean sea—Guiana in 1619, Barbados in 1624, St. Kitts in 1625. Since 1619 Buckingham had been Lord High Admiral and had been attempting to clean up the administration of the Royal Navy; the urgency of the task had been shown by the failure of the expedition of 1620-21 under Sir Robert Mansell, Sir Richard Hawkins, and Sir Thomas Button, against the Barbary pirates centred upon Algiers. When the expedition had returned in 1621—with a fine chart of Algiers Bay and the fleet anchorage there by the versatile Robert Norton—the Hispano-Dutch Truce had come to an end and the Dunkirkers were active again in the Channel. By 1624 England had begun rearming for war with the Hollanders against Spain. The Cadiz expedition of 1625 followed hard upon Charles's accession to the throne. Led by a soldier, Lord Wimbledon, it ended in failure. The incompetence of the higher command was matched by the ineptness of many of the subordinate commanders. Only in Indian waters, where Captain Weddell of the East India Company's fleet won the Battle of Gombroon, and so assured the

*professor thereof in London. LONDON, Printed by Edward Allde, and are to be solde at the Authors house in the fields betweene Princes streete and the Cockpit, 1616.*

This book was recommended by Captain Charles Saltonstall in *The Navigator* (1st ed. 1636). It has been possible to refer only to the third edition of the latter work (1660?), but the indications are that it is similar to the first edition.
continuance and security of the Anglo-Indian trade, did affairs prosper. It was a navigator engaged for the second time in the employment of the Honourable Company of Merchants of *London*, trading to the *East Indies*, Thomas Addison, who now published the first explanation of the solution of navigational problems by means of logarithmic tables—Edmund Gunter, it will be recalled, had merely stated that the tables could be so used. Addison called his book, appropriately, *Arithmetical Navigation or, An Order thereof: Compiled and published for the advancement of Navigation: More particularly, For the benefit of English Mariners, or Sea-faring men that delight therein*. Addison was clearly one of Edward Wright’s students for the logarithms he used were Napier’s, and also one of Gunter’s, for he worked in decimals. He included in his book a set of logarithms for numbers from 1 to 1000, which he, apparently, had compiled himself, and two traverse tables which were an improvement on Gunter’s. Addison’s book is now extremely rare, indeed only one copy appears to be known. This rarity is probably accounted for by his use of Napier’s logs, for, within five or six years of its publication, the far more convenient common logarithms were on sale as part of several text-books explaining their use in navigation. Nevertheless, Addison’s book is important for a number of reasons. For one, its appearance shows that within ten years of their first publication logarithms were being used, as Edward Wright had intended they should be, by seamen. For another, it was the earliest English navigation manual devoted exclusively to arithmetical navigation. It therefore struck a new note on the art now rapidly developing into a science. Gunter’s *De Sectore & Radio*, like Handson’s *Trigonometrie*, while of fundamental importance in the advancement of navigation, can by no stretch of the imagination be described as a purely navigational manual. Addison’s book can. It was in the same class as the works of Cortes, Bourne, Blundeville, and Davis.

Addison explained the contents of his book in his Epistle dedicatory to the ‘Governour . . . Deputy, the worthy Treasurers and Committees of the Honourable Company’ through whose prescriptions (with God’s blessing and their servants’ endeavours), ‘the vast Ocean’, he assured them, ‘is become a knoune path to the remotest parts of the world, unknoune Regions haue beene, and daily are discovered, an ample trade acquired, and’—despite the ‘bloud-thirsty Netherlands’ at Amboyne and elsewhere in the East Indies—‘successfully pursued’. He described his book as the ‘first Fruits of his poore endeavours’, and explained that it aimed at the advancement of navigation ‘by a more exact Method or Order, then

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1 *Arithmetical Navigatio[n]*.

OR, An Order thereof: Compiled and published for the advancement of NAVIGATION: More particularly, For the benefit of English Mariners, or Sea-faring men that delight therein.

*By Thomas Addison, Practicioner in the Art of Navigation. LONDON, Printed for Nathaniel Gosse at Radcliffe, and are there to be sold. 1625.*
formerly hath beeene published to the world'. It is in this light that its worth should be assessed.

Addison laid down nine subjects with which

will be Practitioners in the Art of Navigation, ought to bee acquainted [first] the Sunne and Moones motion . . . for the better finding the time of the Tide in any place. Secondly . . . [acquaintance with] the setting of the Tides or Streames, with the Depths and Landmarkes, for the shunning of Rocks and Sands, in his going out, or comming into the Roade, Harbour or River. [Thirdly the] latitude and variation [of the points of departure and intended arrival]. Fourthly he ought to know the way of a Ship. In the fifth place to protract a traverse. In the sixth, the resolution of plaine Chart Navigation. Seventhly, he must observe, and know the disagreements between the Meridian on a plaine Chart, and the Meridians on a Globe. Eighthly, he ought to know the use of Mercator's Chart, (or Planisphere). Lastly, he ought to know and understand such Astronomicall questions as shall be use full.

Accordingly in 'this short Treatise' there would be found, he explained, for young beginners, rules for 'shifting of the tides'; 'finding of the Latitudes'; making 'a halfe minute glasse'; using 'two protracting Tables; the one for Points, Halfes and Quarters, and the other for every Degree'—the two traverse tables already referred to—the table of logarithms referred to; and a table of meridional parts 'to the Parallel of 60 Degrees'. The call of sea affairs prevented Addison, like Davis before him, from completing the book on the lines he had intended; in his particular case he had wanted 'to have shewed an order of great Circle Navigation'. Being ordered to sea by the Company he left that, perforce, 'to those that have better leisure and liability to performe it'.

Addison's brief rules for finding the moon's age and so the tides, and for adding or subtracting declination to obtain latitude from a celestial observation call for no comment. Ingenious are his instructions for making a tubular half-minute glass, marked off with 120 divisions for use with a Dutchman's log, described as 'a distance on the ships side, of the 120 part of a mile', so that if 'any thing is hove over into the water', the ship would be found to 'passe from the one marke to the other' at a speed in miles per hour equal to 120 divided by the number of divisions 'that the sand sinketh'. For instance, if the sand sank 120 divisions while the ship sailed 42 feet (approximately 1/120th of a mile of 5000') the speed was 1 mile per hour because the 120 divisions had been cleared by the sand in half a minute or 1/120th of an hour. If the sand had passed only the twentieth division while the ship sailed 42 feet, the ship's speed, Addison explained, was 120/20 = 6 miles per hour. Although simple and ingenious, his log-glass was not really practical. The tube was emptied through 'a necke of leather of three inches long . . . fastened to the end of the Glasse, and . . . to a Base of Ivory . . . for receiving of the sand', the rate of flow being controlled—as in the ordinary half-minute glass—by a plate with 'a hole
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**Table 26**

**Traverse Table**

- **2 1/2 Points = 30° 56' 15''**
- ADDISON'S TRAVERSE TABLE

- **3 Points = 33° 45' 00''**
- ADDISON'S TRAVERSE TABLE

- **4 Points = 45°**

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<td>1</td>
<td>028</td>
<td>2054</td>
<td>1</td>
<td>715</td>
<td>4572</td>
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<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>542</td>
<td>3081</td>
<td>2</td>
<td>573</td>
<td>1848</td>
<td>0</td>
<td></td>
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<tr>
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<td>2</td>
<td>056</td>
<td>4108</td>
<td>3</td>
<td>430</td>
<td>9144</td>
<td>0</td>
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</tr>
<tr>
<td>5</td>
<td>2</td>
<td>570</td>
<td>5135</td>
<td>4</td>
<td>288</td>
<td>6430</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>084</td>
<td>6162</td>
<td>5</td>
<td>146</td>
<td>1002</td>
<td>0</td>
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<tr>
<td>7</td>
<td>3</td>
<td>598</td>
<td>7189</td>
<td>6</td>
<td>004</td>
<td>1002</td>
<td>0</td>
<td></td>
<td></td>
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<tr>
<td>8</td>
<td>4</td>
<td>112</td>
<td>8216</td>
<td>6</td>
<td>861</td>
<td>8288</td>
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<td></td>
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<td>9</td>
<td>4</td>
<td>626</td>
<td>9243</td>
<td>7</td>
<td>719</td>
<td>5574</td>
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<tr>
<td>10</td>
<td>5</td>
<td>141</td>
<td>0270</td>
<td>8</td>
<td>577</td>
<td>2860</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Course</th>
<th>Distance</th>
<th>Departure</th>
<th>Diff. Latitude</th>
<th>Dist.</th>
<th>(Cosine)</th>
<th>Diff. Latitude</th>
<th>(Sine)</th>
<th>Departure</th>
<th>Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>4</td>
<td>444</td>
<td>5616</td>
<td>6</td>
<td>651</td>
<td>7568</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>000</td>
<td>1318</td>
<td>7</td>
<td>483</td>
<td>2264</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>555</td>
<td>7020</td>
<td>8</td>
<td>314</td>
<td>6960</td>
<td>7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

449
that may vent the sande... in... halfe a minute'. The log was timed by stopping the sand 'with your finger, till such time as the thing commeth against the first marke', and then letting 'the sande runne till the thing be against the second marke' and then stopping the sand and noting the divisions run out. The whole glass had then to be inverted to get the sand back into the tube, care being taken that the stopper in the end of the tube did not fall out in the process. It must have been too delicate an instrument for most navigators, for it did not lend itself to weathering the hazards of shipboard usage during a long and possibly stormy voyage. Ship's instruments have to be above all things robust and durable. These qualities characterized the usual ship's half-minute glass, but not Addison's

Addison next discussed his first traverse table which he described in the text as 'a protracting Table, for whole, half, and Quarter points of the Compasse, for Miles, from 1 to 10, and so to 20. 30. 40. 50. and if need require to 100. or more at pleasure'. The table itself follows immediately after the last page of text (page 40) thirty-odd pages farther on. As it has no title, no notation of points, half or quarter points, nor any headings to the various columns, it appears at first to be a meaningless collection of figures. Further study shows it to be a table of natural sines and cosines arranged in a special way. Finally, reference back to Addison's fourth section reveals its significance. Reproduced is a portion of this traverse table for whole, half and quarter points with the points and headings of the columns added in italics for clarity (see page 449 above).

The table, Addison explained, was divided into four parts representing four points, and each of these into four parts for quarter points. The layout occupied two pages as below:

<table>
<thead>
<tr>
<th>Points</th>
<th>dep. d. lat.</th>
<th>dep. d. lat.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 pt. or 7½ pt.</td>
<td>1 pt. or 6½ pt.</td>
<td></td>
</tr>
<tr>
<td>1 pt. or 7½ pt.</td>
<td>1 pt. or 6½ pt.</td>
<td></td>
</tr>
<tr>
<td>1 pt. or 7½ pt.</td>
<td>1 pt. or 6½ pt.</td>
<td></td>
</tr>
<tr>
<td>1 pt. or 7½ pt.</td>
<td>2 pt. or 6 pt.</td>
<td></td>
</tr>
<tr>
<td>d. lat. dep.</td>
<td>d. lat. dep.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Points</th>
<th>dep. d. lat.</th>
<th>dep. d. lat.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2½ pt. or 5½ pt.</td>
<td>3½ pt. or 4½ pt.</td>
<td></td>
</tr>
<tr>
<td>2½ pt. or 5½ pt.</td>
<td>3½ pt. or 4½ pt.</td>
<td></td>
</tr>
<tr>
<td>2½ pt. or 5½ pt.</td>
<td>3½ pt. or 4½ pt.</td>
<td></td>
</tr>
<tr>
<td>3 pt. or 5 pt.</td>
<td>4 pt. or 4½ pt.</td>
<td></td>
</tr>
<tr>
<td>d. lat. dep.</td>
<td>d. lat. dep.</td>
<td></td>
</tr>
</tbody>
</table>

The distances tabulated could be counted either as miles or leagues, for the fractions were shown as decimals. For instance, if the distances were taken in miles the first four figures in the departure and difference of latitude columns represented miles and 'parts of a mile, each being divided into a hundred parts, so that each part is a pace' (of 5 feet, making a mile of 5000 feet). The last four figures in each of the columns were quite
superfluous, for no navigator worked to seven places of decimals of a mile when computing a traverse. They were a legacy of the natural cosine and natural sine tables used in compiling the table. Addison indeed recognized that they were unnecessary, and remarked that 'you may cut off 4. 5. or 6 figures towards the right hand', as when working he did himself. In later tables their superfluity was acknowledged by their omission.

The use of the table was principally in working a day's work. The distance run was looked for at the side in the section appropriate to the corrected course in points. If less than four points or 45°, the diff. lat. and dep. were found in the columns so marked at the top; if more than four points or 45°, on the columns so marked at the bottom (but Addison, as already observed, gave no headings to the columns). Addison’s general rule was not so simple:

if the Course be nearer the Meridian then the parallel, then the lesser is the separation [departure], and the bigger the alteration [diff. lat.];
but if the course be neerer to the parallel then to the Meridian, the contrary . . .

He gave an example:

Suppose I sayle upon the third poynpt from the Meridian which is either a N.E. by N. or S.E. by S. or N.W. by N. or S.W. by S. . . . 10 Miles, I demand to know the separation from the Meridian, and the alteration of Latitude, looke in the lower parte of the third Colome against 10, and you shall finde 5 miles 56 parts, and 8 miles 31 parts, the first is the separation, and the second the alteration; but if it were the third poynpt from the parallel of E. or W. that is a N.E. by E. (,) S.E. by E. or a S.W. by W. or a N.W. by W. then should the first bee the alteration, and the second the separation.

If the distance sailed were 15 miles, the numbers against 5 and 10 had to be added 'so shall you have 8.34 and 12.47. If [the distance sailed] 20. 30. 40. or 50. you must multiply the number against 10 by 2. 3. 4. or 5', Addison explained, for 'so commeth the demand'.

As already explained, in casting up a traverse it often happens that a ship's course takes her now to the eastward, now to the westward of the meridian, sometimes in a northerly, at others in a southerly direction. So far none of the navigation manuals published had shown how the resultant departure and difference of latitude could be most easily computed. The distinction for first doing so belongs to Addison. His method was to draw two lines crossing each other at right angles, which he lettered at their ends N. E. S. W. to represent the cardinal points. The various courses sailed he set down in their appropriate quarters, naming them with their course letters, and entering against them the distance sailed on the course, and the resultant departure and difference of latitude. These he added up. Then he transferred the totals so as to add all the easterly departures together and the westerly departures together and subtract the lesser from
the greater, the difference being the departure. Then he added the similar differences of latitude together and found the difference between them, thus: [the headings to the columns have been added for clarity].

<table>
<thead>
<tr>
<th>Co.</th>
<th>Dist.</th>
<th>dep.</th>
<th>d. lat.</th>
<th>Co.</th>
<th>Dist.</th>
<th>dep.</th>
<th>d. lat.</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td>S</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S 1/4 E</td>
<td>10</td>
<td>00</td>
<td>98</td>
<td>S.S.W.</td>
<td>08</td>
<td>03</td>
<td>06</td>
</tr>
<tr>
<td>S. by E</td>
<td>20</td>
<td>03</td>
<td>90</td>
<td>S.W. by S</td>
<td>09</td>
<td>05</td>
<td>00</td>
</tr>
<tr>
<td>S.E. by S</td>
<td>05</td>
<td>02</td>
<td>78</td>
<td>S.W.</td>
<td>10</td>
<td>07</td>
<td>07</td>
</tr>
<tr>
<td>East</td>
<td>40</td>
<td>40</td>
<td>00</td>
<td>South</td>
<td>4</td>
<td>00</td>
<td>00</td>
</tr>
<tr>
<td></td>
<td>47</td>
<td>66</td>
<td>33</td>
<td></td>
<td>15</td>
<td>13</td>
<td>61</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Co.</th>
<th>Dist.</th>
<th>dep.</th>
<th>d. lat.</th>
<th>Co.</th>
<th>Dist.</th>
<th>dep.</th>
<th>d. lat.</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.N.E.</td>
<td>10</td>
<td>09</td>
<td>24</td>
<td>W. by N.</td>
<td>05</td>
<td>04</td>
<td>90</td>
</tr>
<tr>
<td>N.E.</td>
<td>04</td>
<td>02</td>
<td>83</td>
<td>W.N.W.</td>
<td>10</td>
<td>09</td>
<td>24</td>
</tr>
<tr>
<td>N.N.E.</td>
<td>30</td>
<td>11</td>
<td>49</td>
<td>N. by W.</td>
<td>09</td>
<td>01</td>
<td>76</td>
</tr>
<tr>
<td>North</td>
<td>15</td>
<td>00</td>
<td>00</td>
<td>West</td>
<td>10</td>
<td>10</td>
<td>00</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>56</td>
<td>49</td>
<td></td>
<td>35</td>
<td>90</td>
<td>13</td>
</tr>
</tbody>
</table>

\[
\text{[dep.]} \quad \text{[dep.]} \quad \text{[d. lat.]} \quad \text{[d. lat.]} \\
47–66 \ [\text{East}] \quad 15–13 \ [\text{West}] \quad 33–73 \ [\text{South}] \quad 49–38 \ [\text{North}] \\
23–56 \ [\text{East}] \quad 35–90 \ [\text{West}] \quad 61–94 \ [\text{South}] \quad 13–63 \ [\text{North}] \\
71–22 \ [\text{East}] \quad 51–03 \ [\text{West}] \quad 95–67 \ [\text{South}] \quad 63–01 \ [\text{North}] \\
51–03 \ [\text{West}] \quad \underline{63–01} \ [\text{North}] \quad \underline{32–66} \ \text{Alter. South} \\
20–19 \ \text{Separat.} \\
\]

\text{East}

Answer: Departure = 20'. 19 East,
Diff. Lat. = 32'. 66 South.

While Addison was no doubt indebted to John Tapp's 1614 edition of The Variation of the Cumpas for the basic idea of laying out difference of latitude and departure separately so as to facilitate the computation of the difference of latitude and departure resulting from several traverses, his was the first publication to recommend a layout that grouped separately northerly and southerly differences of latitude and easterly and westerly departures so as to eliminate any possibility of confusion in the working.

The resolution of the various traverses in a day's sailing gave 'the two containing sides of a right-angled triangle' by which the course and distance made good could be found by calculation. Addison then referred to
two of eight propositions which he gave for resolving 'right-angled triangles in the use of plaine Navigation' by help of Napier's logarithms. Unlike Gunter, Addison did not give each general proposition as a distinct statement, but ran each into the example with which he illustrated it. It was a bad arrangement.

Addison's second traverse table, for whole 'degrees from North or South, East or West towards the halfe quadrant', that is from $1^\circ$ to $45^\circ$, was similar in layout to that of the table for points, half and quarter points. As, however, it followed, without any headings or indication of degrees, immediately after this table, it was neither easily identifiable nor easy to work with, despite the fact that in the text he gave an example of working out a traverse with it.

One thing is quite certain: Addison cannot be credited with clarity of exposition. For instance, here is the opening of his seventh proposition:

7. Miles sailed 93½ on an Azimuth, of 50. Degrees, what miles of Latitude altered.

As Radius to the Cosine of the Azimuth so shall the miles sayled, be to the miles of Latitude that is altered.

[i.e. d. lat. = dist. cos (Course)]

To the Logari, of the miles sailed, adde the Antilo of the Azimuth, so cometh the Logari of the miles of Latitude, that is altered.

[dist.] 93½ — 23731374
[co.] 50 — 4419408
[d. lat.] 60 — 28150782

Addison evidently expected his 'young beginner' to be thoroughly conversant with Napier's log tables and his own, for nowhere did he explain what he meant by logarithm and anti-logarithm, nor where either was to be found. Actually the logarithms of distances from 1 to 1000 were to be found in the table following immediately after the last page of the $1^\circ$ traverse table, but as these tables also had no title and no headings to the columns their contents could not have been, and are not, obvious to those unfamiliar with logarithms. Table 27 (page 454) is an extract from the lower portion of the first page of Addison's logarithms (the headings have been added for clarity).

In order to find the logarithm of fractions, for example of 93½, it was necessary to interpolate. While the 'young beginner' would find these logarithms in the back of Addison's book, he had to find those of the functions of angles—although Addison gave no clear indication of this—either in Napier's original *Mirifici Logarithmorum* of 1614, or else in Wright's translation of 1616. In either, it is true, the explanation of the various terms used could also be found, but it is to be feared that to the uninitiated this portion of Addison's book must have been incomprehensible. We shall spend no more time on it than is necessary to note that he completed it with six propositions (with examples) for solving 'oblique', that is not
right-angled, triangles 'vsefull for finding distances in sight, by the helpe of a Magnetical instrument', i.e. in survey work. In this he was following Gunter.

TABLE 27

<table>
<thead>
<tr>
<th>[No.]</th>
<th>Logarithm</th>
<th>[No.]</th>
<th>Logarithm</th>
<th>[No.]</th>
<th>Logarithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>36969198</td>
<td>58</td>
<td>28473143</td>
<td>91</td>
<td>23968953</td>
</tr>
<tr>
<td>26</td>
<td>36496733</td>
<td>59</td>
<td>28295290</td>
<td>92</td>
<td>23859669</td>
</tr>
<tr>
<td>27</td>
<td>36119248</td>
<td>60</td>
<td>28150782</td>
<td>93</td>
<td>23751551</td>
</tr>
<tr>
<td>28</td>
<td>35755589</td>
<td>61</td>
<td>27968814</td>
<td>94</td>
<td>23644606</td>
</tr>
<tr>
<td>29</td>
<td>35404691</td>
<td>62</td>
<td>27806230</td>
<td>95</td>
<td>23538783</td>
</tr>
<tr>
<td>30</td>
<td>35068620</td>
<td>63</td>
<td>27646214</td>
<td>96</td>
<td>23434083</td>
</tr>
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<td>31</td>
<td>34737777</td>
<td>64</td>
<td>27488722</td>
<td>97</td>
<td>23330439</td>
</tr>
<tr>
<td>32</td>
<td>34420180</td>
<td>65</td>
<td>27333700</td>
<td>98</td>
<td>23223481</td>
</tr>
<tr>
<td>33</td>
<td>44145668</td>
<td>66</td>
<td>27181011</td>
<td>99</td>
<td>23126351</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>23025928</td>
</tr>
</tbody>
</table>

Addison's method of showing 'the Increase and Decrease, or the widening or narrowing of the meridians and Parallels in a Globe' consisted of abruptly posing twenty-four problems such as, '1. In the Latitude of 50. I demand how many miles of the meridian, or Equator is a Degree of Longitude', or '4. In the Parallel of 60. what miles of equator or meridian a minute of time', or again, '23. One Latitude \(14^1_2\), and another \(49^1_2\)—a Meridian distance betweene 561 miles what Longitude?', and giving the proposition that solved it, with an example of the solution by logarithms. His mid-latitude formula he worded 'as the halfe of the Cosines of both Latitudes is to Radius', etc., instead of 'as the Co-sine of the middle Latitude, to the Sine of 90 gr.', etc., the formula preferred by Handson, who, it will be recalled, had given both. Addison gave no explanation of any of the formulae he cited. He next proceeded to the use of Mercator's Proiecton, which he demonstrated in nine propositions, such as '2. The Rumb and both Latitudes for the distance betweene both places' or 'The Distance and both Latitudes to finde the Rumbe', taking for his examples 'the Lixard, in Latitude 50 degrees, and the Island of Flores in 39—degrees 20'; 'the difference of Longitude 26. degrees, not by the way'. There was here one major source of confusion for the uninitiated student, and that was that nowhere did Addison refer to the important fact that he worked in meridional parts taken from the last table—also untitled—in his book. Until this fact was grasped the solutions in his examples were inexplicable.

Addison's last propositions illustrate finding the logarithmical solution of 'sphericall oblique Triangles', such as calculating the declination of a star or the great circle distance between two places.
Addison’s book is not an easy one to follow. Despite the author’s intention that it should be for ‘young beginners’, and that it should advance ‘Navigation, by a more exact Method or Order, then formerly’, the essential steps in calculation are often omitted and the layout obscure. For all its faults, however, it did present ‘a more exact method than any hitherto published’ of working a traverse, and it contained all the columns of a complete traverse table.

Did Addison’s book exert much influence on the art of navigation? Through its order of working a traverse, the navigator’s daily task, the answer is, undoubtedly, yes. Did it through its use of logarithms? Probably not, for Napier’s logarithms were not easy to work with. In one important respect Addison’s work had a very undesirable influence: many later authors of navigational manuals contented themselves, like Addison, with stating the various navigational and astronomical propositions without any explanation, the result being that the young beginner had perforce to learn them parrot-fashion, uncomprehendingly. Had Addison realized the consequences of his brevity—probably caused by a hasty departure to the East before the book was completed—he might have explained its dangers. As it was, he never subsequently had an opportunity. He sailed as master ‘of the ship called the Palsgrave, bound to the East Indies in the yeare 1624, where he dyed’. He was, we are assured, ‘in his time a good Sea-man’. Few sailors would choose another epitaph.

Thomas’s widow, hearing in due course of her bereavement, set about disposing of his books. It so happened that at that very time a curious character arrived in London (he came by way of the Thames) to set up as a teacher of mathematics and navigation to the poorer and humbler sort of seaman—the coaster and short sea-route skipper, no doubt. The Thames had proved uncharitable to the new arrival. Upon his way he had met with some accident upon the river—a collision perhaps between two wherries—so that he arrived in the metropolis lacking both goods and books. Hearing by chance of the widow Addison’s books he bought the lot, posted a notice upon the door of his house in St. Thomas Spittle offering to teach the poorest seamen navigation gratis, and studied both Addison’s books and the Bible, with intensity. Incredible though it now seems, John Skay—for such was the teacher’s name—must have had sufficient paying pupils to earn his living. For those unable to attend his classes he wrote a book intended to ‘make more easie the booke of M. Thomas Addison’. Indeed, Skay assured ‘the Ignorant and Honest Reader’, that his book would ‘make even the hardest things in his [Addison’s] booke easy for thy understanding’. Poor reader! Skay’s book, the first of several similar effusions, was entitled A Friend to Navigation, and appeared in 1628.1 Of all the hotch-potches of navigational lore and biblical texts this is the

1 A FRIEND TO NAVIGATION Plainely expressing to the capacity of the simpler the whole mistery or foundations of the same Art, for whose sake, the Author hath onely penned the treatise, being himselfe a faithfull goodwille thereto

[Design of Ship in full sail with standard & royal arms]
most curious. Nevertheless, it has, embedded in the jumble of quotations from the Psalms and navigational jargon, tit-bits of information worth the gleaning, for instance, that having a letter from a brother in St. Kitt’s, in the Windward Islands, John Skay went to Gresham College ‘of purpose to look on the biggest Terrestrial Globe’ there and locate the island, which he did, in latitude 16° N and ‘321 deg. of longitude, or thereabout’; that, ‘2s. 6d. on a pair of Compasses, and two pence on a straight ruler is not much to spend’; and that ‘by the [Plain] Scale made on a straight Ruler and Compasses distance is had easily without measuring of them’.

Printed at London, by T.C. 1628


At the end of the treatise are these words:

Now I beseech Almighty God of his mercy in Christ Jesus, that we may so profit in Christs Schoole, that we may bee able thereby to passe the waves of this sea of glasse, that we may all arrive at the haven of eternall happinesse.

Amen.]
Chapter Six

NAVIGATIONAL PRACTICE
1623-1631

'For to learn to observe the Altitude, Latitude, Longitude, Amplitude, the variation of the Compasse, the Suns Azimuth and Almicanter, to shift the Sun and Moon, and know the tides, your Rombs, prick your Card, say your Compasse, and get some of these Books, but practice is the best.

Master Wrights Errours of Navigation.
Master Taps Sea-mans Kalendar.
The Art of Navigation.
The Sea Regiment.
The Sea-mans Secret.
Waggoner.
Master Gunters Works.
The Sea-mans Glasse for the Scale.
The New Attractive for Variation.
Master Wright for use of the Globe.
Master Hewes for the same.

Instruments fitting for a Sea-man. Compasses so many pair and sorts as you will, an Astrolabe quadrant, a Cros-staff, a Back-staff, an Astrolabe, a Nocturnall.

While the art of oceanic navigation was becoming more and more scientific owing to the invention and use of trigonometrical and logarithmic tables and instruments, the art of pilotage was becoming further refined by the publication of more numerous and more accurate charts, and more detailed and better ordered sailing directions. The year 1625 saw the publication of Blaeu’s The Sea-Mirrour, an English translation of Blaeu’s Eerste deel der Sceespiegel, of 1623. It contained, besides ‘A Briefe Instruction In the Art of Navigation’, the ‘Description of the Seas and Coasts of the Eastern, Northerne, and Westerne Navigation’, and one hundred and eight charts, and was a greatly improved version of The Light of Navigation, of 1612. The Sea-Mirrour was divided into three parts. The first part dealt with navigation; the second was a waggoner, in six books, of eastern and northern navigations, that is of the shores of the North Sea, Baltic Sea, and Arctic Ocean; while the third part was a waggoner for the western navigations, that is for voyages between the Texel, St. George’s Channel, and Strait of Gibraltar, and as far as the Canaries and Azores. It too was in six books.\(^1\)

\(^1\) Blaeu, W., THE SEA-MIRROVR. Containing, A BRIEFE INSTRUCTION In the Art of Navigation; AND A DESCRIPTION OF THE Seas and Coasts of the Eastern, Northerne, and VVesterne Navigation; COLLECTED AND
NAVIGATIONAL PRACTICE, 1623–1631

Many of the charts—all were plane charts—show marked improvements in the representation and detail of the coast-lines. The latter are also often hatched to show the cliff-line, more symbols are included in order to clarify details, town and harbour plans are shown on enlarged scales in insets, and general charts, such as the one of the Channel, include latitude scales as well as rhumbs.

COMPILED TOGETHER Out of the Discoveries of many Skilfull and expert Sea-men, BY WILLIAM JOHNSON BLAEVW; And Translated out of Dutch into English, by RICHARD HYNMERS. AMSTERDAM, Printed by WILLIAM JOHNSON BLAEVW, dwelling vpon the Water, by the Old Bridge, at the Signe of the Golden Sunne-Dyall. 1625. Cum Privilegio.

B.M. copy imperfect, wanting general title-page. It is a translation of:


The title-pages of the three parts and various books thereof, of the _Sea-Mirrour_ are as follows:

THE FIRST PART of the SEA-MIRROVR Containing A BRIEF INSTRUCTION In the Art of Navigation; Written by WILLIAM JOHNSON BLAEVW. And Translated out of Dutch into English, by RICHARD HYNMERS. AMSTERDAM, Printed by WILLIAM JOHNSON BLAEVW, dwelling upon the Water, by the Old Bridge, at the Signe of the Golden Sunne-dyall. 1625. Cum Privilegio.


THE FIFTH BOOK of the EASTERN AND NORTHERN NAVIGATION. Conteyning the Description of the Coasts of Norway from the Naze to the North Cape, and also of the New found land Spitsbergen.

THE SIXTH BOOKE of the EASTERN AND NORTHERN NAVIGATION. Conteyning the Description of the Coasts of Lapland and Russia, from the North Cape eastwards to Nova Zembla, and of the whole White Sea.

[Note: the fifth and sixth books just given are not title-pages, but only headings to the text.]
The coasts of Jan Mayen Island and the west coast of Spitzbergen reflect the Dutch whaling interests, for they are here very carefully charted, with latitude scales as well as a distance scale. The general chart of the whole area covered by the waggoner, a finely engraved copper-plate, covers the sea areas between Spitzbergen, the Scillies, Canaries, and Azores. It, too, is complete with rhumbs and latitude scales.

As in *The Light of Navigation* the coastal elevations are represented by woodblocks incorporated in the text. As an example of the up-to-dateness of the sailing directions may be cited those for 'the Spits'—the important shoal in the Thames estuary south of the now better known Longsands. Whereas *The Light of Navigation* referred to 'a tunne'—a buoy—and a wreck as marking the shoal, *The Sea-Mirrour* describes two buoys and a wreck. As for the greater exactness of the sailing instructions, it will be

THE THIRD PART of the SEA-MIRROVR containing A DESCRIPTION OF THE Seacoasts of the Western Navigation; COLLECTED AND COMPILED TOGETHER Out of the Discoveries of many skillful and expert Sea-men, BY WILLIAM JOHNSON BLAEUVW; And Translated out of Dutch into English, by RICHARD HYNMERS. AMSTERDAM, Printed by WILLIAM JOHNSON BLAEUVW, dwelling upon the Water, by the Old Bridge, at the Signe of the Golden Sunne-Dyall. 1625. Cum Privilegio.

The third parts FIRST BOOKE of the SEA-MIRROVR of the Western and Southerne NAVIGATION. Containing THE DESCRIPTION OF THE COASTS of Holland, Zealand, and Flanders, From the Tessell to Callicke and Dover. With privilidge of the H.M. Lords the States Generall of the United Provinces for ten yeares. 1625.

The third parts SECOND BOOKE of the SEA-MIRROVR of the Western and Southerne NAVIGATION containing THE DESCRIPTION OF THE SEA-COASTS OF FRANCE From Callicke unto Vshant. AND OF ENGLAND From Døver about Englands end, to the poynett of S. Davids in Wale. With privilidge of the H.M. Lords the States Generall of the United Provinces for ten yeares. 1625.

The third parts THIRD BOOKE of the SEA-MIRROVR of the Western and Southerne NAVIGATION. Containing THE DESCRIPTION OF THE Coasts of Ireland. With privilidge of the H.M. Lords the States Generall of the United Provinces for ten yeares. 1625.

The third parts FOVRTH BOOKE of the SEA-MIRROVR of the Western and Southerne NAVIGATION. Containing THE DESCRIPTION OF THE Coasts of France and Biscay Betwixt Vshant and cape de Ortegaull. With privilidge of the H.M. Lords the States Generall of the United Provinces for ten yeares. 1625.

The third parts FIFTH BOOKE of the SEA-MIRROVR of the Western and Southerne NAVIGATION. Containing THE DESCRIPTION OF THE Coasts of Gallicca, Porlingall, and Spaine. From the Cape of Ortegaull vnto the Straight of Gibraltar. With privilidge of the H.M. Lords the States Generall of the United Provinces for ten yeares, 1625.

The third parts SIXTH BOOKE of the SEA-MIRROVR of the Western and Southerne NAVIGATION. Containing THE DESCRIPTION OF THE Coastes of Barbarie, From the Straight of Gibraltar unto the Cape de Geer. Together with the description of the Canaries and Azores Ilands. With privilidge of the H.M. Lords the States Generall of the United Provinces for ten yeares. 1625.
found upon comparison with earlier runters and waggoners that the datum for soundings is more often and more specifically mentioned. For example, ‘with a common spring and high water there is’, the navigator is informed, ‘about two fathoms and a halfe, or a little more’ off Sunderland.

The cartouches on many of the charts are full of fascinating and realistic as well as symbolical detail. A good example is the cartouche on the chart of North Russia showing the principal instruments of a navigator—his sea-astrolabe and cross-staff (with three crosses), his rolled vellum chart, and indispensable compasses for pricking his course, his lead and line (the base flattened and broadened by many soundings of the sea bed), and his watch-glass slung from a beam overhead.¹

The ‘brief instruction in the art of navigation’ follows closely the lines laid down by Wagenaer, and followed in The Light of Navigation. It is fuller and better laid out than in these works, and reflects the latest non-mathematical developments. Of particular interest are the opening paragraphs defining ‘Common [Coastal] Navigation’ and ‘Great [Oceanic] Navigation’, for they are a direct translation of Michiel Coignet’s of 1581, quoted in the first chapter of this book. The declination tables included were for the years 1624, 1625, 1626, 1627, ‘to serve without any great prejudice or hurt for twenty yeares’, and were calculated ‘for the Longitude or Meridian of the Lands-end of England, because’, it is interesting to note, ‘they are most used about that Longitude by the English and such Sea-faring men, as well in the entring of the Channell of the Sea, as along the coasts of France, Portugall and Spaine’. The chapters on stars discussed not only the declination and right ascension of stars, but also their mutation or change of declination occasioned by the precession of the equinoxes in a 25,400-year cycle. John Tapp’s system of grouping the stars in the stellar declination tables according to their proximity to one or other of the poles was employed.

The making of the cross-staff with altitude and zenith distance scales was explained on the grounds that ‘a Pilote, who is to have the use of it, should know that it is well made’. It was recommended that the division of the staff (laid for the purpose on stiff paper ‘or it should be better layd with Copper’) should be made with the aid of a table of 10,000 equal parts. The use of the sea-astrolabe (‘holding it with the finger by the ring’) was also explained. It was remarked that this instrument was now often marked with two scales, one for reading zenith distance, the other for altitude. Nor must it be supposed that the observations on the sea-astrolabe were academic, that (as is sometimes asserted) the sea-astrolabe had gone out of use. Captain William Hawkridge, who had accompanied Button on his voyage of 1612–13 in search of the North-West Passage (and in later life was to become a captive of the Algerian pirates), took up the search again this very year, 1625. On reaching the shores of America, ‘having had Fogs and Mists for 6 days before, so as he could not observe’, he ‘observed

¹ See Pl. LXXXII.
by his Astrolabe’, because this ‘day was fayre and cleare weather’ and finding himself to be in latitude 62° 25’ N he reckoned, correctly, that he had entered Frobisher Sound, having passed north of Hudson’s Strait. Nor was he an old-fashioned navigator, for he ‘tooke marks upon the land’, and checked his way through the water ‘by the logge’, according to which the ship ran ‘5 leag. a watch’. Moreover, unless Captain Luke Foxe, who transcribed an account of Hawkridge’s voyage in about 1630, re-phrased passages, Hawkridge was sufficiently up to date to work in knots, logging his day’s run, for example, as ‘to this day noone, 20 knots S.E. and 10 knots S.W.’.

On the use of the cross-staff Blaeu has this to remark:

Although in taking the height of the Sunne with the Cross-staffe men doe vse Red or Blew Glasses for saving and preserving of the Eyes, yet it is notwithstanding a great let and verie troublesome for the sight, especially if it be high.

He recommended instead the use of ‘a backe Staffe or double Triangle’, a peculiarly apt description of the version of Davis’s back-staff or quadrant most popular amongst the Dutch.

For showing the correction of altitude observations for declination Blaeu used Bourne’s diagrams. He also gave an exceptionally clear description of correcting the declination in the tables (based it will be recalled on the longitude of Land’s End) to the longitude of the position of observation.

In discussing the variation of the compass he summarized the variation met with on a voyage to Venice and on a voyage to the Celebes in order to show both how variation differed over the face of the world and how it could be used to check position. But the pilot was reminded that, for ‘the Common Navigation’, that is for voyages in European waters, ‘the steles’ were still ‘made fast under the Flye of the Compasse (for to cause the Flowre de Luce to pointe right north) about two thirds of a point towards the East’, and that, to avoid having ‘to alter the Compasses, or to make any other reckoning’, the courses and ‘lyings of one land to the other in the common Sea cardes of these coasts’ were still ‘made after such Compasses’.

In order to enable the seaman to find the time by the difference of the sun’s and star’s right ascension, tables of the sun’s right ascension every five days of the year and that of thirty fixed stars were included, with an explanation of their use.

Taken together, the three parts of The Sea-Mirrour can be considered to contain a remarkably up-to-date epitome of navigation and to embody the

latest sailing directions with the most up-to-date and clearly drawn charts of the waters of north-west Europe.\footnote{At about the time of Captain Smith's death (1631) a new edition of The Sea Mirrour was published, under the title of The Fierie Sea-Columne.}

In view of the hostilities that had broken out with Spain and that now seemed to be imminent with France also, the publication of Blaeu's Sea-Mirrour could have been considered by the Admiralty and by Trinity House only as most opportune. Equally opportune must have been the publication in the following year, 1626, of An Accident for Young Seamen: or, Their Path-way to Experience, by Captain John Smith,

briefly shewing the Phrases, Offices and Words of Command, Belonging to the Building, Ridging, and Sayling, a Man of Warre; And how to manage a Fight at Sea. Together with the Charge and Duty of every Officer . . . Also the Names, Weights, Charge, Shot, and Powder, of all sorts of great Ordnance . . .

for Wimbledon's Cadiz fiasco of 1625 had been matched by equally futile attempts at fleet operations in 1626, by which time the seizure and retention of French prizes had brought France also into the war against England. The fact of the matter was that the effects of a quarter of a century's bribery, jobbery, and corruption in the naval service were revealing themselves under the stress of war—and this, for England, was primarily a naval war. It was not, as it happened, a life-and-death struggle for England, though it was for Spain, so the series of English naval disasters arising from incompetence were mortal only to the inarticulate seamen who died in their hundreds from malnutrition, exposure, and disease, and to the pride of many of the higher commanders. The war humbled the latter. First the sea humbled many of them when it prostrated and incapacitated them with sea-sickness, next it humbled them when, having gained their sea-legs, they began to attempt to handle their ships, their squadrons, and their fleets. Many found their orders apparently disregarded, only to be told they were impossible of execution; they found they knew neither the names of the various parts of the ship nor, when they had learned them, the orders appropriate to their use. They found that competence in seamanship necessitated apprenticeship, that their subordinates were their superiors in technical knowledge and in professional skill; and that to the novice

One copy of the second edition, of 1637, only is known, preserved in the Admiralty Library, Whitehall. The full title is: THE FIERIE SEA-COLVMNE; Wherein Arc shewed the Seas, and Sea-coasts of the Northern, Eastern, and Western Navigation, manifestly inlichtened, and the sailings and mistakes of the former LIGHT or SEA-MIROUR amended. Gathered from the experience of expert Sea-men, and written by IACOB COLVMNE. Here unto is also annexed a briefe instruction in the Art of Navigation; together with new Tables of Declination, and an Almanach for sixteene yeares following. The second Edition, amplified with an hundreth new Figures, describing the situation of the Lands and Sands out of the Sea. With the Privilege of the High and Mighty Lords, the States General, for twelve yeares. AMSTERDAM, By IACOB COLUMNNE, on the Water, in the Fierie Columne. ANNO 1637.
the art of war was far more exacting, far more hazardous, and far more dangerous at sea than on shore. Some thankfully escaped to dry land as soon as they could; others swallowed their pride and learned the hard way, by bitter experience; some others learned first from the writings of competent seamen, and then perfected their book-lore by practice under skilled supervision. Those who persevered became in their turn, skilful seamen. It was such men who called forth the new form of English literature of the sea, known later as 'Sailors’ Word Books', of which John Smith’s *Accidence* is the earliest printed example.

The need for Smith's *Accidence* did not spring entirely out of Jacobean naval negligence. It is true that corruption and incompetence in the Jacobean administration, and the callous indifference generally displayed towards the sailors’ plight, kept many good men from serving at sea as officers at this time, and that, in default of better, many ‘young, needy, and inexperienced gentlemen captains’ gained commands. Nevertheless, the problem of the proper recruitment of officers for the fighting sea-service had given concern in Tudor, and particularly in late Elizabethan days. King Henry VIII, by officering his royal ships with the nobility and by insisting that such nobility should be seamen, had gone far towards ensuring a high standard of professional—because educated—ability. It was these officers, and others drawn from the Tudor gentry, who had developed the ships, naval ordnance, naval gunnery, and naval tactics that defeated the Armada and subsequently kept Spain at bay. Their families, by a tradition of naval service akin to apprenticeship, transmitted their naval lore to each successive generation. From the 1580s to the end of Elizabeth’s reign war with Spain on the high seas, with the prospects of rich prizes and of fame as attractions, had kept the recruitment of gentlemen volunteers, and letters of marque men, fairly steady. Nevertheless, there seems to have been anxiety over training suitable men. The introduction of lieutenants at the end of the sixteenth century was an outward and visible sign. A captain, as Sir William Monson stated, was chosen to command one of the Queen’s—or King’s—ships ‘for his warlike part’; his charge, as Captain Smith put it, was ‘to command all, and tell the Master to what Port hee would goe, or to what Height; In a fight he gave direction for the managing thereof’. The purpose of the office of lieutenant was sound enough; it was to ensure the proper training of future sea captains, or, as it was expressed at the time, ‘to breed young gentlemen for the sea-service . . . whereby gentlemen of worth and quality might be encouraged to go to sea . . .’, and so save the State from having to rely ‘wholly on meckanick men that have been bred up from swabbers’. Too many of these, it was considered, ‘would cause sea service in time to be despised by gentlemen of worth, who will refuse to serve at sea under such captains’.¹ It was made the lieutenant’s duty to take command in the event

of the absence or death of the captain, for he was, in effect, his understudy. While this arrangement was logical, it undoubtedly had the effect of discouraging many keen masters. It also led to a debasement of the art of ship-handling, pilotage, and navigation.

When King James summarily ended hostilities and put an end to all English letters of marque men, he at once not only forced many honest men from sea employment, he also cut off the supply of future commanders. The sea unquestionably lost its appeal to most ‘gentlemen of worth and quality’, for it was no longer lucrative. When those who yet had a passion for sea service saw the steadily increasing nepotism and corruption in the cut-down and decaying Royal Navy, they sought elsewhere for employment if they were men of mettle and honour. It was in default of better that the ‘young, needy, and inexperienced gentlemen captains’ were put in command. Inevitably the Tudor tradition became out-moded. This had been that the captain not only fought his ship but also, like the master, knew how

to enquire and take account of all the ways that the ship hath made and upon what points of the compass she hath been steered in every watch; and . . . to take a view of the traverse board, and to consider of all the dead reckonings. And by his observations [had] had to take the height of the sun or star, or both, with his astrolabe, backstaff, Jacob staff, or quadrant and accordingly to prick his cart.1

Such humdrum tasks, together with ‘the cunning [conning] of the ship, and trimming of the sails’, the young gentleman captain of early Stuart days left to the master and his mates. Such captains came to be called ‘freshwater soldiers’ and had the reputation of becoming ‘sick with the savour of the sea’. Many were the stories told of their incompetence. There was the one of ‘the young Neptune’ whose ‘men pumping the ship in their watch, it gave a noisome smell’ at which he demanded the cause, and being told, cried, ‘Cast it overboard for if it stink so, I will have none in my ship!’ Equally popular was the anecdote of the young captain ‘who, being at sea in his argosy, a sail was descried’. The Captain demanded where, answer was made, ‘Right in the wind’. The Captain full of bell metal, cried, ‘Bear up, for I will speak with him’. The master told him it was impossible to bear up against the wind, whereat his fury assuaged, he prayed God to send him safe to Salisbury Plains, ‘for there’, he exclaimed, ‘I can ride and never observe the winds’.2

1 Boteler’s Dialogues, N.R.S., Vol. 65, p. 29.
2 Hodges, W. H. and Hughes, A., Select Naval Documents (1922), No. 44, ‘Gentlemen Captains’.

The point about the ‘argosy’ is that to bear up is to bring the helm towards the wind and thus to turn the ship away from the wind. The captain should have ordered ‘bear down’ in order to bring the ship closer to the wind. But as the other vessel was dead to windward she could only have been reached by a long series of boards or tacks which would have enabled him to work his ship up to windward.
Years before he became Captain-General, or supreme commander, of the English forces mustered so successfully against the Armada, Howard of Effingham had won as a young man a reputation for skill and knowledge in sea affairs based upon service at sea under his father. It is to be feared, however, that, with Sir John Hawkins’s probity and business acumen removed from the Navy Board and from the counsels of war, Howard failed to discern as the years went by the faults in the naval administration. His supersession as Lord High Admiral by Buckingham in 1619, was a measure long overdue. Not that Buckingham was any seaman: but he had imagination and drive, took his responsibilities seriously, and did try to improve the state of the Royal Navy. It was precisely because Buckingham, Wimbledon, and similar landsmen commanders found themselves either in ‘command at Sea, or . . . called upon to censure and judge of the sea affairs’, and were without ‘the knowledge of terms, names, words, the parts, qualities, and manner of doing things with ships’ which hitherto those in authority had learned by experience, that Mainwaring wrote his *Seamans Dictionary* between 1620 and 1623 and dedicated it to Buckingham. There is plenty of evidence to show that Mainwaring’s manuscript was copied, studied, and carried at sea by the higher, ex-military naval commanders of this time.\(^1\) They may have lacked experience but they had brains, and, as Mainwaring put it, a book like his could at least ‘make a man understand what other men said, and speak properly himself’. Actually Mainwaring claimed far more for his book. Just as ‘to understand the art of navigation’ was now comparatively easy through ‘the many books, which give easy and ordinary rules for obtaining to it’, so he claimed, with this book

in six months, he, who would but let him read this book over with him, and be content to look sometimes at a model of a ship and see how things were done, should (without any great study, but conversation) know more, be a better seaman, and speak more properly to any business of the sea, than another gentleman who should go two or three years together to sea [without studying it]. ‘Till then [he truly claimed], there was not so much as a means thought of, to inform anyone in the art of seamanship and of the handling of warships in particular.

While it was perfectly true that much could be learned with a book of sea-terms, a ship-model, and an alert intellect, the result of the operations of the war of 1625 to 1630 with Spain showed that knowledge of sea terms and of the order of sea-fights had still to be wedded to experienced ship handling if success was to ensue. Just as it is one thing to learn on shore the theory of navigation and of taking observations, and another to take observations and fix a ship’s position at sea, so it was found that there is no substitute for service at sea. Captain Smith knew this and emphasized it in his *Accidence*. Six years later Captain Luke Foxe wrote, ‘It is not enough

to be a Sea-man’, a man must be ‘a painfull’—pains-taking—‘Seaman’. Foixe, furthermore, did not allow any to be a good seaman that had not served in almost every capacity aboard ship and that in his youth had not ‘bin both taught and inured to all labours’, and ‘to endure and suffer, as a hard Cabbin, cold and salte Meate, broken sleepe, mould[y] bread, dead beere, wet Cloathes’, and ‘want of fire’. He did so with good reason. Nothing demoralizes men more in time of stress at sea than cold food, wet clothes, and lack of sleep.

In producing glossaries of sea terms and phrases at this time the English were not being original. Once again, indeed as always in things pertaining to sea affairs, their pattern was Spain. The Spaniards had produced their first nautical dictionary a century before.¹ Nor is it difficult to see why the ‘Capítulo que tracta de la nao e de sus partes y de los vocablos usitados en la navegación’ in the manuscript Quatri partitu encosmographia pratica i por otro nombre llamado espeio de navegantes, written about 1520–38, should have been compiled at that time. The New World, discovered by Columbus thirty years before, was at last coming up to the expectations of adventurers. To those who succeeded in crossing the Ocean Sea, and returning again, it was now yielding the accumulated wealth of the Aztec and Inca civilizations. For centuries the Spaniards had of necessity been soldiers, in order to reconquer their land from the Moors. The completion of that conquest coincided with the discovery of the New World. To exploit it the erstwhile soldiers had to learn the rudiments of seamanship and navigation. While the military commanders of expeditions left much of the nautical detail to their properly qualified subordinates there is not the slightest doubt that, contrary to modern popular belief, the Spaniards produced naval commanders in the sixteenth century of the highest strategic and tactical ability, with a thorough grasp of navigation, and considerable ship-handling skill. Their rise can be traced to the 1520s when the first foreign interlopers in American waters sounded a warning note that did not go unheeded. It should never be forgotten that for a century, until Piet Hein captured the Silver Fleet off Havana in 1628, the Spanish convoys crossed the Atlantic unscathed by French, Flemish, English, and Dutch naval forces, and that the one resounding defeat that the English experienced in the great war with Spain was in 1591, when Sir Richard Grenville fell foul of the escorts of the convoy for which the English force, including Revenge, had been lying in wait.²

In the course of the sixteenth century four more Spanish nautical dictionaries were compiled. One is to be found in Juan de Moya’s Arte de

¹ The oldest Spanish nautical dictionary was written between 1520 and 1538: Alonso de Chaves’s ‘Capítulo que tracta de la nao e de sus partes y de los vocablos usitados en la navegación,’ in Quatri partitu encosmographia pratica i por otro nombre llamado espeio de navegantes. See Woodbridge, H. C., ‘A Tentative Bibliography of Spanish and Catalan Nautical Dictionaries, Glossaries, and Word Lists’, M.M., Vol. 37.
Marear of 1564, another in Andres de Poza's 'Declinación de algunos vocablos marítimos' in his Hydrografía, printed in 1585 (in good time for hostilities with England), yet another in Diego García de Palacio's 'Vocabulario de los nombres que usa la gente de mar en todo lo que pertenece a su arte' in his Instruction nauticha para navegar, printed in Mexico, in 1587; and a fourth in Eugenio de Salazar's 'Vocabulario' in his manuscript of about 1600, Navegación de el Alma por el discurso de todas las edades de el hombre. Finally, in 1611, a glossary of seventy-two nautical words, 'Declaración de los vocablos que se usan en la fabríc de baxeles', was included in Thomé Cano's Arte para fabricar, fortificar, y apearar naos de guerra y mercante, published in Seville, and a manuscript of 1614, Derotero de mar mediterraneo, embodied a 'Vocabulario de los nombres que usa la gente de mar en todo lo que pertenece a su arte por el horden alfabético'.

Thus the English of the 1620s, endowed with a limited supply of potential leaders and faced, like the Spaniards a hundred years earlier, with the conflicting calls of land-warfare, sea-warfare, and colonization, were completing the pattern of evolution towards sea power by trying to aid those inexperienced in sea affairs to master rapidly the technicalities of their subject through the study of books of sea terms and phrases.

Sufficient mention has already been made of Captain John Smith to indicate that he was a remarkable, indeed an exceptional man. Born in the little Lincolnshire village of Willoughby, early in 1580, educated at Louth Grammar School, from the age of fifteen he was a wanderer, soldiering in the French wars at sixteen, and in the Low Countries until he was nineteen, he was shipwrecked on Holy Island on his way to Scotland, and after a short visit to Edinburgh, a recluse in a 'woody pasture' some way from his native village, where he constructed a 'parlour made of boughs by a fair brook' and was the curiosity of the countryside. In his sylvan retreat he studied the art of war as taught by Marcus Aurelius and Machiavelli, and practised his skill in horse- and swordsmanship. The next year he returned to the wars in the Low Countries. From here he wandered south and east, joined a French trader on a voyage to Alexandria and, when he turned privateer, continued with him, sharing in due course in the capture of a richly laden Venetian ship. Thence he passed on to the Turkish wars; was captured and enslaved; escaped; travelled through Russia, Germany, France; explored Spain; crossed to Morroco; and early in 1604, more by accident than intent, found himself in an English ship at Safi. Being carried out to sea in the ship by a storm and meeting later with two Spanish ships of war, Smith took part in a most desperate and lively sea battle before he saw port again. Then he made his way to England. Here he became involved with the Virginia Company, and, as mentioned earlier, crossed with the first of its settlers in 1607 to share in the founding of Jamestown and to pull the colony through its first two years of settlement. His capture by French privateers in 1616 added to his knowledge of sea-stratagems, seamanship, and straightforward sea-fighting. In 1626 there probably was no man of forty-five in England so well qualified to instruct the 'many
young Gentlemen and Valiant spirits, of all sorts' desirous, now that war had broken out with Spain again, and with France, and now that letters of-marque were again being issued 'to trye their Fortunes at Sea'.

An Accidence was entered in the Register of the Stationers' Company on 23 October 1626. Its purpose Captain Smith made clear enough by dedicating it 'To all the Right Honourable and most Generous Lords in England, and Others; Especially of his Majesties Privy Councell of Warre . . . In regard of the Present Occasion' [of war with France and Spain]. It was intended to further the 'Arte of Navigation'; and be 'an introduction for such as wants [lack] experience, and are desirous to learn what belongs to a Sea-man'. With tact and shrewdness he addressed himself 'To the reader and all generous and Noble Adventurers by Sea; And Well-Wishers to Navigation. Especially the Masters, Wardens, and Assistance of the Trinity House.' The Accidence was well named. Except for the opening pages detailing the names and duties of the various officers and men in a ship, the organization of the ship's company on a two-watch system (four hours on, four hours off, two men sharing a bunk, each in opposite watches), and the build of ships, the book really did contain no more than the rudiments of the grammar of the sea—the words and phrases used by seamen in the course of their duties. They were grouped according to marginal headings under 'Generall Sea termes belonging to ships'; 'ropes'; 'tackles'; 'anchors'; 'sails'; 'harbours'; 'winds'; 'Tearmes for the Sea'; 'Termes of Warre'; terms 'Concerning Sayling or working a Ship'; 'of a boate'; names of 'Orndance', with a table of weights, charges and shot; and a list of books on gunnery; the shares due to every officer and man seizing a prize; a list of the books to be studied and instruments to be used in order to learn the art of navigation; and advice on the care of victuals, the seamen's health, and the selection of comforts for them.

Typical of the 'generall sea terms' is the following: ' . . . In the steerage roome, the whip, the bittakell, the travas boord, the Compasse, the Fly, the needle, the lanthorne, the socket . . . About the Gun-roome, the Tiller, the rudder . . .'. Although the function of each part was not given, its location was. The landlubber could thus at least connect the names of things with places. Their functions he had to learn by inquiry or observation.

Smith's orders for setting sail, managing a fight, and coming to an anchor were accurate and, if allowance be made for the vagaries of punctuation, as lively as any seaman could want. Having received his orders from the captain to weigh and make sail, and the ship's company being aboard, the master comes out upon deck and orders the sails to be bent to the yards, and hoisted 'halfe mast high', and the yards to be crossed. Meanwhile the boatswain and his mates have brought the cable to the capstan and, on being ordered to 'fetch an anchor aboord', heave round on the capstan to 'break ground, or way Anchor'. By then the foremost men or younkers are in the tops and upon the yards ready to heave out the topsails, and the sailors are standing by the tacks and the sheets to set the sails.
A STORM AND A SEA-FIGHT

‘Come, is the Anchor a pike?’ hails the master, addressing the broad back of the boatswain, who is peering over the bulwarks forward for the first sign of the anchor and cable being up and down. As the bos’nun waves his hand in affirmation the master orders, ‘Heave out your topsayles, haul your sheets’, and demands of the boatswain, ‘What’s, the Anchor away?’ and being answered, ‘Yea, yea’, orders, ‘Let fall your fore sayle.’ As it fills, and the ship draws slowly ahead, the anchor is catted and lashed fast with the shank painter, the boat is stowed amidships and, finally, the order given, ‘Let sayle your maine Saile.’ The wind being fresh and following, the master orders, ‘On with your bonnets and drabler’ [additional strips of sail laced to the foot of the fore and mainsails], and directs the helmsman to ‘steare before the wind’. As the wind shifts so the sails are trimmed with the sheets, the bowlines and the braces, and as the wind rises sail is shortened until, a gale threatening, the gunner is ordered to ‘lash sure the Ordnances’, the bos’nun to strike the topmasts to the cap (lower and house them against the lower masts), and the helmsman to ‘lash sure the helm a ley’. The ship then lies hove to and an attempt is made to ride out the storm that has arisen. Eventually the ship is forced to run or ‘spoune before the winde’ while her company fears ‘she will founder in the Sea’. However, the gale eases and they ‘put out a goose-wing or a hullock of a sayle’, and, with the return of ‘Faire weather’, the master orders, ‘Out with all your sayles.’

It is now that the excitement begins for suddenly comes the cry: ‘A Sayle!’

‘How stands she, to windward or leeway?’ demands the Captain, and orders: ‘Set him by the Compasse.’

‘He stands right a head’, comes the reply.

‘Out with all your sayles; a stydy man to the helme; sit close to keep her stydie: give chase’, is the immediate response.

As anxious eyes judge the rate of closing, one mutters, ‘He holds his owne’; another responds, ‘No, we gather on him.’ Suddenly there goes up the cry: ‘Out goeth his flag and pendance’; others take up the commentary: ‘also his Colours, his wast-clothes and top-armings!’

‘He furles and slings his mainesail!’

‘In goes his spret sayle and misen!’

‘He makes ready his close fights fore and after!’

‘Well, we shall reach him by and by’, observes the captain and demands:

‘What! is all ready?’

‘Yea, yea’, comes the eager reply.

‘Every man to his charge. Dowse your top sayle, salute him for the sea’, orders the Captain, and, as the vessels come within distance of speech, orders:

1 Strips of canvas hung over the bulwarks between the fore- and after-castles to conceal the men in the waist of the ship.

2 Canvas aprons to conceal the men in the tops.

3 Stout nets triced up from the bulwarks to make boarding difficult.
'Hale him!'  
'Whence your ship?' goes forth the hail.  
'Of Spayne! Whence is yours?' comes back the reply.  
'Of England!'  
There is a dubious silence, then, from the Spaniard, 'Are you Merchants or Men of Warre?'  
'We are of the Sea.'  
The Spaniards' answer to this is to prepare to fight!  
'He wayse vs to leyward for the King of Spaine, and keeps his loufe',  
oberves the Captain, adding: 'Give him a chase pece.'  
As this does not have the desired effect he directs the gunner to give her  
'A broadside', and the Master to 'Runne a head', and 'Make ready to tack  
about!' As the English ship tacks her Captain orders: 'Give him your  
sterne peecees!'  
But the shooting has not been one-sided, and the Englishman is forced to  
haul clear to let the crew 'breathe and refresh a little', and for shot holes  
between wind and water to be plugged, and the pumps tried to see how  
much water has been made.  
When the fight is resumed an attempt to board is frustrated by the  
Spaniards setting fire to the English ship so that, to avoid destruction, the  
order has to be given, 'Cut anything to get cleare, and smother the fire  
with wet clothes!' Until the report is made, 'We are clecre, and the fire is  
out!' none is free of fear. It was a heartfelt 'God be thanked!' that acknowl-  
edged it.  
The next morning, with a sounding of drums and of trumpets, and with  
loud shouts of 'St. George for England!', the fight is resumed.  
At last the Spaniard hangs out a flag of truce. 'The Captaine, Purser and  
Gunner, with their Commission, Cocket or bills of loading' are ordered  
aboard in their ship's boat to be examined 'in particular'.  
'Then conclude your conditions', advised Captain Smith, 'with feasting,  
freedome, or punishment, as you finde occasion. Other wayes if you  
surprise him or enter perforce, you may stowe the men, rifle, pillage or  
sack, and cry, "A Prize!"'  
Then was repeated what had been done the night before. At sundown  
the Captain had said, 'The day is spent, let us consult.'  
When all had been gathered together he had continued: 'Surgion, looke  
to the wounded, wind vp the slaine, with each a weight or bullet at his  
head and feete.'  
To the gunner he had ordered: 'Give three pieces for their funerals.'  
Then, these grim rites attended to, more briskly he had directed:  
'Swabber, make cleane the shippie.'  
'Purser, record their names.'  
'Watch! be vigilant to keepe your berth to windward: and that we lose  
him not in the night.'  
'Gunners! Sponge out your Ordinances.'  
'Souldiers! Skower your peeces.'
'Carpenters! About your leakes.'
'Boteson, and the rest! Repaire the sayles and shrouds.'
'Cooke! see you observe your directions against the morning watch.'
And so the ship had been put in readiness against the morrow.
Ere dawn the Captain had been awakened, and coming upon deck, had called: 'Boy!'
'Holla, Maister, Holla!' had come the quick reply.
'Is the kettle boyled?'
'Yea, Yea,' the boy had answered.
With a final order—'Boteswaine, call vp the men to Prayer and Breakfast'—the day's work had begun.

Captain Smith does not have a great deal to say 'concerning the particular theormes, or tearmes for great Ordnances'. 'For your better satisfaction, . . . Mr. Digs his Pantrymetria, Mr. Smith, or Mr. Burnes Arte of gunny, or Mr. Robert Nortons expositions upon Maister Digs. Any of these', he explained, 'will shew you the Theoricke; but to be a good Gunner'—and he spoke from great personal experience—'you must leare it by practise', adding, 'the Gunners scale is made in Brasse at Tower Hill, with prospectuie glasses, and many other instruments by Mr. Bates.'

The first proclamation of Charles I's reign had been one 'for the well manning and arming the ships of war belonging to this realm upon their setting forth to sea'. This had ordered that the crews of ships were to be exercised regularly 'that they might learn the perfect use of their Arms'.

In contrast, therefore, to King James's days every sailor was now ordered to learn to handle firearms and every master to become a competent gunner. Captain Smith's recommended reading list was in consequence particularly timely. The type of weapons the men were expected to use is to be found illustrated together with various nautical gear, on the cover of copies of Mainwaring's manuscript Seaman's Dictionary.

The most recent book on gunnery in Captain Smith's list was Robert Norton's Of the Art of Great Artillery, published only two years before. While its basis was the problems and obscurities posed by Digges in his Stratioticos and his Pantometria, it was probably as a result of Norton's experiences on the Algiers operations of 1620–1 that he had felt it necessary to improve the art. In an entertaining preface he points out that just

1 1625. Charles I. 'A proclamation for the well manning and arming the ships of or belonging to this realm upon setting forth to sea,'

2 OF THE ART OF GREAT ARTILLERY, Viz. THE EXPLANATION of the most excellent and necessary Definitions, and Questions, pronounced and propounded, by that rare Soulidier and Mathematician, Thomas Digges Esquire; and by him published, in his Stratioticos, and Pantometria, concerning great Ordinance, and his Theorems thereupon. Together, With certaine Expositions, and answers thereunto adioyned: Written by Robert Norton Gunner. And by him Dedicated, to the Worshipfull John Reinolds Esquire, Master Gunner of England. LONDON, Printed by Edu: Alide, for Iohn Tap, and are to bee sold at his Shop at the corner of Saint Magnus Church. 1624.
as the soldier with sufficient brains only to do sentry-go thinks he is the perfect soldier, and the sergeants and officers know there is far more in soldiering than he dreams of, and 'as the Common Saylor, if he can but say his Compasse, furle a Sayle, and take turn at Helme and Leade, doth lesse know his ignorance then such a Master or Pilot as hath sayled a ship by his Chart, Compasse and Art, round the world', so the expert gunner realized how much more there was in gunnery than met the uninformed eye. Indeed under the impetus of war developments came apace. John Browne, the King's gun-founder, succeeded in 1626 in casting cannon lighter and stronger than ever before. The next year Thomas Smith's *Art of Gunnery* was to be reprinted with an important *Addition* by the author describing new projectiles designed to dis-mast ships, cut their rigging or set them on fire.¹ His *The Complete Souldier*, the same year,² with Robert

¹ THE ART OF GVNNERY.
Wherein is set forth a number of serviceable secrets, and practicall conclusions, belonging to the Art of Gunnerie, by Arithmeticke skill to be accomplished: both pretie, pleasant, and profitable for all such as are professors of the same facultie.
Compiled by THOMAS SMITH of BARWICKE vpon Tweed Souldier. LONDON, Printed for WILLIAM PONSONBY. 1600.
pp. [i–x], 1–[109]—followed by
CERTAIN ADDITIONS TO THE BOOKE OF GVNNERY, with a supply of Fire-Workes. All done by the former Author Thomas Smith Souldier of Barwicke vpon Tweede. *Both pleasant and profitable*. LONDON, Printed by H.L. and are to be sold by R. Dawelman, in Fleet-street neere the great Conduit. 1627.
pp. [3]–76.

² THE COMPLETE SOULDIER. Containing the whole Art of GVNNERY, with certaine new and rare Additions concerning FIRE-WORKS. *Wherein is exactly layd open a great number of serviceable, and practicall Conclusions, belonging to Militarie Profession. As also certaine new deuices of sundry experienced Fire-workes, verie necessary to be vsed both for Sea and Land-servises. Set forth for the benefite of this Kingdome in these troublesome times of Warre. The second edition, newly perused and amended.*
*By THOMAS SMITH Souldier.*
LONDON, Printed for R. Dawelman, at the Brazen Serpent in S. Pauls Churchyard. 1628.
Containing, within, two title-pages, as follows:
THE ART OF GVNNERY, Wherein is set forth a number of serviceable secrets, and practicall conclusions, belonging to the Art of Gunnerie, by Arithmeticke skill to be accomplished: both pretie, pleasant, and profitable for all such as are professors of the same facultie. Compiled by THOMAS SMITH of Barwicke vpon Tweed Souldier.
LONDON, Printed for WILLIAM PONSONBY. 1600.
CERTAIN ADDITIONS TO THE BOOKE OF GVNNERY, with a supply of Fire-Workes. All done by the former Author Thomas Smith Souldier of Barwicke vpon Tweede. *Both pleasant and profitable.*
LONDON, Printed by H.L. and are to be sold by R. Dawelman, in Fleet-street neere the great Conduit. 1627.
LXXXIV. An Early Stuart Navigator’s Instruments of Pilotage, c. 1631.
LXXXV. An Early Stuart Navigator's Instruments of Navigation, c. 1631.
Norton's magnificent *The Gunner*, and *The Gunners Dialogue* of 1628 were to bring the handling and manufacture of small arms and great ordnance right up to date. Incidentally, it is clear that Captain Smith had taken a military work and its title as the model of his *Accidence*, namely Gervase Markham's *The Souldiers Accidence*, of 1625.

It goes without saying that, as the first book of its kind, and a well-compiled one at that, Captain Smith's *Accidence* was popular, and another edition appeared the next year. Markham, in 1626, had published the first part of his *The Souldiers Grammar*—the second part came out the next year.

1 THE GVNNER SHEWING THE WHOLE PRACTISE OF ARTILLERII: With all the Appurtenances thereunto belonging. Together with the making of Extraordinary Artificiall Fireworkes, as well for Pleasure and Triumphes, as for Warre and Service. Written by ROBERT NORTON, one of his Maiesties Gunners and Ingeniers. LONDON, Printed by A. M. for HVMPHREY ROBINSON, and are to be sold at the three Pidgeons in Pauls Churchyard, 1628.

2 THE GVNNERS DIALOGUE. With the Art of great ARTILLERY. BY ROBERT NORTON, Engineer and Gunner. LONDON, Printed for Iohn Tap, and are to be sold at his Shop at Saint Magnus Corner. 1628.

3 THE SOVLDIERS ACCIDENCE, or AN INTRODUCUTION Into MILITARY DISCIPLINE, Containing the first Principles and necessary knowledge meete for Captaines, Muster-Masters, and all young Souldiers of the Infantry, or Foote Bandes. ALSO The Cavallarie or Formes of Trayning of Horse-Troope, as it hath benne received from the latest and best experienced ARMIRES. A Worke fit for all Noble, Generous, and good Spirits, that loue Honor, or Honourable Action.

VIRG. AENEII. At nunc Horrentia Martis.

G. M.

LONDON Printed by I.D. for IOHN BELLAMIE, and are to be sold at his Shop at the three golden Lyons, neere the Royall Exchange, 1625.

4 THE SOVLDIERS GRAMMAR: Containing, The High, Necessarie, and most Curious Rules of the Art Militarie: As first,

Whether it be in Great Motions in Generall? or Foote Motions Especially?
Or Motions of Horse, Generall, or Speciall?
The Ranges of Foote, or Horse?
The Ranges of Officers.
The Seuerall Imbattailings of Foote, and Horse.
The Imbattailing of a Regiment.
The Joyning of many Regiments.

Or the Forming of Maine Battailies, of any extent, or Number; With their Formes, and Figures, in liuely Demonstration, &c.

By G. M. Gent.

Printed at Londin, for William Shefford, and are to bee sold at his Shop in Popeshead Alley, going into Lombard Street. 1626.

THE SECOND PART OF THE SOLDIERS GRAMMAR: OR A SCHOOLE FOR Young Soldiers. Especially for all such as are called to any place, or office, (how high or low soever) either in the Citie, or Countrey, for the Training, and exercising of the Trayned Band, whether they be Foote or Horse. Together with perfect Figures and Demonstrations for attaining the knowledge of all manner of Imbattailings, and other Exercises. By G. M.

LONDON, Printed for Hugh Perry, and are to bee sold in Britaines Burse, at the signe of the Harrow. 1627.
year—and Captain Smith, again taking his cue from Markham, brought out a revised and considerably amplified version of his own *Accidence* in this year of 1627, under the title of *A Sea Grammar*. It was published, Captain Smith tells us in his *True Travels* of 1630, through the good offices of Sir Samuel Saltonstall, one of whose sons, Charles (it is interesting to note) was an experienced sea captain who was to publish a navigation manual in 1636.¹ It seems probable that the initials under two of the commendatory verses in the *Sea Grammar* were those of Sir Samuel Saltonstall, and his literary-minded son, Wye.

The year 1627 was that of the Rochelle expedition, and its unrelieved failure underlined the imperative need for a higher standard of seamanship and command in the conduct of maritime operations. As the subtitle of the *Sea Grammar* explained, the book was *'a plaine exposition of Smith's Accidence for young Sea-men'*, written, as it was put in one of the panegyric verses that introduced the author and his works to the reader;

That now th'untraueld land-man may with ease
Here know the language both of ships and seas.

The *Sea Grammar* in fact did for ships and seamanship what had already been done by other writers for navigation and gunnery; it collected, collated, codified, defined, and explained the ordinary workaday knowledge of seamen and their ships; how they built, rigged, manned, victualled, armed, handled, fought, and sailed a ship at sea.

It starts with 'Dockes and their definitions', continues with 'How to build a ship', 'How to proportion the Masts and Yards', 'The names of all the Masts', and so goes on progressively through the whole gamut of the seaman's craft. From now on Captain Smith's stricture, 'that much hath bin writ concerning the art of war by land, yet nothing concerning the same at Sea', could no longer be applied to the English.

Captain Smith's 'Advertisements for yong Commanders, Captaines and Officers', while full of sound advice evidently drawn from his own experience, is equally clearly based upon that earliest of English writers on the

¹ THE NAVIGATOR: SHEWING AND EXPLAINING All the Chief Principles and Parts BOTH THEORICK AND PRACTICK, That are contained in the famous Art of NAVIGATION. WITH A NEW AND ADMIRABLE WAY OF Sayling by the Arch of one of the greatest Circles. Containing excellent Tables most exactly Calculated, shewing the true Proportion of all Parallels in respect of the Meridian. With the proper Phrases used in working of a Ship according to all weathers. With A Word of Advice to all Sea-men not to meddle with the Plaine Charts used in their time, their decepts discovered, and a way to prove the projection of any Plain Chart; how to marke the Log-line according to a true Degree in the Meridian.

The third Edition corrected and enlarged. By Captain CHARLES SALTONSTALL. LONDON, Printed by R. and W. LEYBOURN for George Hurlock, and are to be sold at his Shop at Magnus Church. [Corner] [B.M. copy cropped. No date visible. B.M. catalogue gives '1660?'].
seaman's art, William Bourne. Nor does Smith try to fool the young landsman into thinking life at sea is all cakes and ale.

Men of all other professions in lightning, thunder, stormes and tempests, with raine and snow, may shelter themselues', he pointed out, 'in dry houses, by good fires, and good cheare', whereas those are the very times 'that Seamen must stand to their tackelings, and attend with all diligence their greatest labour upon the Deckes', for 'there is no dallying nor excuses with stormes, gusts, overgroune seas, and leyshores....' Indeed, he confessed, 'In foule weather, the labour, hazard, wet and cold, is so incredible I cannot expresse it.'

Perhaps, as he wrote, the words of the psalm-singing men of the sea were in his ears:

... at his word the stormy wind ariseth: which lifteth up the waves thereof. They are carried up to the heaven and down again to the deep: their soul melteth away because of the trouble. They reel to and fro and stagger like a drunken man: and are at their wit's end...

If so, unlike the Psalmist, he gave no inkling of that blessedness, known to seamen alone, that comes with relief from the turmoil of storm, when

he delivereth them out of their distress. For he maketh the storm to cease: so that the waves thereof are still. Then are they glad, because they are at rest: and so he bringeth them unto the haven where they would be...

We can see the ship bearing in with the land, under topsails and courses a leadsman in the chains, the bos'un and his party forward, bending the cables and buoys to the anchors. 'Deep six!' sings the leadsman, and as he heaves the lead again, 'By the mark, seven!' At a word from the master the youngsters leap into the shrouds, and shin aloft to get in the topsails while the seamen busy themselves about the courses. As the ship glides between the wooded headlands of some West Country or New England estuary, and is brought smartly round, head to wind, we hear the splash of her anchor in the water and, as the courses come in, and her way is checked by the bitted cable, the plash of oars and the gruff command of the coxswain as a skiff is brought alongside for the captain to go ashore...

If the captain has been a wise man the crew will be in good health for he will have supervised the purchase of the victuals and will have provided a petty-tally for the comfort of the sick. It will have included rice, currants, prunes, sugar, oil, butter, 'Aqua vitae, the best Wines, the best Waters, the iuyce of Lemons for the Scurvy, white Bisket, Oate-meale, Gammons of Bakon', and such like fortifiers and delicacies. These he will have issued when a man has been ill, or at the point of death, or 'after a storme, when poore men are all wet, and some have not so much as a cloth to shift him, shaking with cold'. In such events the good captain has been blessed by his
men, for at sea there 'is neither Ale-house, Taverne, nor Inne to burne a faggot in, neither Grocer, Poultierer, Apothecary, nor Butchers shop' where men may seek liquor, victuals and warmth after a night of storm.

Again, if the captain were a wise man, like his master he would know how 'to observe the Altitude, Latitude, Longitude, Amplitude, the variation of the Compass, the Suns Azimuth and Almicanter, to shift the Sunne and Moone, and know the tides, his Roomes, pricke his Card, say his Compass'. To be able to do this he would have equipped his ship with leads and lines, and a dipsie lead and line; common sea-compasses, a dark compass, and an azimuth compass; half-hour, hour and four-hour watch glasses, and a watch bell; a traverse board; a log and log-line, log-board, and half-minute or one-minute running glasses; and in his chest his instruments would include plane, circumpolar and Mercator charts; compasses and a protractor; a terrestrial globe and compasses; a plain-scale and a Sector or a Gunter's Scale; an astrolabe, astrolabe quadrant or celestial globe; ring-dial or pocket sun-dial; a nocturnal; a tide-computer; a lodestone; a sea-astrolabe, cross-staff or back-staff, and a Davis quadrant, a log-book and a journal. He would probably prize a telescope, and might well keep a six-inch dial watch in his cabin. He would be able to handle these instruments correctly because he would probably carry a copy, and would certainly be well acquainted with the contents, of the 1610 edition of Wright's *Certaine Errors of Navigation*; of the 1625 edition of Tapp's *The Seamans Kalender*; of the 1615 edition of Tapp's revised text of Eden's translation of Cortes's *The Art of Navigation*; of the 1620 edition of Bourne's *A Regiment for the Sea*; of the 1626 edition of Davis's *The Seamans Secrets*; of Blaeu's *The Sea-Mirrour* of 1625; of Gunter's *De Sectore & Radio* of 1624; of Aspley's *Speculum Nauticum* of 1625; of the 1614 edition of Norman's *The Newe Attractive*, with Borough's *Of the Variation of the Cumpas*; of Wright's *Description and Use of the Sphere*, reprinted this very year 1627; and of either Hues's *Tractatus de Globis* of 1624, printed in Amsterdam, or his *Tractaet van Globe*, Amsterdam, 1623, or his *Traité des Globes*, Paris, 1618. This, as we have seen, did not necessarily exhaust his reading list, but, as Captain Smith implied, these books enabled a man to get a very thorough knowledge of the art of navigation, a knowledge, moreover, which differed basically but little from that possessed by a navigator to-day. The differences were chiefly ones of detail. The astronomical principles involved and their application were in general as well understood then as now. It is through instrumental development, in particular of the reflecting quadrant and of the chronometer in the eighteenth century, which made the accurate determination of longitude possible and through the patient collection and collation of observations of natural phenomena, in particular of tidal and magnetic data in the nineteenth century, that the differences are chiefly apparent.

Captain John Smith died on 21 June 1631 in the house of Sir Samuel Saltonstall, and was buried in St. Sepulchre's Church, Holborn. Although neither the *Accidence* nor the *Sea Grammar* had been reprinted again
during his lifetime, there were subsequent editions of both. The Sea Grammar, in particular, was a popular work, and (as he hoped would happen) as the century wore on it was several times reissued corrected, revised, and expanded as The Sea-man's Grammar at the hands of 'worthy Adventurers by Sea, and well-wishers to Navigation'.

The war with France and Spain had dragged on till 1630, giving rise as we have seen to a number of books on gunnery. It also called forth a new and enlarged edition of Woodall's The Surgions Mate in 1628, which he entitled Woodall's Viaticum.1 But there were few books published on Navigation in the four years between the appearance of the Sea Grammar and Captain Smith's death. In 1630 John Tapp reprinted Cortes's Art of Navigation and Handson's Trigonometrie, with its nautical appendix; in the next year the last edition of Bourne's Regiment appeared. The Seamans Kalender and perhaps the second edition of Asley's Speculum Nauticum came out during these four years, while, as remarked in the preceding chapter, 1630 was probably the year which saw the first publication of an engraved chart of the Atlantic on Mercator's projection.

It has already been stated that it was Edward Wingate who first described and illustrated in detail Gunter's logarithmical line of numbers. In 1626, the year that Wingate published The Use of the Rule of Proportion, he published in Paris Arithmetique logarithmetique.2 Two years later appeared his Construction and Use of the Line of Proportion. In 1630 he brought out a work that combined the contents of both his latest works, Arithmetique Made Easte, in Two Bookes . . . of Natural . . . and . . . Artificial Arithmetique.3 The first part dealt with 'Naturall Arithmetique'—that is,

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1 WOODALLS VIATICVM: The path-way to the Surgions Chest. CONTAINING CHIRURGICALL INSTRUCTIONs FOR the yonger sort of Surgions now employed in the service of His MAJESTIE for the intended reliefe of ROCHELL. And Composed by John Woodall, one of the present Masters or Governors of the Companie of Barber Surgions. LONDON. Intended chiefly for the better Curing of Wounds made by Gun-shott. Published by Authoritie: Ommia Terrenae per vices sunt Alienae. August 11. 1628. Imprinted at London. 1628.

2 Wingate, Edmund, Arithmetique logarithmetique, Paris, 1626.

3 (Napier in the Constructio used the term numerus artificialis, i.e., artificial number).

ARITHMETIQUE Made easie, IN TWO BOOKES. The former, of Naturall Arithmetique: CONTAINING A perfect Method for the true knowledge and practice of Arithmetique, according to the ancient vulgar way, without dependance upon any other Author for the grounds thereof. The other of Artificial Arithmetique, DISCOVERING How to resolve all Questions of Arithmetique by Addition and Subtraction. Together with an Appendix, resolving likewise by Addition and Subtraction all Questions, that concerne Equation of Time, Interest of money, and Valuation of Purchases, Leases, Annuities, and the like.

By Edm. WINGATE.

Boehtius Arith. lib. 1 cap. 2.

Ommia quaescuncae a praeemia rerum naturâ constructa sunt, Numerorum videntur ratione formata: Hoc enim fuit Principale in animo Conditoris Exemplar.

LONDON, Printed for Phil. Stephens and Chr. Meredith at the Golden Lyon in Pauls Churchyard. 1630.
multiplication, division, addition, and subtraction, including the use of decimals and a method of division approaching the modern one—and the second part dealt with 'Artificiall Arithmetique', or the nature and use of common logarithms. It was this latter part that was so useful, for it presented the ordinary student with the first comprehensive description in English of logarithms and their use, and contained, in addition to tables, the folding engraved plate of 'the Lineall Construction of Logarithms' of his earlier works. Wingate accompaniced the plate with directions on how to construct it and also on how to use it—with a pair of compasses. The result was that, as with the use of tables of logarithms (those two intricate branches of Arithmetique), Multiplication and Division, which so confounded and perplexed the new Practitioner, that hee took them to be Hercules Pillers, and wrote upon them Non plus Ultra', now lost their terror. Mounted upon a wooden ruler, Wingate's logarithmical line of numbers placed in the hands of the ordinary student the most generally useful of the lines on Gunter's scale. Being printed upon stout paper from a 30-inch-long copper plate it incorporated a high degree of accuracy with the cheapness necessary to place it within reach of the many. While what we may term Wingate's scale, in conjunction with a pair of dividers, was in effect a slide-rule, it was this very year of 1630 that there appeared the first description of an actual slide-rule. This was Richard Delamain's Grammelogia.¹ The instrument he had invented and now described was not, however, one of sliding rulers but of rotatable discs. Delamain was a teacher of mathematics in London who had long pondered the problem of contriving some motion so that the whole body of logarithms might 'move proportionally the one to the other' as occasion might require. He had struck upon the circular motion the year before he published Grammelogia. It had the advantage over all others, as he pointed out to King Charles I, to whom he dedicated his work, that 'there was to be had at a glance all the proportionals throughout the whole body of logarithms so that you had but to bring one number to another, and right against any other number was the answer'. Moreover, it could be manipulated with one hand whilst writing and—as he somewhat ingenuously observed

¹ GRAMMEOLOGIA Or, the Mathematicall Ring. Extracted from the Logarhythmes, and projected Circular; Now published [an] inlargement thereof un to any magnitude fit for use: shewing any rea[son] able capacity that hath not Arithmetick, how to resolve and worke, all ordinary operations of Arithmetick: And those that are most difficult with greatest facilitie, the extensi[on] of Rootes, the valuation of Leases, &c the measuring of Plaines and S[pheres] ? page cropped] with the resolution of Plaine and Sphericall Triangles applied to the Practicall parts of Geometrie, Horolographie, Geographie, Fortification, Navigation, Astronomie, &c. And that onely by an ocular inspection, and a Circular motion, Invent[ed] [&] first published, by R. Delamain, Teacher, and Student of the Mathemati[kes]. Naturaec secreta tempus aperit.

Typus proiectionis Annulli adaeuti, vt in conclusione lybri praelo commissi, Anno 1630 promisi.

['Typus . . . promisi' engraved in script.]
—was as fit for use on horse-back as on foot! Elias Allen manufactured Delamain's circular slide-rule. It was probably one of his making that King Charles treasured and parted with only on the scaffold.

Delamain had been a student of the Reverend William Oughtred, the Surrey parson whom we have already noticed earlier as being one of the most brilliant mathematicians of the time. One day in the long vacation of this year 1630 another rising young mathematician, William Forster, was at Oughtred's house and happened to mention that in an attempt to get greater instrumental accuracy he had made and used a Gunter's rule 6 feet long which he worked with a pair of beam compasses. Oughtred at once answered that that was a poor invention since its use was so troublesome, and, disappearing for a few minutes, reappeared with two Gunter's rules to be used 'by applying one to the other, without any compasses'. Oughtred in fact had devised the slide-rule. He next showed Forster the logarithmic lines cast into a circle, with another disc upon it—a slide-rule somewhat similar to Delamain's. These inventions Oughtred claimed to have had by him many years, having concealed them hitherto because, as a teacher, he believed the true way of solving problems was by demonstration and not instrumentally. Now, however, he allowed Forster to persuade him to describe his instruments to the world—partly no doubt because both accused Delamain of having got the idea of his circular slide-rule from Oughtred—and so, a year after Captain Smith's death, appeared Oughtred's Circles of Proportion and, in 1633, An Addition into the Use of the Instrument... for the Working of Nautical Questions.1 Oughtred's instrument differed from Delamain's in that it did not consist of two movable discs but of fixed circles, 'with an index to be opened after the manner of a pair of compasses', this apparently being the arrangement preferred by Elias Allen, who manufactured it also. There was a long and bitter controversy between Oughtred and Delamain, who brought out a second edition of his work this same year, on the question of priority of invention. To us it is now a matter of indifference. The point of particular interest is that the slide-rule in its three characteristic forms, straight, circular, and spiral (the latter hit upon by a joiner, Thomas Browne), was an English invention of the late 1620s designed primarily to facilitate nautical calculations.2

1 THE CIRCLES OF PROPORTION AND THE HORIZONTALL INSTRUMENT. Both invented, and the vses of both Written in Latine by Mr. W'. O. Translated into English and set forth for the publique benefit by William Forster. LONDON Printed for Elias Allen maker of these and all other Mathematical Instruments, and are to be sold at his Shop over against St. Clements church without Temple-barr. 1632.

Note: The whole of this title is engraved. 'T. Cecill Sculps.'

2 For a history of the slide-rule see the works of Cajori, F. He suffered from the handicap of not having access to all the books, so that his treatment of the genesis of the slide-rule needs to be received with caution, particularly the Oughtred-Delamain-Forster controversy.
As we have followed Richard Norwood’s career as a young student of navigation, it is fitting that we should now notice the earliest of his contributions to the improvement of the art of navigation. By 1631 he had been teaching mathematics and navigation in London for close on fifteen years, and he now published the first of his navigational works, *Trigonometrie*. For the last few years he had been devoting his attention primarily to the task of ‘conforming the Doctrine of Triangles, to the nature of Logarithmes now in use’, that is to say, to common logarithms, in such a way that the rules could also be used with natural sines, tangents, and secants, and instrumentally. He had based his studies, naturally, upon Napier’s, Wright’s, Gunter’s, and Briggs’s works, and he admitted being particularly indebted to Briggs’s *Arithmetica Logarithmica* of 1624, and the still incomplete draft of Briggs’s *Logarithmica Britannica* which he had been shown. Nevertheless, as he pointed out in his ‘Address to the Reader’, dated from Tower Hill 1 November 1631, though he and Briggs had handled similar matters, each had done so in such a different manner that there was scarcely one proposition handled by them both. Moreover, unlike Briggs, Norwood had intended his work to be simply and solely a manual of navigation devoted to the use of plane and spherical trigonometry. However, being absent all the summer of 1631 he had been unable to compose the navigation manual and so in its place he dealt in his *Trigonometrie* with the resolution of certain problems of plane, Mercator’s and great circle sailing. He had not deferred publication in order to complete his full plan because he had found that some other mathematician—he evidently meant Wingate—had been getting previews of his work, apparently at the printer’s, and embodying the gleanings in his own publications abroad, and had now done so at home also. If Norwood is to be believed, Wingate’s *Arithmétique* of 1630 contained much pioneer logarithmical work of Norwood’s doing. However, that may be, at the end of 1631 appeared Norwood’s *Trigonometrie* . . .

Despite its main title, the *Trigonometrie* was really a navigation manual after the manner of the modern Admiralty *Manual of Navigation*, Volume II. Its contents, though largely trigonometrical, like those of the Admiralty manual, related to the mathematical solution of problems of astronomical and oceanic navigation. It was, if we can put Addison’s work in the same class, the second of the modern mathematical navigation manuals.

As the full title explains, Norwood’s *Trigonometrie* dealt with the application of common logarithms, first to the problems of plane trigonometry, next, to those of spherical trigonometry, and lastly to those of navigation. The text was well arranged and amplified with numerous line drawings. Unquestionably it gave the clearest and most succinct explanation of the nature and manifold uses of common logarithms published to date.

In the first book, which occupied thirty-nine pages, after defining the lines used in trigonometry, the author explained ‘the nature and affections of Logarithmes’, then the four fundamental axioms of the doctrine of plane triangles, and the cases deduced from them.
The second book, that dealing with spherical triangles, occupied eighty-one pages, and was quite the ablest and most complete treatise on its subject yet published for the general public. In particular, by taking two of Napier’s propositions as fundamentall Axiomes for the solution of all the cases of sphericall triangles’, Norwood was able to simplify and clarify the calculations for finding the sun’s amplitude, azimuth, declination, etc.

To any student who mastered these two books Norwood’s navigational Annexe was simplicity itself. Like Gunter before him, Norwood proceeded from the simple to the complex. Although he understood and ably explained the errors arising from the use of the plane chart, he also devoted the first part of the Annexe to the logarithmical solution of fifteen propositions based on the use of the plane chart. This he excused on the reasonable grounds that the method was ‘most easie, and much used, and the errors in small distances not so evident’.

It was in the course of showing the logarithmical solution of the various propositions first propounded by Hues, Handson, and Gunter that Norwood posed the interception problem of the warship and the pirate ship cited earlier.

Before showing the logarithmical solution of problems of Mercator’s sailing Norwood explained the defects of the plane chart and the advantage of Mercator’s chart, and inserted a table of meridional parts for degrees and tenths of degrees abridged from Wright’s ampler table. For his examples of Mercator’s sailing he took the voyages from Shakespeare’s ‘still-vex’d Bermoothes’, or ‘Summers Is’ [Somers Is], as he himself generally called the Bermudas, to the Lizard, placing the former in latitude 32° 25’ N and longitude 70° W of the Lizard, and the latter in latitude 50° N, and taking the nautical mile as being 5000’ in length. He explained how to find the meridional parts of the difference of latitude (1,417’) and, this having been done, how to calculate the rhumb-line course and distance between the two places, drawing a navigational triangle ABD, (with north at the bottom), to illustrate the problem and obtaining answers of: ‘Co Summers I to Lizard one 3° 51’ E [N.71° 21’ E. or E.N.E. 4 E. (nearly)] from Lizard to Summers Is W. S. W. 3° 51’ W,’ and a distance of 3,299 miles or ‘almost 1100L along the rumb’.

Norwood took as his formula for finding the rhumb-line course:

\[
\frac{\text{d. long.}}{\text{d.m.p.}} = \tan (\text{Co}) = \frac{4,200}{1,417}.
\]

giving the working:

as d. lat. 1417 mer. parts 6,84863 [log]
so d. long. in mer. parts is 4200 3,62325 [log]

to tan. of course 71° 21’ 10,47188 [log tan]’.

That is to say, the rhumb line track from the Bermudas to the Lizard was N 71° 21’ E or E.N.E. 4 E. (nearly).
To find the distance he used the formula:

$$\text{dist} = \frac{\text{d. lat.}}{\cos (\text{Co})} = \text{d. lat.} \times \frac{1}{\text{sine (Complement of Course)}}$$

for he expressed the working as:

'As Sine Compl. of r. A 18° 39' 0,49514
\[ 1055 \quad 3,02325 \]
\[ 3299 \quad 3,51839 \]

almost 1100 along the rumb.'

With a book like this in his hand there was now no reason why the navigator should not solve all problems of plane and Mercator’s sailing logarithmically. Norwood had weaned logarithmical navigation from the lecture hall.

It was after this last problem that Norwood observed, ‘There is a nearer cut by great circle navigation.’ Great circle navigation has been mentioned in earlier chapters. Cortes pointed out that the shortest distance between two places lies on the arc of a great circle—the arc of a circle on the earth whose plane passes through its centre. We have seen that on occasion some of the later Elizabethan navigators actually practised great circle sailing. How did they do so? It is almost certain that they did not calculate the courses and distances involved, and most probable that they obtained them from a globe. They would do so by rectifying a terrestrial globe so that their point of departure and of arrival lay under the *quarta altitude*; they would then measure the distance between every fifth and tenth meridian, or parallel, along the arc of the great circle represented by the edge of the *quarta altitude*; they would also measure the angle which it made with each of these meridians or parallels. They would then follow these courses and distances. If we take a modern globe and stretch a thread upon it between, say, the Lizard and the Bermudas, so that the thread is clearly the arc of a circle whose plane passes through the Lizard, the Bermudas, and the centre of the globe, we have delineated the arc of the great circle between the Lizard and the Bermudas.\(^1\) It will be noticed that this arc cuts each successive meridian at a slightly different angle so that, in order to follow it—this great circle track—we have at first to shape our course from Bermuda N.N.E. by E., then E.N.E., then E. by N., then E., and finally E. by S. Whereas these frequent changes of course enable us to follow a straight track on the surface of the globe, should we adhere to a course of N.N.E. by E. throughout the voyage, that is, should we cross each successive meridian at the same angle, a curved, actually spiralling or rhumb line track would result. If we stretch a string on the globe so that it marks out this rhumb line track we shall find that it passes north of the Lizard. Norwood, it will be recalled, had calculated the rhumb line course that, if followed from the Bermudas, would arrive at the Lizard,

\(^1\) See Fig. 42.
GREAT CIRCLE SAILING AND RICHARD NORWOOD'S EXPLANATORY TRIANGLES IN HIS Trigonometrie (1631)
and had found it to be N 71° E (E.N.E. ¼ E.). He had also calculated the rhumb line distance and made it to be 3299 miles. He had been able to calculate both by the use of a table of meridional parts and the use of logarithms. He had also been able to plot the result as a straight line on a Mercator’s chart.¹ Had he wished, he could have found the rhumb line course and distance on the Mercator’s chart directly by plotting—by plotting the position of Bermuda and the position of the Lizard and joining the two by a straight line. What, however, he could not do on this chart—and what can still not be done on a Mercator’s chart—was to find the great circle track by similar geometrical methods. He could find it graphically only on a globe—or a circumpolar chart. The reason is that a great circle track when

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¹ See Fig. 43.

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**Fig. 43**

**THE GREAT CIRCLE AND RHUMB LINE TRACKS AND COURSES, ON A MERCATOR’S CHART; THE BERMUDAS TO LIZARD**

(After Norwood, *Trigonometric, 1631*, and *The Seaman’s Practice, 1637*)

drawn on a Mercator’s chart appears as a curved track above (in the northern hemisphere) the apparently straight rhumb line track. The great circle track thus appears to be longer than the rhumb line track. In reality it is shorter, as can be checked by measurement, the reason being that on a Mercator’s chart the latitude scale, which is also the distance scale, continually increases the nearer the pole is approached.

The problem facing the up-to-date navigator of early Stuart days was how to find the great circle track between two places in the middle latitudes. He had probably discarded the terrestrial globe as being either too fragile, too cumbersome, or too expensive, or if he carried one, rightly regarded it as insufficiently accurate, because of its small scale, for his standards of navigation. Some navigators—Addison, for instance—expert in logarithms
and spherical trigonometry, may have evolved a personal system of calculation before Richard Norwood published his method to the world, for Peter Apian had shown one method of calculating the great circle bearing and distance between places a hundred years before, but it was very laborious.¹ It was of course known to Dr. Dee and evidently embodied in the navigational manuscript of 1575 he had hoped to have printed. However, until the introduction of logarithms great circle navigation (except by the globe) involved calculations too laborious for practical navigators. It seems therefore that Norwood deserves the credit for making great circle navigation a practical proposition (in so far as wind and sea permitted) by first publishing the formulae involved and their use in logarithmical navigation. Norwood was undoubtedly a brilliant teacher. While capable of original ideas and possessing the powers of penetrating to the heart of a problem, and of pursuing its solution tenaciously in the face of physical as well as mental difficulties, he had a great gift of lucid exposition. He now explained that, whereas in the preceding problems of plane and Mercator’s sailing he had used meridians, parallels, and rhumbs, in the succeeding problems of great circle sailing which he was about to describe, he did not use rhumbs because they were ‘helispherical lines’, nor parallels because they were not great circles; instead, he explained, because the sides of every spherical triangle must be arcs of great circles he used the arcs of meridians, of the equinoctial, and of ‘other great circles drawn or imagined to be drawn, from one place to another’. He proceeded from the explanation of the simple cases of places in the same meridian, or on the same parallel of latitude, to the more complex one of two places in different latitudes and longitudes, demanding to know the shortest distance along the arc of the great circle joining them and ‘the direct position’ of one from the other. As formerly he took the Bermudas in latitude 32° 25’ N and 70° 00’ W of the Lizard, which he placed in latitude 50° 00’ N. The problem was to resolve the spherical triangle ADE, where A = the North Pole, D, the Lizard, and E the Bermudas.² The underlying principles were that the arcs of the meridians of the two places intercepted between them and the nearest pole were two sides of the triangle; that the arc of the great circle intercepted between the two places was the third; that the angles contained between that arc and the meridians of either place were the angles of position, and that the angle contained between the meridians of the two places was their difference of longitude. He drew the triangle (with A, the North Pole, rather confusingly at the bottom) to show that the great circle distance was the length of the arc DE, that the direct position of the Lizard from the Bermudas was the angle AED, and of the Bermudas from the Lizard was the angle ADE. He then gave the formulae for solving the triangle, and how to resolve the problem using logarithms. The great circle distance he arrived at was 53° 24’, or 3204’ (1068 leagues), and the direct position of the Lizard from the Bermudas he found to be

¹ See Appendix 8.  
² See Fig. 42.
NE 3° 47' E, that is, N 48° 47' E. Having found these answers, the next thing to do, Norwood explained, was to find through what latitudes and longitudes the arc of the great circle passed. He actually calculated how far a ship should sail from the Bermudas towards the Lizard before altering course 1°. However, in practice such accuracy, as he pointed out, was (and is) unnecessary. It is quite sufficient for a ship to sail near the great circle, and therefore all that is necessary is to calculate by what latitudes and longitudes the arc of the great circle passes for every fifth or tenth degree of longitude (or of latitude if the d. lat. be greater than the d. long.). Norwood illustrated the point by drawing a diagram, for long included in every subsequent navigation manual, of the triangle ADE, and he now made the pole ‘D’, the Bermudas ‘A’, and the Lizard ‘E’, broken down into seven component triangles ADI, ADO, ADU, etc., in each of which the angle at the pole was 10°, (one-seventh of the difference of longitude, 70°). After calculating and tabulating the solutions of these several triangles, the navigator could prick the results upon a chart or upon a blank Mercator’s chart, and join the various points up with straight lines. The result upon a Mercator’s chart is ‘a curve on a blanke’, as Norwood expressed it, and for reasons already given.¹

Norwood tabulated the result of calculating the points through which the great circle between the Bermudas and the Lizard passes at 5° intervals of longitude, as below, ‘A’ being the Bermudas:

<table>
<thead>
<tr>
<th>Longitude</th>
<th>Latitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>from A.</td>
<td></td>
</tr>
<tr>
<td>00 00</td>
<td>32 25</td>
</tr>
<tr>
<td>05</td>
<td>35 52</td>
</tr>
<tr>
<td>10</td>
<td>38 51</td>
</tr>
<tr>
<td>15</td>
<td>41 24</td>
</tr>
<tr>
<td>20</td>
<td>43 34</td>
</tr>
<tr>
<td>25</td>
<td>45 24</td>
</tr>
<tr>
<td>30</td>
<td>46 54</td>
</tr>
<tr>
<td>35</td>
<td>48 07</td>
</tr>
<tr>
<td>40</td>
<td>49 04</td>
</tr>
<tr>
<td>45</td>
<td>49 47</td>
</tr>
<tr>
<td>50</td>
<td>50 15</td>
</tr>
<tr>
<td>55</td>
<td>50 31</td>
</tr>
<tr>
<td>60</td>
<td>50 33</td>
</tr>
<tr>
<td>65</td>
<td>50 23</td>
</tr>
<tr>
<td>70</td>
<td>50 00</td>
</tr>
</tbody>
</table>

Having been a practical navigator, he was peculiarly well qualified to show the manner in which a competent navigator made use of such information. He therefore explained that such a navigator first measured off

¹ See Fig. 43.
on his chart the initial course angle and, on leaving the Bermudas, set course NE ½ pt. E [N 51° E]. He chose this course because it was the nearest to ‘N.E. 3° 47' E' [N 48½° E] which the helmsman could hold, it being, in his personal experience, impractical to attempt to steer within ¼ point accuracy, as the helmsman’s ‘Card’ (the earliest mention in print of this term for the compass fly) was usually only divided into points. This course having been held for 600 miles, the navigator found himself in latitude 38° 45' N and longitude 9° 30' E of the Bermudas. He therefore altered course to N.E. by E. [N 56½° E] and held it for 300 miles when, finding himself in latitude 41° 32' N and longitude 14° 56' E of the Bermudas, he altered course to ENE ½ N [N 61½° E]. Having sailed 495 miles along this course and finding himself in latitude 45° 25' N and longitude 24° 28' E of the Bermudas, he altered course to E.N.E. [N 67½° E], following it for 390 miles. Being then in latitude 47° 54' N and longitude 33° 42' E of the Bermudas, he altered course to ENE ½ E [N 73½° E], which course he followed for 264 miles until he was in latitude 49° 11' N and was 40° 05' E of the Bermudas. He then steered E by N [78½° E]. This course, after being followed for 210 miles, brought him into latitude 49° 52' N and longitude 45° 22' E of the Bermudas. On reaching this latitude, or thereabouts, although by his reckoning, corrected by observations, he was still some 950 miles short of the Lizard, the navigator no longer followed the great circle, which would take him into a higher latitude—to 50° 33' N—before bringing him back to the latitude of the Lizard, but, in order that he might make his landfall more certainly, he ran his eastering down this parallel. He did this the more particularly, Norwood explained, because the reckonings of outward and homeward voyages made to the Bermudas and West Indies disagreed so greatly that it was the safest course to follow to ensure making the desired landfall. He cited position errors of ‘200 leagues’ and more, which he correctly attributed to the still general use of the plane chart for Atlantic voyages, coupled with the effects of currents, and of the practice of making the outward course a southerly one to as far south as latitude 30° N in order ‘to get a wind’ on which to run to the westward. While these outward courses resulted in a track far longer than the great circle distance, those of the return voyage, which took the navigator in search of the westerly winds up to the Newfoundland Banks, meant that the return track approximated closely to the great circle and was consequently much shorter than the outward one.

By the time Richard Norwood published The Seamans Practice in 1637 he had come to the conclusion, it will be recalled, that the length of a nautical mile was 6120 feet and not 5000 feet as generally accepted. He therefore pointed out in that work that if the great circle distance between the Lizard and the Bermudas, using a mile of 5000 feet, were ‘3299 miles, as some charts make it’, then using a mile of 6120 feet ‘their distance will be little more than 2695 miles; and consequently, the difference of Longitude little more than 55½ degrees’ (in fact the distance is 2812 miles and their
difference of longitude 60°). While this shows as well as anything the immense improvement in navigational accuracy resulting from a more accurate estimate of the length of a mile, the fact is mentioned because Norwood included in The Seamans Practice what he reckoned to be the typical track of a ship sailing from the Bermudas to the Lizard. He did this to illustrate ‘A formal and exact way of setting down and perfecting a Sea-reckoning’. It might be supposed that we are going beyond our period to refer to it here. But this is not so. Norwood makes it perfectly clear that he is merely reprinting what he himself had practised ‘many years since’, and had since been teaching to his students of navigation. Indeed he claimed that the traverse table which he included, and the use of which he fully explained, he had also ‘made many years since’. He added ‘that he had had it of no man’, but ‘that if any man claimed the first making and use of such an one, he might have it’. Perhaps he was the originator. This much at least is sure, he gave the formula used in its construction, and also a short table for finding departure and difference of latitude for courses to the nearest half-point and distances between 1 and 10 miles. He also included a large ‘Table For the Difference of Latitude, and Departure from the Meridian’ to ‘every single Degree’ and for distances of up to 100 miles. Although the columns were not titled Norwood explained in the beginning that for every course angle there were three columns; in

**TABLE 28**

<table>
<thead>
<tr>
<th></th>
<th>½ poin.</th>
<th>7½ poin.</th>
<th>1 poin.</th>
<th>etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>M.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5.37½</td>
<td>84.22½</td>
<td>11.15</td>
<td>etc.</td>
</tr>
<tr>
<td>2</td>
<td>995</td>
<td>98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>etc.</td>
<td>etc.</td>
<td>etc.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 29**

The traverse table for every degree ran typically as follows:

<table>
<thead>
<tr>
<th>M</th>
<th>30d</th>
<th>60d</th>
<th>M</th>
<th>30d</th>
<th>60d</th>
<th>Min.</th>
<th>30d</th>
<th>60d</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9</td>
<td>5</td>
<td>35</td>
<td>303</td>
<td>175</td>
<td>69</td>
<td>598</td>
<td>345</td>
</tr>
<tr>
<td>2</td>
<td>17</td>
<td>10</td>
<td>36</td>
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<td>320</td>
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<td>71</td>
<td>615</td>
<td>355</td>
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<tr>
<td>34</td>
<td>294</td>
<td>170</td>
<td>68</td>
<td>589</td>
<td>340</td>
<td>300</td>
<td>2598</td>
<td>1500</td>
</tr>
</tbody>
</table>
the first was given the distance run on each particular course; in the second
the resultant change of latitude; in the third the resultant distance sailed
east or west.

It showed, for example, that on sailing 70 miles upon a course 30°
from the meridian, say N 30° E, the ship moved 60·6 miles north and 35
miles east, in other words that its d. lat. was 60·6 N, and departure 35° E;
also that on following for 70° a course 60° from the meridian the resultant
difference of latitude was 35° and the departure 60·6.

The particular importance of Norwood’s traverse tables is that he accom-
panied them with full and explicit instructions for their use enabling a
navigator to plot his position regularly on both a plane and a Mercator’s
sea-chart, throughout a long voyage. Again, he chose the homeward voyage
from the Bermudas, the voyage he himself had made many years before,
though he made up the reckonings, because he had lost his original ones
long since. He also included a section of a blank Mercator’s chart with the
rhumb line and great circle tracks pricked upon it. He carefully explained
not only how to use the traverse tables in order to compute the difference
of latitude and the departure but also how to calculate the latitude and
longitude using logarithms and meridional parts, and the middle latitude
formula. The latter method he considered, incidentally, the ‘most apt
and agreeable of all others that he had seen or thought upon to all sorts of
Charts or Maps, and to the Globe itself; and to all the kinds or ways of
Sailing’. He was careful to stress the importance of observing the variation
—half an hour’s work daily, or once in two or three days, abundantly
recompensed—and of correcting the compass course with the known vari-
tion, in order to obtain the true course before commencing the calculations.
To assist in the latter operation he included a table of angles and points
(Table 30), and an instrument for helping to resolve which way to apply the
variation correction. It consisted of two roundles, the lower and larger one
divided into quadrants and each quadrant into 90° numbered from the
north and south points towards the east and west, the uppermost and
rotatable one divided ‘as the Card of the Compasse into XXXII Points’,
and with half and quarter points. The rules and examples he gave of how
to apply variation clearly showed how his table and discs simplified finding
the true course, hitherto always something of a conundrum.

Finally, to use Norwood’s own words, ‘Although the time be already
expired which I assigned for this Work, and mine own more urgent occa-
sions call me away; yet seeing it is necessary in Navigation to take notice of
Currents and to make competent allowance for them’, we must mention
that Norwood devoted a chapter to various problems of currents that he
had sometimes thought upon. We must do so the more particularly as he
was the first man to handle the subject. He thus resolved the last of the
navigator’s outstanding problems, and indeed his explanations of relative
velocity could not be bettered. While he explained how to calculate the

1 See Fig. 43 p. 484.

35—A.O.N.
effect of a current on a ship’s track, and thus to calculate the velocity of a current, Norwood did not go into the question of the measurement of currents. We have seen that to find the velocity of currents the East Indians used a pinnace, log-line, and half-minute glass, the log-line being veered over the pinnace’s stern and timed while the pinnace was rowed to windward to counteract the wind’s effect. This was not a very satisfactory method, and probably by 1631 the method had been evolved that was popular in the latter half of the century. This was to attach a ship’s kettle—a big iron pot—to a long line and lower it over the pinnace’s bow to a depth of fifty to a hundred fathoms so that it acted as a sea anchor in the depths of the ocean where the effects of the surface currents were no longer felt. The log-line was then veered astern and timed as before, while the direction of its drift was checked by the boat’s compass in order to find in what direction the current was flowing.

**TABLE 30**

**A Table of the Angles of Every Point and Half Point of the Compasse with the Meridian**

<table>
<thead>
<tr>
<th></th>
<th>North</th>
<th>South</th>
<th>D.</th>
<th>M.</th>
<th>North</th>
<th>South</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N. by E.</td>
<td>S. by W.</td>
<td>05</td>
<td>37</td>
<td>N. by W.</td>
<td>S. by E.</td>
</tr>
<tr>
<td>1/2</td>
<td>N.N.E.</td>
<td>S.S.W.</td>
<td>16</td>
<td>52</td>
<td>N.N.W.</td>
<td>S.S.E.</td>
</tr>
<tr>
<td>2</td>
<td>N.E. by N.</td>
<td>S. by W.</td>
<td>28</td>
<td>07</td>
<td>N.W. by N.</td>
<td>S.E. by E.</td>
</tr>
<tr>
<td>3/4</td>
<td>N.E.</td>
<td>S.W.</td>
<td>39</td>
<td>22</td>
<td>N.W.</td>
<td>S.E.</td>
</tr>
<tr>
<td>4/5</td>
<td>N.E. by E.</td>
<td>S.W. by W.</td>
<td>50</td>
<td>37</td>
<td>N.W. by W.</td>
<td>S.E. by E.</td>
</tr>
<tr>
<td>5/6</td>
<td>E.N.E.</td>
<td>W.S.W.</td>
<td>61</td>
<td>52</td>
<td>W.N.W.</td>
<td>E.S.E.</td>
</tr>
<tr>
<td>6/7</td>
<td>E. by N.</td>
<td>W. by S.</td>
<td>73</td>
<td>07</td>
<td>W. by N.</td>
<td>E. by S.</td>
</tr>
<tr>
<td>7/8</td>
<td>East</td>
<td>West</td>
<td>84</td>
<td>22</td>
<td>West</td>
<td>East</td>
</tr>
</tbody>
</table>

Adde East variation Subtract West
Adde West variation Subtract East
All the points that Norwood had discussed and explained he synthesized in his *Journal of our Voyage intended by Gods assistance from S.I. in the latitude of 32 deg. 25 mins. to the Coast of England, etc.*\(^1\) Such a journal, he advised, should be written in a folio book, with two leaves to a sheet of paper, the left-hand page being kept blank for entries concerning winds, alterations of course, allowances for leeway, hourly reading of the log ('how many knots or Miles in each hour'), the latitude found 'by observation of the Meridian-altitude of the Stars', and any other points of importance; the right-hand page he recommended should be ruled throughout the book into twelve columns: (1) the 'day'; (2) 'the moneth' (at the head of the column) beneath the month the 'Latitudes' found by observation of the sun's 'Meridian Altitudes'; (3) the course (the *Lee-wardway*, if there be any leeing allowed); (4) the 'Variation of the Needle'; (5) true *Course* (the course (3) corrected for variation); (6) 'distance in miles run upon the Rumb'; (7), (8), (9), and (10) 'the Northing or Southing, Easting or Westing' found by the traverse table; (11) 'your Latitudes' by dead reckoning; (12) the *Longitude*, either from the point of departure or 'from place to place'.

His example is set out in the Tables on pages 492-493. It will be noticed that he shows how (using the traverse table) he corrects his dead reckoning position for longitude as well as latitude when he gets good observations on 24th February, and again on 5th March; and how, being on an easterly course, he corrects only for latitude on 27th February; how on 8th March he allows for the estimated current—a wise precaution when approaching the Soundings; and how on the 10th he records his landfall (the distance run has been from noon to noon, noon being the time at which he calculated the ship's position).

Such a journal, contrasted with Sir Humphrey Willoughby's of the 1550s, or even with Captain John Davis's of the 1580s, makes it clear that the English navigator of the 1620s who learnt his craft from Richard Norwood and kindred teachers of navigation, now practised the science as well as the art of navigation. The appointment by the Navy Board, about the time of Captain John Smith's death, of a mathematical teacher to the Royal Dockyard at Chatham as 'Reader of Navigation to the Mariners' in order to render them the more serviceable to the King and country, marked official recognition of the change and of its significance.\(^2\) The appearance in 1631 of an illustrated pamphlet on a 'wether glasse' showed that even the origin and vagaries of those stormy winds which the seaman used to drive his frail vessel across the oceans were to be probed to his advantage.\(^3\)

From small beginnings in the 1550s great things had come to pass. 'That great fish pond' had been mastered for commerce, colonization, and war.\(^4\)

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1. *S.I. stands for Somers Is., the Bermudas.*
2. *See Appendix 23.*
3. *Table. A Table Plainly Teaching Ye making and Vse of a wether glas.*
4. *Illustrated in Taylor, E. G. R., *Late Tudor and Early Stuart Geography* (1934).*
The Journal of our Voyage intended by Gods assistance from S.I. in the latitude of 32 deg. 25 min. to the Coast of England, &c.

<table>
<thead>
<tr>
<th>da.</th>
<th>Lat. by observation</th>
<th>course.</th>
<th>Variation</th>
<th>Deg. from the Mer.</th>
<th>di. in miles</th>
<th>North</th>
<th>South</th>
<th>East</th>
<th>Lat. by dead R</th>
<th>Longitude</th>
</tr>
</thead>
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<td>ne 48d</td>
<td>100</td>
<td>1191</td>
<td>1322</td>
<td>34.24</td>
<td>02.38</td>
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<tr>
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<td>100</td>
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<td>679</td>
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<td>ne 54d</td>
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<td>di. in miles</td>
<td>Nor'-th</td>
<td>South</td>
<td>East</td>
<td>Lat. by deadR</td>
<td>Longitude</td>
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<td>7</td>
<td>so by cast</td>
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<td>6 de. East</td>
<td>se 89 1/4 d</td>
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<td>700</td>
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<tr>
<td>10</td>
<td>east ¼ po. n</td>
<td>6 de. East</td>
<td>se 89 1/4 d</td>
<td>52</td>
<td>41</td>
<td>520</td>
<td>49.54</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>March</td>
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<td></td>
<td>Summe is</td>
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<td>49.54</td>
<td>54.53</td>
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<td></td>
<td>Here the Lizard</td>
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<td></td>
<td>bears N by E</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
Chapter Seven

CONCLUSION

'. . . that sum memorie myght thereof remayne to our posteritie if eyther iniquitie of tyme consumyngge all things, or ignoraunce crepyngge in by bar-
barousnesse and contempte of knowledge, shulde hereafter bury in oblivion so woorthy attemptes, so much the greater ye to bee esteemed as before neuer enterprysed by Englysshemen . . .'

Richard Eden, 'The Description of the two Viages into Guinea', from The Decades of the New Worlde, 1555.

UNTIL the middle of the sixteenth century the English merchantman
was a small ship seldom exceeding two or three score tons. Her
master was a coaster or channeller: he seldom lost sight of land
for more than a few hours, or at most, as on the Scandinavian or Peninsular
trades, a few days. In the early sixteenth century, as a member of one or
other of the three Trinity House fellowships, he had learned the art of
pilotage since youth by following the precepts and practice of the masters
under whom he had served. Sooner or later he had himself become a
master, either by acquiring a ship and hiring her out, or by finding accep-
tance by a ship-owner as a competent master. The trades he served were
well established, and in consequence the routes along which he sailed sel-
dom varied. The shortness and frequency of the voyages made it possible
for him to rely largely on visual memory for fixing his ship's position, and
for avoiding the dangers of the sea. The colours, contours, scent and texture
of the sea-shores and of the sea-bcd were so impressed upon his memory
that, rather like a blind man in a familiar room, he could feel his way about
the coasts with confidence, here skirting a promontory, there avoiding a
hidden ledge of rock, now skilfully allowing for the treacherous in-draught
into some bay experienced when the flood—or maybe the ebb—stream
set around a certain point, now judging by the depth of water and nature,
smell, and colour of the bottom how far he was off shore.

However, to prompt his memory the master had a rutter, a book of sail-
ing directions either in manuscript, or as was becoming more common by
the middle of the century, in print with—if it were French or Dutch—
rough woodcuts of coastal elevations to amplify the bald statements of the
text. His written directions might contain a few roughly sketched harbour
plans, and even, by the mid-century, an outline chart of the coasts of north-
west Europe—these were not, however, essential.

In addition to his rutter he carried an almanac and tide-tables. These
amplified the tidal information contained in the rutter; and enabled him
to calculate the state of the tide on any given day wherever he might happen
to be.
CONCLUSION

His instrumental aids were as few and as simple: a compass, housed in a rectangular chest-like binnacle which could also contain a candle lantern for illuminating the compass-fly at night, to give him a sense of direction when out of sight of land, and, used as a clock-dial, a sense of time when finding the state of the tide; a lead and line armed with tallow and flannel for sounding the depth of the sea and the nature of the bottom; and a dial or sandglass for measuring the passage of time for estimating his progress and for equalizing watch-keeping duties. These simple aids sufficed him, for his was essentially the art of pilotage.

When, however, in the middle of the century, under the stress of economic necessity, the English decided to take part in the oceanic trade which had developed in the last half-century between Europe, Africa, Asia, and the New World, they found that their knowledge of pilotage contributed little towards fixing a vessel’s position in the ocean, and nothing towards finding it off unfamiliar shores in tropic or in arctic seas. Nor were their ships suitable for ocean passages on a commercial scale. In their need the English turned to Spain for expert tuition in the art of navigation and in the economics of oceanic trading. At first by bribery, and then by virtue of the fact that the King of Spain was the consort of their Queen, they learned all that the Spaniards could teach them of the art of navigation. While French, Italian, and Portuguese pilots also assisted them, their mainstay was the knowledge of the Spaniards, with their highly organized system of navigational instruction and examination, their remarkable hydrographic office, and its products. It was the Spanish system, as interpreted for them by Sebastian Cabot in the 1550s, and by Stephen Borough in the opening years of Elizabeth’s reign, and as modified by the Privy Council to suit the English temperament and institutions, that lay behind the chartered trading companies, of which the Muscovy Company was the first to foster navigation, and behind the legislation of the 1560s, which ensured a sufficiency of seamen and, through Trinity House, of licensed masters, to serve the country either in peace or war. It was the Spanish system which provided the English with their first manual of navigation, which was also their standard one throughout Elizabeth’s long reign, and indeed up to the time of the Civil War in the seventeenth century. It was the Spanish system which inspired the lectureships on navigation that were eventually established.

But the English did not content themselves with copying and adapting Spanish navigational teaching and techniques; they immediately set about improving them. Text-books, instruments, charts, and the ships themselves, were rapidly improved and increased in numbers. The more extensive knowledge that the longer and more varied voyages made necessary was stored up in a variety of publications—rutters, waggoners, and charts—unknown to earlier generations. Lack of local knowledge of many parts of the world was thus made good by the printed word, the woodcut coastal elevation, and the engraving in chart or harbour-plan form. Detailed directions, presented systematically, amplified the pictorial representation
of coasts and the formal symbolism introduced into charts. At the same time, instruments were invented and developed which placed in the master's hands means of determining his position in the ocean sea with an accuracy far greater than ever before attainable. The sea compass was improved in sensitivity and reliability; the azimuth compass was developed for the accurate determination of magnetic variation; the dip-needle was introduced in an endeavour to exploit the possibilities of magnetic dip. The astrolabe and cross-staff were improved, then largely superseded by the far more accurate quadrant developed from them in order further to improve the accuracy of celestial observations; the log, log and line, and half-minute glass were developed for measuring the ship's speed accurately so that the distance sailed could be calculated more exactly; the log-book was introduced, then expanded into the systematic and comprehensive recording of navigational data; an accurate chart projection was developed upon which a ship's position could be plotted confidently; the mathematical processes were formulated by means of which a ship's position at sea could be found by calculation; and the telescope was adopted to enable the master to identify his landfall with greater speed, precision, and confidence.

In the first quarter of the seventeenth century the mathematical calculations which had been such a hindrance to rapid and accurate position-finding were reduced by the use of logarithms to the simple processes of addition and subtraction, while instruments were developed which eliminated even these elementary mental processes. The result was that the Stuart ship-master with a smattering of mathematics could ply in waters strange to him, and cross the broad oceans with a degree of confidence unknown to even the greatest of the Elizabethan navigators.

Many had contributed to this advance: navigators like the two already mentioned, the venerable Cabot and Stephen Borough, Stephen's brother William, John Davis, Richard Polter, and Richard Norwood; and navigators like Hawkins and Drake, who, by demonstrating the rewards of mastery of their art, inspired Englishmen to emulate them; artificers like Bourne and Norman; craftsmen like Cole, Ryther, and Allen; publicists like Eden, Billingsley, the Hakluys, Blundeville, and Purchas; scientists like Cumingham, Dr. Dee, Dr. Gilbert, Barlow, and Ridley; mathematicians like Robert Recorde, the Digges, Hues, Hariot, and Wright, Hardson, Napier, Wingate, and Asphey, Oughtred, and Delamain; publishers like Tapp; statesmen, noblemen, courtiers, and officials like Burghley, Walsingham, Cumberland, Gilbert, Raleigh, and Ashley; teachers like Hood; academic professors like Briggs and Gunter.

But the fundamental contribution had been made by the gentlemen and merchant venturers themselves, for they had sent the seaman forth in their ships to trade. It was they, moreover, who had chosen Sebastian Cabot to initiate Englishmen into the art and science of oceanic enterprise: it was they who had supported his schemes, upheld his ordinances and put his precepts into practice; it was they who had tapped the sources of his profound
knowledge—the Casa de Contratación at Seville—and had encouraged the publication in English of the finest manual of navigation of the day, Cortes's Arte de Navegar. Succeeding generations had financed the dissemination of the art of navigation in public lectures, had encouraged and paid for both theoretical research and practical development that transformed it into a science. Such were Sanderson, and Raleigh, Thomas Smith and his son, Wolstenholme, and Dudley Digges, to name but a few. Yet when all is said and done the name of one stands out from all the rest, that of Sir Thomas Gresham. While he lived it was his extraordinary financial acumen, consolidated in the Royal Exchange, that made possible so much of his fellow-citizens' wealth and enterprise. After his death his profound grasp of the practical fundamentals of oceanic commerce was embodied for the benefit of his successors in the form of Gresham College. It was through the research, teaching, and example of his professors of geometry and astronomy that many of the greatest scientific advances of the seventeenth century were made, not merely in navigation, but as the century advanced, stemming from them, in all branches of scientific investigation and invention. But up to 1631 their principal contributions were made primarily with the object of developing and popularizing mathematical navigation to the end that the merchants' ships should sail upon the seas as safely as possible. How successful they were may be gauged by the fact that Martin Cortes had claimed, with some truth, that in his day a man needed a special aptitude, to be inspired by God, in order to be a successful navigator, while by 1631 it was appreciated that what was most necessary was for a man to have a good grasp of the principles of the sciences of geometry, trigonometry, and astronomy, and the ability to add, subtract, multiply, and divide simple figures accurately. In fact, by then navigation had developed far towards becoming a mathematical science. This is reflected in the manuals of navigation compiled after this date. All treat their subject from the mathematical aspect.

This does not mean to say that by 1631 all masters were mathematicians and all practised scientific navigation. Indeed many were poor mathematicians and even worse navigators. They had no standard qualifying examination to pass under the auspices of Trinity House, and in consequence many inherited and transmitted a deep distrust of 'cyphers'. But the successful navigators were far more numerous than is commonly averred; the growth of English commerce and colonization in the early seventeenth century and the success of naval operations in the mid-century wars with the Dutch alike vouch for this.

Just as today, so then the coaster practised a simpler form of navigation than the deep-sea trader. Much of the trade was still coastal. It follows that much of the navigation was coastal, and much of it pilotage. But to argue from this, as is often done, that the navigational knowledge of the period was rudimentary, and the practice unskilful, is to deny the evidence of the published books on the subject, of the exquisite accuracy of the
surviving instruments, and, above all, the meticulous entries of many a master mariner’s journal.

So much had navigation been reduced to a science that, as Barlow had once averred, it was now possible for a man to become a competent navigator in a matter of months merely by studying books on the subject, and being instructed in the handling of the instruments. No longer was it necessary for a navigator to be bred up to the sea from youth. Moreover, thanks to Captain John Smith, he could even learn on shore the idioms of the sea. These facts gave rise in the Royal Navy a few decades later to the bitter feud between ‘tarpaulin’ and ‘gentlemen’ captains. We see it fore-shadowed in the personalities and practice of two captains who made voyages in 1631 to discover the North-West Passage—Captain Luke Foxe and Captain Thomas James. Both published their journals and both published their charts.¹ Foxe, the son of a master mariner of Hull, had been sea-bred from boyhood, and had sailed often in the home, Mediterranean, and Baltic seas, ‘along the coast and crossing the Sea’; he was a friend—and probably pupil—of John Tapp, and of a globe-maker, Thomas Sterne, from both of whom he learned much. In fact Foxe was essentially a man of the sea, acquainted with storms and inured to shipboard hardships. James was a complete contrast. He was of the gentry. He had been highly educated; he was a barrister of the Inner Temple, a student of mathematics, an amateur seaman. Foxe was furnished with money to purchase books ‘especially for those of study’. He scorned their purchase on the grounds that ‘there would be no leisure’ to study them, and that if he lacked the knowledge of what to do in emergency it would be too late ‘(like the Holland Skipper to runne to his Chest to looke upon his Waggoner boke)’. He provided himself with three instruments for observations, a back-[?] staff, seaman’s ring, and forward staff; and used a log-line, half-minute glass, and a log-board consistently for estimating his distance run, and for finding the tidal stream. James carried a chest full of the best and choicest ‘Mathematicall bookees’ that could be got for the money, Hakluyt’s and Purchas’s voyages, and other books of travel. He had fifteen instruments of observation—cross-staves, semi-circles, and back-staves made especially for him, and used a log-line, divided according to Gunter’s direction, with specially made glasses for timing it. He took also two watches, and two pairs of globes. The chart he drew was on Mercator’s projection. The chart Foxe drew was on a circumpolar one. They voyaged independently—being rivals. When they met, James’s discourse was scientific—of observations, calculations, and the like, whereby Foxe declared that he perceived him ‘to bee a practitioner in the Mathematicke’ and ‘no Seaman’. Foxe made no special observations on his voyage. James twice observed for the longitude. By prior arrangement an eclipse of the moon which he observed, Gellibrand at Gresham also observed, with the result that they determined the longitude of James’s position to within

¹ See Pls. LVII and LXXXVI and Appendix 25.
15', making it to have been 79° 30' W of Gresham College instead of the actual 79° 45' W. The other observation was in error by 45'. Thus despite Foxe's gibes James proved himself to be a most skilful navigator—his observations were not being bettered a hundred years later—and, by weathering some awe-inspiring storms, a competent seaman.

We conclude then that, by the time of Captain John Smith's death, and in the space of seventy years, the English from being ignorant of the art of navigation had, almost entirely through their own efforts, largely transformed it into a science. Only the solutions to the mechanical and optical problems of measuring time and altitude accurately still eluded them.
Appendix No. 1

Part of Robert Copland's Prologue to The Rutter of the Sea (1st edition, 1528), from the edition of 1550.

Robert Copland, translator of the rutter entitled The Rutter of the Sea. With the Hauens Rodes, Soundings, Kennings, Windes, Floods, and Ebbes daungers and coastes of diuers regions with the lawes of the Ile of Auleron, and ye iudgements of the Sea, which is in fact the earliest printed rutter in English (1st edition 1528), explains his attitude to navigation in the following words in his ‘prologue’.

I conieect that in the feat and course of Nauigation or sailing a man may presume & take vpon him by his speculation to conduct a vessel as a blinde man in a desolat wildernes doth walk til he be lost. But ye sure, wise & enured maister mariner, or lodesmā, not ignorantly trusting his own sesual reason diligently for the safegard of his doings and assurance of his practice considereth yf his vessel bee sure, and decked at all pointes, and with great solicitude seeketh, enquireth & geteth such necessary instruments as behoueth to the industrie of his practise, as the cardes, compas, rutter / dyall and other / which by speculate practise sheweth the plat, that is to say the costes, hauens, roodes, soûdings, daungers, floodes, ebbes, windes, kēnings / courses and passages fro land, to land. and to be the more sure in the conducting of his voyage, he busilie purveith for all taclellings & store therto behoofful as cables / ropes, ankers, mastes, sayles, ores, artillery, vitaille / fresh water fewel and other necessaries.

All these discreetly pondered by a sad ingenious and cyrcumspect Mariner of the Citie of London beeing in the towne of Bourdewes bought a pretty booke Imprinted in the frenche language called the Rutter of the Sea, containing many proper feates of his science. And considering that it was expedient and necessary for all English men of his facultie to haue it in their owne language to the erudition, and safegarde of our marchantes as other haunting the sea, not knowinge the contents theroff. The which booke he instantiated me to translate into english which ouer seen, me thought very difficulte to me, not knowing the terms of maryners, and names of the costes and hauens, for I never came on the sea, nor by no coste theroff. But folowing my copye by the aduise, and ouer sight of certaine cunning men of that science which bolded, and informed me in many doutes, I did vndertake in dooing my diligēce, as a blīde horse in a mil turning the quern ignorantly, saue by conducting of the Milner that setteth him on woorke.

Desiring al expert maisters to correct this and make other for the comon vtilitie and safeguard of these our native contrey men and goods flowing / in diuers regions in the which doing they shall not onely obtaine thankes, laude and be praied for in this world and also in the other but be highly rewarded of almightie God which is chief maister and lodesman of and to euery streme and coste. To whom be Gien laude and glory in the world of worlds. Amen.

The translator
Robert Copland

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Appendix No. 2

The Voyage of the Barbara to Brazil, 1540.


The material is drawn from the records of the High Court of Admiralty, formerly known as 'Examinations of Pirates'.

The vessel was the Barbara of London, her captain, John Phellyppes and her master Robert Browne. Besides a large English crew she carried 'xij Frenchmen and iij boonys'.

On the voyage out they seized a Biscayan, put her crew into a small caravel and a prize crew into the Biscayan. The master they chose for this was an Englishman, but they took 'one Frenchman for pilott'. The pilot of the Barbara was also a Frenchman, 'one Robert Nycoll of Depe'. In the Caribbean the Barbara's crew seized a Spanish ship whose crew they set on board the Barbara, now unseaworthy, 'savyng the pilotte, the master, and ij of their servauntes', for their own French pilots, their French barber (surgeon) and French trumpeter and all the rest of the Frenchmen had run by now and made off. On returning to England the Barbara's crew was arrested by the Mayor of Dartmouth on suspicion of piracy, and interrogated. The depositions make fascinating reading. The Emperor, Charles V, as King of Spain, was evidently very anxious to get hold of the charts stolen from the Spanish ship in the Indies, the Barbara of Seville.

John a Wood of Saynt Katherynes late masters mate of the Barbara of London . . . Beyng interrogated where became the pilotte's carde, the master's carde, the master's money, his whistle and other his stuffe and rayments, saithe that the captayne, John Phellippes, had the pilotte's carde, and one Rycherde Stone of Dartemowth had the master's chest and a little carde therein with an estrolaby, which was the pilotte's, a balestely, an instrumente belonging to the office of a pilotte for the nyght . . . Rycharde Stone deluyeryd this inquisite furthe of the master's cheste a carde of the master's whiche he bequethed hym in his testamente [the master died on reaching Dartmouth]. And that carde this inquisyite brought home withe hym . . . Grene [one of the merchants who died on the voyage] had a very excellent goodly carde for all the parteyes of England, Fraunce and Bryttagne, Spayne, and Portyngale, the Strayghtes of Malaga, unto Scio, all the quoaste of Barbaria, the quoaste of Gynny, through the Strayghtes of Magalyna, all the quoaste of Brasell, and Kennyballes, all thempiroours Indions, so alonel Newe founde lande, withe dyvers other straunge places. Which cardre William Hare of Berkynge [one of the quartermasters] bought of Gremell [Grene's executor] for ixs.

Further depositions give the details of the goods and tackleing of the Barbara and a testimonial by 'Petro Ryvero late master and Redrygo Allveris late pyllott' of the Barbara of Seville.

While this incident casts light upon the early activities of the English in the
Brazil trade it exemplifies clearly the dependence of the English mariners and masters upon French and Spanish navigators. The astrolabe, cross-staff and nocturnal of Robert Nycoll of Dieppe, his and the master's charts will not pass unnoticed. The magnificent portulan of the merchant Green was probably stolen from the Spanish ship and its loss was evidently a cause of deep concern to the Spanish authorities.
Appendix No. 3

MS. Pocket Tide-Tables of the middle and latter half of the sixteenth century.

See Pls. VII, VIII, XI, XXVI, and LII.

The early rutters listed in the body of the text the establishment of various ports and headlands, that is to say the time at which high-water occurred at those places on days of 'full and change', on the days of full moon and new moon.

They gave the time in terms of rhumbs of the wind. Davis explained this terminology as follows:

John Davis on the Compass Fly as a Clock dial.


How is the hower of the day knowne by the Compass?

It hath been an ancient custome among Mariners to deluide the Compasse into 24, equall partes or howers, by which they haue used to distinguish time, supposing an East Sunne, to be 6. of the clocke, a Southeast Sunne 9. of the clocke, and a South Sunne 12. of the clocke, etc. . . . But this accompt is very absurd, for with us in England (the Sunne having his greatest North declination,) it is somewhat past 7. of the clock, at an East Sunne, and at a Southeast Sunne, it is past 10. of the clock . . . therefore the distinctions of time may not well be given by the Compass, unless the Sunne be upon the Meridian, or that you be farre toward the North, in such places where the Sunnes Horizontal motion is very oblique, for there the hower may be giuen by the Compass without any greater error . . . if there bee good consideration of the variation of the needle . . .

The relationship between Rhumbs and Time was as follows:

Table of the Rhumbs of the Wind and the Hours and Minutes on the Compass Fly used as a Clock-Dial

<table>
<thead>
<tr>
<th>Rhumb</th>
<th>Hour</th>
<th>Rhumb</th>
<th>Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.</td>
<td>Midnight</td>
<td>N. by W.</td>
<td>11:15 p.m.</td>
</tr>
<tr>
<td>N. by E.</td>
<td>0.45 a.m.</td>
<td>N.W.</td>
<td>10:30 p.m.</td>
</tr>
<tr>
<td>N.N.E.</td>
<td>1.30 a.m.</td>
<td>N.W. by N.</td>
<td>9:45 p.m.</td>
</tr>
<tr>
<td>N.E. by N.</td>
<td>2.15 a.m.</td>
<td>N.W.</td>
<td>9:0 p.m.</td>
</tr>
<tr>
<td>N.E.</td>
<td>3.0 a.m.</td>
<td>N.W. by W.</td>
<td>8:15 p.m.</td>
</tr>
<tr>
<td>N.E. by E.</td>
<td>3.45 a.m.</td>
<td>W.N.W.</td>
<td>7:30 p.m.</td>
</tr>
<tr>
<td>E.N.E.</td>
<td>4.30 a.m.</td>
<td>W. by N.</td>
<td>6:45 p.m.</td>
</tr>
<tr>
<td>E. by N.</td>
<td>5.15 a.m.</td>
<td>W.</td>
<td>6:0 p.m.</td>
</tr>
<tr>
<td>E.</td>
<td>6.0 a.m.</td>
<td>E. by S.</td>
<td>5:15 p.m.</td>
</tr>
<tr>
<td>E. by S.</td>
<td>6.45 a.m.</td>
<td>W.S.W.</td>
<td>4:30 p.m.</td>
</tr>
<tr>
<td>E.S.E.</td>
<td>7.30 a.m.</td>
<td>S.W. by W.</td>
<td>3:45 p.m.</td>
</tr>
<tr>
<td>S.E. by E.</td>
<td>8.15 a.m.</td>
<td>S.W.</td>
<td>3:0 p.m.</td>
</tr>
<tr>
<td>S.E.</td>
<td>9.0 a.m.</td>
<td>S.W. by S.</td>
<td>2:15 p.m.</td>
</tr>
<tr>
<td>S.E. by S.</td>
<td>9.45 a.m.</td>
<td>S.S.W.</td>
<td>1:30 p.m.</td>
</tr>
<tr>
<td>S.S.E.</td>
<td>10.30 a.m.</td>
<td>S. by W.</td>
<td>12:45 p.m.</td>
</tr>
<tr>
<td>S. by E.</td>
<td>11.15 a.m.</td>
<td>Noon</td>
<td></td>
</tr>
</tbody>
</table>

Long experience had shown that the tides were related to the motions of the moon, and that according to the age of the moon, the tides occurred every day
later and later—48 minutes later each day. Thus to find the time of high-water—
full sea—on any given day it was necessary to know only the age of the moon
(this was found from an almanac) and the establishment of the port. John
Davis explained the method as follows:

*For the accompt of Tydes.*

When you desire to know the time of full Sea in any place at all such
seasons as occasion shall require, you must first learne what moone maketh
a full Sea in the same place, that is, vpon what point of the Compasse the
Moone is, when it is full Sea at the said place, you must also know what hower
is appropriated to that point of the Compasse . . . for vpon the change day it
will alwaies be full Sea in that place, at the same instant of time, by which
considerations you must thus proceed for the search of tides . . . knowing
how many daies olde the Moone is, . . . place the Moone upon that point
of the Compasse which maketh full Sea at the place desired, and then reckoning
from that point with the sunne according to the diurnal motion . . .
accompt so many points, and so many times 3. minutes as the Moone is daies
olde, . . . and there finding the Sun . . . consider what is the hower allowed
to that point . . . for that is the hower of full Sea . . .

In the latter half of the sixteenth century wooden and metal tide computers,
of the kind that John Davis called ‘an horizontall tyde Table’ became popular,
as they eliminated all calculation. Their forerunners were pocket manuscript tide-
tables, produced first in the 1540s and 1550s by Breton almanac makers who in
the first half of the sixteenth century produced almanacs for illiterate farmers
often using symbols in place of words and numerals.

I (Jean or Jacques or Yves) Trodec and G (Guillaume?) Brouscon were
Bretons of Conquet who adapted the idea of symbolical representations of events
to the use of illiterate seamen desirous of using tide-tables. One of Brouscon’s
almanacs is in the British Museum (C. 36. aa. 4).

His tide-tables are to be found at:
2. Chantilly, Musée Condé, xiv, D.15.
5. Greenwich, National Maritime Museum (belonging to Samuel Pepys).

Trodec’s tide-tables are to be found at:
1. Paris, Bibliothèque nationale, Ge. 77,14412.

John Marshall, who, in the latter part of Henry VIII’s reign and in that of
Edward VI’s, travelled to France, Flanders, Brittany, Ireland, and Spain, noting
as he went ‘suche things as be for all those that traveile on the Seas very expedy-
ent & necessarie’, copied in translation and presented to the Earl of Arundel
one of Brouscon’s tide-tables with a short explanation on the manner of using
them. (British Museum, Royal 17. A. II).

No. 1. of Pepysian Library, Magdalen College, Cambridge, is a small duo-
decimo pocket tide-table and almanac on vellum by G. Brouscon, of about
36—A.O.N.
1545. In the front fly it has written 'F. Drak', and it is considered that it may have belonged to Sir Francis Drake, whose signature in the 1580s, however, was always in the form of 'Fr. Drake'. Although in the course of his voyage of circumnavigation he described himself to the Spaniards as second to none in the art of navigation, Drake relied upon Portuguese and Spanish rutters, charts, and, when he could get them, pilots for his sailing directions in the Atlantic and Pacific. It is probable that he used Breton tide-tables in home waters, at least in the early years of his rise to fame, for they were the best, and most numerous. The Brousson tide-tables and almanac at Cambridge consist of twelve vellum pages of illuminated diagrams, charts, and tables, and of a large folding chart, 11 ¼ inches × 10 ½ inches, of the coasts of western Europe between the Strait of Gibraltar, the Firth of Forth, and Dantzig in the Baltic. On this chart (see manuscript, Pl. XXVI) ports and islands are named. National arms are shown on some of the countries. A meridian line with degrees of latitude marked on it from 34° N to 58° N is drawn west of Ireland. As the chart is French, these numerals and all names written in the sea are upside down, French charts being orientated at this time, like the ancient Roman maps, with the south uppermost. Three compass flies, one in Spain, one south of Ireland, and one in England, with their rhumbs prolonged, form the basis of the network of rhumbs covering the chart. A distance scale in typical Mediterranean style, but with no indication of the distances denoted, is included. Shoals and dangerous rocks are indicated by dots and crosses.

The body of the book contains four tidal charts, which come at the end, indicating the establishments of ports: one is of the Biscay ports; one of the French Channel ports; one of Irish ports; and one of English ports (see Pl. VII). Each chart has a compass fly, and each port is connected to the fly by a line joining it to the rhumb of its establishment.

Accompanying the tidal charts are eight circular diagrams, one for each rhumb. These diagrams enable the time of high- or of low-water at a port of known establishment to be computed when the age of the moon is known (see Pl. VIII).

Plate VIII reproduces the tide computer diagrams for ports with establishments of south-south-east (Susuest) and south (Sv), that is to say where, on days of full and change, high-water occurs at 10.30 and twelve o'clock respectively. It should be added that high-water, which occurs twice a day in most ports and havens, was assumed to occur at twelve-hour intervals, so that, although there are sixteen main rhumbs on a compass fly, it is necessary for tidal computation to have diagrams for eight only. In the British Museum copies of the tide-tables by Brousson and those by Marshall, arabic numerals are used to indicate days and hours, with a ‘dot’, ‘dash’, and ‘three’ to indicate quarter, half and three-quarters of an hour. In the Cambridge copy of the Brousson tide-tables it will be seen that symbols take the place of arabic numerals for the days—these are on the outer circle, and indicate the age of the moon. One to four are indicated by strokes (fingers); five by a circle with a tail (forefinger and thumb touching); six to eight by the five symbols and strokes as appropriate; nine by a stroke and a cross; ten by a cross; eleven by a cross and a stroke and so on, with appropriate combinations of the symbols to thirty ( + + + ).

The next circle, working inwards, contains symbols representing spring tides, neap tides, and the phases of the moon.

The next circle contains the time of high-water, the innermost one the time
of low-water for each day of the moon's age, according to the establishment of the port, the establishment or rhumb of the port being indicated by the rhumb of the central compass fly, which points to the bottom of the page. The same symbols are used for hours as for days except that noon is represented by a circle, and red or black dots and short dashes represent quarter, half and three-quarter hours. In the centre of each fly is a letter or letters spelling out the author's name. Thus the S.S.E. and S. diagrams contain the first two letters of Brousson's name, 'B' and 'R'.

Finding the time of high-water at a port or haven is quite simple. Having found the age of the moon on the desired day, suppose it to be three days old, look up the haven, say the Thames mouth, on the tidal establishment chart (Pl. VII). A line from Thames mouth leads to the south rhumb. High-water therefore occurs here on days of full and change when the moon bears south and north—at noon and midnight. Turn now to the tide computer diagram (Pl. VIII) for a south rhumb (Sv). When the moon is three days old it will be found that: (1) spring tides occur; (2) high-water is at 2.15; (3) low-water at 8.15 (the red 'dot' indicating 15 minutes has not reproduced well).

This method of using the tide-tables was explained ably by John Marshall.


Tables of the Tides vpon ye Coasts of England, Irland, Flanders, Fraunce and Spa[ync]. To the right honorable his singular good Lorde and Master The Erie of Arundell John Marshall wisshethe healthe with encrease of morhe honor.

Havinge byn dyverse and many yeres paste in the late regnies of the most noble princes our soveraignes Kinge Henrie the Eight & kyng Edward ye Sixte, a poore travayler in their services, not onlie within this Realme of Englond, but allso, abowte the Costes of Frawnce, Flawnders, bryttaine, Wales, Irelonde, & Spayne, at myne earnest desyre then mad, styll as I travayled to marke in ech place suche thinges as be for all those that travaile on the Seas very expedyente, & necessarie: whiche in deade I diligentlie dyd, takinge at other mens handes awsewel theire owne profes, as allso myne owne observatyons yeven so syns after my retourn at hawers of leasure I haue drawnen all suche into this one Little booke. whiche althoghwe I suppose not woorthie to come to your Lordeshippes handes, yet as symple as it ys, I supposed yt to stonde with my most bownden dewtye to presente the same, as to your Lorshippe a small token of good wyll, to me A swete frute of my sower Labors, where in are contayned aswell the tymes of full Seas as Lowe waters, springe and neapes for all tymes of the yere in the places above corrected as appers by the rewle followinge.

The Rewle to understeande this boke. First yf ye will knowe how yt floweth in any haven, ye must note firste whether yt floweth Est, or west, or any other waye, whiche ye shall fynde by ye settinge forthe of the Costes of cowntreyes in this book where the winde be devyded into 32. partes, from whence Lynes be drawne to every haven accordinglie as the havens lye, as for example, yf you will knowe howe yt floweth at the Thames mouthe, Looke yow upon the description of the havens of Englane, and there shall ye fynde, that there yse a Lyne drawen from the Sowthe to the Thames mouthe, so that ye maye preave that yt floweth the Sowthe. Then must yow fynde owte your pagine for the
Sowthe, wherin it sett forth in Circles one within Another, your Springeres, Neapes, Flowdes, & Lowe waters. Then after yow knowe by your allmynacke howe manye daies olde the moone ys, Loke for the same in the uppermoste of your circles for the Sowthe & there shall ye fynde yt/As yt it were the third daye, Loke in the next circle within your circle of the dayes of the moone, and there shall ye fynde nexte under yt the Circle of Springeres & Neapes, in which circle directely under the 3. daye ye shall finde to be the best springe tyde for that parte of ye mone And in the nexte Circle, which ys for flowdes, directelie under the sayed 3. daye ye shall fynde that yt shalbe full Sea At the Thames mowthe, a quarter of an hower after ii of the clocke before noone And in the next Circle, which is for Lowe waters, directelie under as before, that yt wilbe Lowe water, there thesame daye, a quarter of an hower after fyve\(^1\) of the clocke/In like manner, ye maye knowe howe it Ebbes & flowes in the other havens herin sett forthe.\(^2\)

The Pepysian tide-tables and almanac at Cambridge has clearly been rebound at some time with the various pages out of their correct order. The tide computer diagrams are in the front of the book and have inserted amongst them half a page of the almanac. They are followed by a circular diagram of the Rule of the North Star and the amount to Raise and Lay a Degree of Latitude, and by the first page of the almanac—for January (I), and February (F). (Pl. XI.)

The circular diagram of the Rule of the North Star shows the position of the guards on the circumference. In the centre is a compass. Enclosing this is the circle giving the angular distance of the Pole Star from the true pole. The maximum distance 31° shows that the table was correct for the middle of the fifteenth century. Between this circle and the circumferential one, containing the names of the principal rhumbs, are the distances to raise and lay a degree of latitude, the distances on the rhumbs between north and east being given in symbols, in all the other rhumbs in arabic numerals.

As bound at present the almanac, giving each month with its Dominical Letters and holy days, follows the last diagram for computing tides. Each month has at its head the initial letters of its name, and a symbol beside it indicating the length of daylight and another to show the chief activity of the month, such as a sickle for August, a flail for September, a cider cask for December. In the columns of the days of the month the most notable holy days are represented by figures or symbols, e.g. a key for 'Peter'. In the centre of the pocket-book, between the almanac for June and July, comes the table giving the twenty-eight-year cycle of the seven Dominical Letters, A, B, C, D, E, F, and G, and the movable feasts in order from the top, Septuagesima, Shrove Tuesday, Easter day, Rogation Sunday, Ascension Day, Pentecost, Trinity Sunday, and Corpus Christi. It was the rest of this table that was inserted between the circular tidal diagrams.

The four establishment charts are inserted in the monthly almanac between October and November. The last pages of the pocket-book consist of the calendar for November and December, and a blank half.

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\(^1\) Should read 'eight'. There has been an erasure in the MS. here, so possibly 'eight' was first written.

\(^2\) According to usual bibliographical practice contractions in manuscript have been extended (and indicated by the use of italics) but retained in printed materials.
Appendix No. 4

Sebastian Cabot's Ordinances of 1553 referring to navigation, and a summary of the crews of the three ships forming the expedition to the North-East.


*Cabot's 7th Ordinance*, 'for the direction of the intended voyage for Cathay', of 1553, reads:

7. Item, that the marchants, and other skilful persons in writing, shall daily write, describe, and put in memorie the Navigation of every day and night, with the points, and observation of the lands, tides, elements, altitude of the sunne, course of the moon and starres, and the same so noted by the order of the Master and pilot of every ship to be put in writing, the capitaine generall assembling the masters together once every weeke (if winde and weather shall serve) to conferre all the observations, and notes of the said ships, to the intent it may appeare wherein the notes do agree, and wherein they dissent, and upon good debate, deliberation, and conclusion determined, to put the same into a common leger to remain of record to the company: the like order to be kept in proportioning of the Cardes, Astrolabes, and other instruments prepared for the voyage, at the charge of the companie.

*Cabot's 9th Ordinance* directed:

the steward and cooke of every ship, and their associats, to give and render to the capitaine and other head officers of their shippe weekly (or oftner) if it shall seeme requisite, a just or plaine and perfect accomplish of expenses of the victuals, as well flesh, fish, bisket, meate, or bread, as also of beere, wine, oyle, or vinegar, and all other kinde of victuallling under their charge, and they, and every of them so to order and dispense the same, that no waste or unprofitable exesse be made otherwise then reason and necessitie shall command.

*Cabot's 12th Ordinance* read:

12. Item, that no blaspheming of God, or detestable swearing be used in any ship, nor communication of ribaldrie, filthy tales, or ungodly talke to be suffred in the company of any ship, neither dicing, carding, tabling, nor other divelish games to be frequented, whereby ensueth not onely povertie to the players, but also strife, variance, brauling, fighting, and oftentimes murther to the utter destruction of the parties . . .

*Cabot's 13th Ordinance* appointed:

that morning and evening prayer, with other common services appointed by the kings Majestie, and lawes of this Realme to be read and saide in every ship daily by the minister in the Admirall, and the marchant or some other person learned in other ships, and the Bible or paraphrases to be read devoutly and Christianly to Gods honour, and for his grace to be obtained, and had by humble and heartie praiies of the Navigants accordingly.

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The 14th directed:

that every officer is to be charged by Inventorie with the particulars of his charge and to render a perfect accompt of the diffrajing of the same together with modest & temperate dispensing of powder, shot, and use of all kinde of artillery, which is not to be misused, but diligently to be preserved for the necessary defence of the fleete and voyage, together with due keeping of all instruments of your Navigation, and other requisites.

Cabot's 15th Ordinance enjoined strict cleanliness and directed instruction of the young in these terms:

Item, no liquor to be spilt on the ballast, nor filthiness to be left within boord: the cook room, and all other places to be kept cleane for the better health of the companie, the gromals & pages to bee brought up according to the laudable order and use of the Sea, as well in learning of Navigation, as in exercising of that which to them appertaineth.

In the event of sickness, Cabot's 18th Ordinance ordered that:

the sicke, diseased, weake, and visited person within boord, to be tended, relieved, comforted, and helpen in the time of his infirmite, and every maner of person, without respect, to beare anothers burden and no man to refuse such labour as shall be put to him, for the most benefite, and publike wealth of the voyage, and enterprise, to be achieved exactly.

A note, found written in the Bona Esperanza, Sir Hugh Willoughby's ship, which 'wintred in Lappia, where Sir Hugh Willoughby and all his companie died, being frozen to death', gave 'the names of the shippes of the fleete, and of their burden, together with the names of the Captaines, and Counsellors, Pilot Major, Masters of the ships, Marchants, with other officers, and Mariners'.

The Bona Esperanza, flagship or 'Admirall of the fleete', was of 120 tons, with a pinnace and a boat. She carried Sir Hugh Willoughby, knight, as 'Captaine generalle of the fleete'

William Gefferson, master
One master's mate,
Six merchants.

The 'Mariners and officers according to the custome, and use of the Seas', were

One master gunner
One bos'un
One bos'un's mate
Four quarter-masters
Four quarter-master's mates
Two carpenters
One purser
One purser's mate who also acted as cooper
One cook
One cook's mate
Ten mariners
Two surgeons.

The Edward Bonaventure, of 160 tons, had a pinnace and boat. She carried:
Richard Chancellor, 'Captaine, and Pilot major of the fleete'.

Stephen Borough, master
One master's mate
One minister
Seven gentlemen and, perhaps, pages.
The 'Mariners and officers according to the custome and use of the Seas', were

One master gunner
One gunner's mate
Two gunners
One surgeon
One bos'un
One bos'un's mate
Four quarter-masters
One steward

One steward's mate
One cook
One cooper
One carpenter
Twenty-one mariners including 'gromals' such as young William Borough, brother of Stephen, and Arthur Pet.

The *Bona Confidentia*, of 90 tons, with a pinnace and boat, had:

Cornelius Durfoorth, master
One master's mate
Three merchants.

The 'Mariners and officers, according to the use and custome of the Sea’, were

One master gunner
One gunner's mate
One bos'un
One bos'un's mate
Four quarter-masters

One steward
One cook
One cook's mate
One carpenter
Eleven mariners.

It will be remarked that two of the three ships had Spanish names, that it was necessary to provide the masters with their navigational instruments, that the spiritual and physical welfare of the crews were considered of fundamental importance, that defence against attack was adequately catered for, and that the training of the young in the mystery and science of the sea was duly arranged.

In the latter connexion the orders of the fleet to St. Nicholas dispatched in 1557 specified (Art. 7):

that notes & entries be daily made of their Navigations put in writing & memory, and that the young Mariners and apprentices may be taught & caused to learne and observe the same’. And it was laid down (Art. 8) that the ‘Captaine shall have the principall rule and government of the apprentices: And . . . also all other the sailors’.

Clement Adams’s account of the setting forth of the 1553 voyage and its prosecution indicates vividly its novelty, and narrates the extraordinary measures that the fitting out of the three ships entailed.

‘Many things seemed necessary to bee regarded in this so hard and difficult a matter’ that a special committee was formed.

The ships were specially built and one ‘they made most stanch and firme . . . by covering a piece of the keele of the shippe with thinne sheets of leade’ against ‘a kinde of wormes’, of which they had had reports.

Having ‘furnished them with armour and artillerie then followed a second care no lesse troublesome and necessarie then the former, namely, the provision of victuals’ for an eighteen months’ voyage.

This proved a particularly difficult task, for at Harwich, after having left Radcliff Reach in the Thames only a month before, ‘Richard Chanceler . . . was not a little grieved with the feare of wanting victuals, part whereof was found to be corrupt and putrified . . . and the hogges heads of wine also leaked, and were not stanch.’
Appendix No. 5

Transcript of a page of Sir Hugh Willoughby's Journal of 1553.

B.M. Otho E. VIII. 6. fol. 16. See Pl. XXIX.

... sight of it, ...
... we got the ...
... with it untill night, then ...
... shorc to us, we gatt us into the ...
... have Sea roome, ...
... 12th of September, we haled to the shorc ...
... having then Indifferent wynd, and weather, ...

being next vnto the Shore, and the Tyde a spent, we came to an Anker in. 30. fadoms water The 13th day we ranne along the Cost North [b]y Northwest, and by West and southeaste & by East The 14th day we came to an Anker within. 2. [l]eag of the shore having. 60. faddomes There we went a shorc with our Bote, and found ij. or three good harbouroths, the land Being Rocky, and highe, But as for people cold we se none. The 15th day running still along the Cost untill the 17th day, when the wynd being contrary to us, we thought it best to retourne vnto the harbouroth which we had found before, and so we bare roomer with the same, howbeit, we cold not accomplishe our desire that day. The next day being the 18th of September we entered into the haven, and there came to an Anker at. 6. faddomes. This haven runneth into the mayne about 2 leags, and is in breadth half a leag, wherein were very many Seale fysshes, and other great fysshes. And vpon the mayne we saw Beares, greate deare, foxes with divers strange Beasts, as Guilones, & suche other, which were to us unknowen, and also wonderfull. Thus remayning in this haven the space of a Sevenight; seing the yere far spent, & also very evill weather, as frost, Snow, and hayle, as though it had bene the depe of winter, we thought it best to enter there, wherefore we sent oute iii men

The Ha[ven] of

Leith.
Appendix No. 6

Stephen Borough's Petition for the Creation of the Office of 'Pilott Maior'.

B.M. Lansdowne MS. 116, ff. 6 and 7 [1562].

Three especiall causes and consideracions amongst others wherfore the office of Pilott maior ys allowed and estemed in Spaigne Portingale and other places wheras Navigacion florishethe.

The first is it gieveth occasion to make perfect mariners wheras otherwise the navigantes shold haue remained in their accustomed iggnorauncye.

The second that throughge their excellecye in navigacion greate benefyte honor and fame redoundeth to their cuntrey.

The third ys that they haue no losses of shippes or shipwrecke throughge ignoraunce of mariner craft as in other cuntres where the same wanteth it chauncethe.

And for better explainacion of the said three causes to the first that it maketh perfect mariners, it is, that there ys not permitted to take charge of any of their princes shippes, or any other shippes of charge or chargeable viages unlesse he haue bine first examined admitted and allowed by the pilott maior, And haue to shewe vnder his seale that he is allowed to take the name and charge vpon him of a pilott or master, (I meane not of the olde and approvid good masters and mariners, but suche as dayly of youthe springeth vpp) ; And yf at his examinacion he be found vnsufficient then he to continewe in exercise in his mariners craft vntill he be found hable in that behalf by the said pilott maior—And for further declaracion of the premisses yt is to be vnderstand that they haue degries of their navigauntes as Folowithe, Chishly the pilott, the master, the mariner, the grommet, the page, and the boye and cyther of them hathe their estimacion accordinge to their degrie, dewlie opprovide, whiche good order I wishe in God it were in practisinge in this noble Realme of England as we haue not the more is the pittie in our Englishe shippes but man and boye, And assone as a yonge man ridithe to any reasonable stature, he will loke for his Age and not for his knowledge to haue the name of a man and also of a mariner although he vnderstande litle in the arte, And so when he can apparell him selfe like a mariner to haue a whistyle and chayme of silver about his necke, And that he can some thing talke of the Arte, he thinketh then to be a good mariner wheras in deade he is farre from good and necessary knowledge in the same.

To the second cause viz that wheras throughge their excellecy and good order in other Regions in the Arte of Navigacion, what wonderfull attemptes they do performe and what habundaunce of Riches and commodite they bringe into their cuntrey, it is manifestly knownen and dayly seene besides the furniture of skiffull men in those regions, that yf it please the prynce and others of habilitie to attempt anye viages of discouery or viages vnaccustomed to be travaleyd, that then they may be sure to haue men of their owne cuntrey to serve their turne and not to be constrayned to seke into other cuntreis for men of skill in that arte when they shall haue nedie of them, as hathe bine here In England of late yeres to send into
spanish and fraunce for men skilfull in that arte I meyne one of Spaigne the good olde and famuse man master Sebastian Cabola, and also pilottes out of Fraunce for the gemmye viages etc.\(^1\)

To the third, that they haue no losses of shippes or shipwrecce through the ignoraunce of mariner craft, yt is because of their dayly exercise in the principles of the arte which is to know the latitude of the sonne or starres, the variacion of the cumpas, withe divers other sundry rules and waies wherby they knowe and reckonne their shippes waies exactly althoughe the sonne and starres be hid longe from them, and not be scene.

Whiche exacte rules and reckoninges it ys the fewest sorte of mariners in this noble Realme of England that dothe practise or seke the knowledge thereof (the mor is the pittie) the greatest number of our Englishe mariners contenting them selves with the olde Auncient rules, as they terme it, whiche ys erronious ynoygh: albeit ther be somme whiche wold gladly lerne yt they had a techer, but they whiche know the mor in that arte than the common sorte of pilottes or masters dothe wold not gladly teache other, for hinderinge of their owne lyvinge.

There are two sortes of pilottes and masters whiche seme they wold gladly be skilfull in the Arte yt they wist howe, And that are these, the on[e] sorte of them, because they wold not seme to be vnskilfull or ignoraunt in the principle rules of navigacion, threfore they carry instrumentes to the sea with them, belonginge thervnto, although they be ytterly ignoraunt in any vse of the same, but they wold gladly lerne, were it not that shame dryvith them to hide their ignoraunce because they haue alredy the name of and preferment of a master or pilott.

The other sorte are they whiche hathe som thinge practised to observe the latitude etc. And when they understander a litle, they thincke they knowe all, And they also thinketh, they haue clymed to the toppe, before they cum to the roote, And hath bine the chiftest occasion of the castinge awaye of many mens lyves as well as the losses of Shippes and goodes whiche hathe happened to manifestlye within these fewe yeres yt it had bin Godes will to the contrary by the ridinge and goinge of our Englishe shippes into Andalozia somn of them hathe perished upon the coast, others hathe perished vpon the Cape finstre in Galizia and also others vpon the stymes and the coast of britaine.

The chiftest of these losses (as I am able to approue) hathe happened through ignoraunce of the Arte, and the presumption of the vnskilfull, whiche maye be provided for, And remedied by the appointinge and Authorisinge of a lerned and a skilfull man in the arte of navigacion to teache and instructe the said ignorauntes in the same and not otherwise.

And because I suppose there will not lacke suche as will to hinder this my purpose make divers apparent objections, against the premisses, I desire that yt any suche be they maye be constrained to put the same in writinge, And I to be called to make Answere.

\(^1\) gemmye = Guinea.
Appendix No. 6

B

Draft of Stephen Borough's Appointment as 'Cheyffe Pylott of this our realme of Englande'.

B.M. Lansdowne MS. 116, ff. 4 and 5 [?1563–Jan. 1564].

Elyzabeth—by the grace of God—&c. for the advoyding of dyvers great perills and dawngers, as well the Losses of shipps and goodes, as mens lyves, whiche owr welbeloved Subiectes haue heretofore manye waies, and yett doe daylye susteyne and incurred, throwghe the presumption of the vsnskillfull pilott or master; therefore we think it good for the redresse thereof, to appoynte a man skillfull in maryne affaires, to be the Cheyffe Pilote of this owr realme of Englande, which Cheyffe Pylott, shall haue the examynacion and appoyntyng of all suche maryners as shall from this tyme forwarde take the charde of a pilott or master vpon hym, in anyc shipps within this owr realme, that shalbe of the burden or portage of fourtye tonnes and vpwardes. And for the speciall knowledge sight, and experience in Navigation whiche we have reposed in owr etc. Stephen Borowghe we haue geven and graunted, and by these presentes for vs owr heires and successores, do geve and grawnt vnto the said Stephen Borowghe, the office and rowme of Cheyffe Pilott of this owr realme of England as afore said, we make ordeyn and constitute by these presentes, to haue, holde, exercysce, occupye, and enioye, the office and rowme of Cheyff Pilotte vnto the said Stephen Borowghe, by hym selff, or his sufficient deputie, or deputys, during the naturall Lyffe of the same Stephen, And that no man hereafter, take on hym the office of a mariner, before he be examyned, allowed, and authorysed by the Cheyffe Pilott, or his sufficient deputie, upon payn of the forfaytt of XX ss. of good and Lawfull monye of this realme of England, the one halffe thereof to the admryall for the tyme beyng, and the other halffe to the Cheyffe pilott, And that when he is allowed a man meytt for his knowlege to that rowme, that he haue the testimonye of the Cheyffe pylott, or his sufficient depute or deputys, in wryting and signed with his or their Seall, afore he be admytted, and accepted to the exercysce of that office. And also that no man here after take on hym the office of a Boatswayne, quarter master, or masters mate, whiche is nott before examyned approved and allowed (as is afore said) worthye a maryner, eyther [to] prove an other man skillfull as his presentes (according to the used manner and custome of this noble realme) or els to prove as a boye, page or grommett.

And also that no man here after take on hym the office of a pilott or master whiche hathe nott before bene approved, and proved in the office of a marriner, namely Boteswayne, quarter master, or masters mate, vpon payne of the forfaytt of xl ss. of Lawfull monye of England, the one halffe thereof to the L. admryall for the tyme being, and the other halffe to the Cheiffe pilott, And that he be allowed and admytted, onelye to souche office, by the Cheiffe pilott or his suffici- ent and speciall deputie, so that at his admysson he be examyned before two other that be skillfull in that art, if souche may be had, or els the Cheiffe pilott alone or his depute may appoynt hym yt he fynd hym meytt—And that the
Cheyffe pilott bothe at the admisson and approbachion of the maryner, and also of the pilott or master, doe geve rules and Instructions touchinge the poyntes of navigacion and at all other tymes to be redye to enforce them that seke knowleg at his handes.

And also we do appoynt the fore said Stephen Borowghe to be one of the fowre masters that shall have the kepyng and over syght of owr shippes in Medowe waters, that is to saye at Jellingham, Chattam &ca. And further more of owre especiall grace. Certayne knowleg and merc mocion, we haue geven and grawnted, and by thies presentes for vs, owne heires and successours doe gyve and grawnt, vnto the said Stephen Borowghe, for the exercysyng and occupyeng of the said office of Cheiff Pylott, and kepyng of owr shippes in harbouer, the fee and wages of 1 li lawfull monye of Engeland, by the yeare, to gether with all and syngular other profittes, Commodities, Emolumentes, rewardes, and advantages, what so ever to the said office belonging or in any wyse appartaynynge, to haue, holde, enioye, receyve, and yerelyc perceyve, the said fee and wages of 1 li by the yere, vnto the said Stephen Borowghe and his assignes, duryng the naturall Lyffe of the same Stephen, of vs owr heires and successuors, by the handes of the Threasurcer of owr Navye for the tyme beyng, out of the ordinary charges, which is allowed for the keeping of owr shippes in harbouer, at fowre terms of the yeare, That is to saye: at the feastes of Thanunciation of owr Ladye, The Nativytce of Saynt John Baptyst, Saynt Myghell the archaungell, And the byrthe of owr Lord God, by even porcions yerelye to be paid to gether with all and singular other the foresaid profittes commodoties, and advantages what so euer to the said office belonging or apparteynyng.

1 Number of pounds left blank in text.
Appendix No. 7

Pocket Dials, by Humphrey Cole, dated 1569, and traditionally described as having belonged to Sir Francis Drake. See Pl. XLIII.

(National Maritime Museum, Greenwich).

The dials fold flat, forming an oval box of gilt and chased brass about \(\frac{1}{2}\) inch thick and 3 inches long. Design and workmanship are wonderfully neat. Its form is much superior to that of the pocket-book dial by Cole of 1568 (in the Lewis Evans Collection at Oxford) and of the similar pocket dial, almanac, compass, and tide-table by V.C. of 1554 (in the Bodleian Library). All are inspired by Leonard Digges’s *Prognostication* of 1555: many of his tables are contained in the pocket dial of 1554.

(a) shows the dials opened with the universal sun-dial set for latitude 48° and the horizontal plane dial set for taking bearings and distances.

(b) The universal sun-dial opened but with the quadrant and style folded flat. In addition to the hours it has engraved on it ‘Humfray. Colle. made. this. diall. anno 1569’.

(c) Table of latitudes for setting the sun-dial.

(d) Declination table and lunar table ‘The.cours.of.the.Sonne.and.Mone. through.[the].12.Signes.’

Cortes illustrated a similar instrument in his *Arte de Navegar* of 1551 (English translation 1561) and explained the manner of using it. It was ‘An instrument’, he wrote, ‘whereby may bee knowne the place of the Sunne [the sun’s declination]: and knowing . . . the dayes of the Moone [the moon’s age], shall also bee knowne her place in the Zodiacke, and howe muche of her is lightened, and what aspekte, she hath with the Sunne. . . .’ The aspects are

- Conjunction ⊘: The planets have the same position in the zodiac.
- Opposition ⊙: The planets are 180° apart in the zodiac.
- Trinall △: 4 signs or 120° between the planets.
- Quadrine □: 3 signs or 90° between the planets.
- Sextile *: 2 signs or 60° between the planets.

In the dial the moon pointer has been broken off and only a stub remains. The dial shows that on 26th February the sun was in the 22° of Pisces and the moon was 11 days old and in the 26° of Cancer. It was almost in Trinall with the sun, and it was approaching full moon and so about two-thirds illuminated.


(f) Tide-calculator.


It is set to a port with a S.S.W. moon (high-water at 1.30 on days of full and change) and for a four-day-old moon. High-water should occur there at
5 o'clock on that day. Reference to the tide-table shows that the calculator was set for either:

Dumbarton ('Döber in. Scot')
or?
('Coding Rode')
or Berwick on Tweed ('Barwic')
or Holy Island ('Holy Iland')
   Farne Islands
   the coast & all
   south to
   Tynemouth ('& so to Tinmot')
   Coquet Is. (Cro Ila.)

The hole in the moon roundel shows the appearance of the moon when four days old.

(g) The horizontal plane sphere for taking bearings, and for finding distances by means of 'The Geometrical Square'.

(h) 'A Kalender with ye Saints daies. And moueable feastes for euery' with the maker's initials 'H C' and date '1569' in the centre.

There are ten concentric circles. The outer three are divided into quarters, so that each of the twelve months has a quadrant on which are shown the dates of the fixed feast days and of the sun entering the various signs of the zodiac.

Working inwards from these rings are circles devoted to the date of Easter Day—'East.D'—

The dominical letter—'Dô Le.'
The prime.
The dominical letter—'Dô Lc.'
The dominical letter for leap years—'Le Y.'
The golden number 'Pyv.'
The 'Epact.'

These dials were quite common in the latter half of the sixteenth century and in the early seventeenth century. There is a fine but incomplete and incorrectly repaired example of 1593 by James Kynvyn in the British Museum. It once belonged to Elizabeth's favourite, the Earl of Essex. See Appendix No. 7B.
Appendix No. 7

B

*The Pocket Dial of the Earl of Essex, by Kynvyn, dated 1593.*

(British Museum)

The Essex Dial measures 2½ inch in diameter and 1 inch in depth. It is of gilded brass. The two leaves, which fasten down, one on each side of the centre compartment, give it the appearance of a round box when closed. Round the edge of the box is inscribed:

HE THAT TO HIS NOBLE LINNAGE ADDETH.
VERTY AND CONDIFICATIONS IS TO BE PRAYED.

and,

THEY THAT BE PERFECTLY WISE DESPISE WORLD.
HONOR WHERE RICHES ARE HONORED GOOD MEN ARE DESPISED.

The nocturnal is designed for use with the guards of the Little Bear—the handle (broken off) was opposite 21st October, the opposite point being 21st April. On these dates (O.S.) the guards of the Little Bear transit below and above the meridian respectively at midnight.

The almanac or calendar contains all the fixed festivals of the Church of England in three outer concentric circles, with the addition of the dates when the sun entered into the several zodiacal signs. This is expressed in the usual astronomical manner.

On the five inner concentric circles are engraved tables for 'Easter da[y]', the Prime, the Epact, the 'Dominic' letter for ordinary years, and finally 'This Table beginneth at 1593 and so for ever.'

This is actually a 35-year calendar, 1593–1627.

The Easter days given are (with a few mistakes) those which would occur over those thirty-five years. Thirty-five is the exact number of the possible days on which Easter may fall, but Easter does not recur on the cycle engraved on this dial.

The prime or golden number and the epact run on in continually recurring cycles of nineteen years in the order laid down, but not in respect of the dominical letters, leap years or Easter days.

The calendar is correct for 1595, but, immediately after, the parts fall out of relation to one another. There should be the same number of primes, epacts, and dominical letters (counting the double letters of the leap years for this purpose as one), but there are primes and epacts for only nineteen years, and dominical letters for only twenty-eight years, while there are thirty-five Easter days enumerated.

The inaccuracy of the Easter Day table results in the fourth Easter (1596) being shown as falling on '11th M[arch]'. It is an impossibility, since Easter never falls before 22nd March. It should be 11th April. The eighteenth Easter
day (1610) should read 8th not 1st April; the twenty-second (1614) should be 24th April not 17th; the twenty-fifth (1617), the 20th April, not 15th; and thirty-fourth (1627), 25th April, not 25th March.

The great number of common almanacs for the pocket with their tide-tables, latitude tables, tables of moonlight, sunrise and sunset, note tablets, etc., issued annually by the close of the sixteenth century seem to have rendered these metal pocket dials expensive luxuries that soon became rare. A common almanac and a pocket universal ring dial with compass sufficed for the traveller and voyager.
Appendix No. 8

Dr. John Dee on the Art of Navigation and associated subjects, 1570.

Dee gives the first English definition of the art of navigation (excluding Richard Eden's translation of Martin Cortes's—Art of Navigation, 1561) and one that it is hard to surpass. It is from:

The Elements of Geometrie of the most auncient Philosopher Euclide of Megara. Faithfully (now first) translated into the Englishe tongue, by H. Billingsley, Citizen of London. Whereunto are annexed certaine Scholies, Annotations, and Inventions, of the best Mathematicians, both of time past, and in this our age. With a very fruitfull Praeface by M. I. Dee, specifying the chiefe Mathematicall Scieces, what they are. and whereunto commodious: where, also, are disclosed certaine new Secrets Mathematicall and Mechanicall, vntil these our daies, greatly missed. Imprinted at London by John Daye. [Colophon, 1570]

THE ARTE OF NAVIGATION, demonstrateth how, by the shortest good way, by the aptest Directiō, & in the shortest time, a sufficient Ship, betwene any two places (in passage Nauigable,) assigned: may be cōducted: and in all stormes, & naturall disturbances chauncyng, how, to vse the best possible meanes, whereby to recouer the place first assigned. What nede, the Master Pilote, hath of other Artes, here before recited, it is easie to know: as of Hydrographie, Astronomie, Astrologie, and Horometrie. Pre-supposing continually, the common Base, and foudacion of all: namely. Arithmetike and Geometrie. So that, he be hable to vnderstand, and Judge his own necessary Instrumentes, and furniture Necessary: Whether they be perfectly made or no: and also can, (if nede be) make them, hym selfe. As Quadrants, the Astronomers Ryng, The Astronomers staffe, the Astrolabe vniversall. An Hydrographical Globe. Charts Hydrographical, true, (not with parallel Meridians). The Common Sea Compas: The Compas of variacion: The Proportionall, and Paradoxall Companes (of me Invented, for our two Moscouy Master Pilotes, at the request of the Company) Clockes by sryngs: houre, halfe houre, and three houre Sandglasses: & sundry other Instrumentes: And also, be hable, on Globe, or Playne to describe the Paradoxall Compasse: and duely to vse the same, to all maner of purposes, whereto it was inuented, And also, be hable to Calculate the Planetes places for all tyme.

Moreouer, with Sonne Mone or Sterre (or without) be hable to define the Longitude & Latitude of the place, which he is in: So that, the Longitude & Latitude of the place, from which he sayled, be gien: or by him, be knouene. whereto, appertayneth expert meanes, to be certified euer, of the ships way. &c. And by foreseeing the Rising, Settyng, Nonestedyng, or midnightyng of certaine tempestuos fixed Starres: or their Coniunctions, and Anglynges with the Planetes, &c. he ought to have expert coniecture of Stormes, Tempestes, and Spoutes: and such lyke meteorologicaall effectes, daungerous on
Sea. For (as Plato sayth,) *Mutationes, opportunitatisq temporum presentire, non minus rei militari, quam Agriculturae, Nauigationis conuenit. To foresee the alterations and opportunities of tyme, is convenient, no lesse to the Art of Warre, then to Husbandry, and Nauigation. And besides such cunningy meanes, more evident tokens in Sonne and Mone, ought of him to be knowne: such as (the Philosophicall Poëte) Virgilius teacheth in hys *Georgikes. Where he sayth, ... [Quotation from the 1st book of the Georgies, beginning 'Sol quoq & exoriens ...']

And so of Mone, Sterres, Water, Ayre, Fire, Wood, Stones, Birdes, and Beastes, and of many thynges els, a certaine Sympathicall forewarnyng may be had: some tyme to great pleasure and profitt, both on Sea and Land. Sufficiently, for my present purpose, it doth appeare, by the premisses, how *Mathematicall, the Arte of Nauigation, is: and how it nedeth and also vscth other *Mathematicall Artes: And now, if I would go about to speak of the manifold Commodities, commyng to this Land, and others, by Shypps and Nauigation, you might think, that I catch at occasions, to vs many wordes, where no nede is.

Yet, this one thyng may I, (justly) say. In Nauigation, none ought to haue greater care, to be skilfull, then our English Pylotes. And perchaunce, Some, would more attempt: And other Some more willingly would be aedyng, if they wist certainly, What Priuiledge, God had endued this Island with, by reason of Situation, most commodious for Nauigation, to Places most Famous & Riche. And though (of Late)\(^1\) a young Gentleman, a Courageous Captaine, was in great readynes, with good hope, and great causes of persuasion, to have ventured, for a Discouerye, (eyther Westerly, by *Cape de Paramantia: or Esterly, aboue *Nova Zemla, and the *Cyremisses) and was, at the very nere tyme of Attemptyng, called and employed otherwise (both then, and since,) in great good scruice to his Countrey, as the Irish Rebels haue\(^2\) tasted: Yet, I say, (though the same Gentleman, doo not hereafter, deale therewith) Some one, or other, should listen to the Matter: and by good aduise, and discrete Circumspection, by little, and little, wynne to the sufficient knowledge of that Trade and Voyage: Which, now, I would be sory, (through Carelesnesse, want of Skill, and Courage,) should remayne Vnknowne and vnheard of. Seyng, also, we are herein, halfe challenged, by the learned, by halfe request, published. Thereof, verely, might grow Commodiyce, to this Land chiefly, and to the rest of the Christen Common wealth, farre passing all riches and worldly Threasure.

The following passages from Dee's Preface are also noteworthy:

\[\ldots\] GEOGRAPHIE teacheth wayes, by which, in sudry formes, (as *Sphaerike, Plaine or other), the Situation of Cities, Townes, Villages, Fortes, Castells, Mountaines, Woods, Hauens, Riuers, Crekes, & such other things, vpō the outface of the earthly Globe (either in the whole, or in some principall mebër and portion therof cōtayned) may be described and designed, in cōmemon- surations Analogical to Nature and veritie: and most aptly to our view, may be represented. Of this Arte how great pleasure, and how manifolde commodities do come vnto vs, daily and hourly: of most men, is perceaued. While,

\(^{1}\) Anno 1567.  
\(^{2}\) Anno 1569.
some, to beautifie their Halls, Parlors, Chambers, Galeries, Studies, or Libraries, with: other some, for thinges past, as battels fought, earthquakes, heavenly fyringes, & such occurantenes, in histories mentioned: therby liuely, as it were, to vewe the place, the region adjoyning, the distance from vs: and such other circumstances. Some other, presently to vewe the large dominion of the Turke: the wide Empire of the Moschouite: and the little morsell of ground, where Christendome (by profession) is certainly knowne. Little, I say, in respecte of the rest, etc. Some, either for their owne iorneys directing into farre landes: or to vnderstande of other mens traualles. To conclude, some, for one purpose: and some, for an other, liketh, loueth, getteth, and vseth, Mappes, Chartes, and Geographickall Globes. Of whose vse, to speake sufficiently, would require a booke peculier.

HYDROGRAPHIE, deliuereth to our knowledge, on Globe or in Plaine, the perfect Analogall description of the Ocean Sea coastes, through the whole world: or in the chiefe and principall parts thereof: with the Iles and chiefe particular places of daungeres, conteyned within the boundes, and Sea coastes described: as, of Quicksandes, Bankes, Pittes, Rockes, Races, Counter-tides, Whorlepooles, etc. This, dealeth with the Element of water chiefly: as Geographie did take principally the Element of the Earthes description (with his appertennances) to taske. And besides thyis, Hydrographie, requireth a particular Register of certaine Landmarkes (where markes may be had) from the sea, well hable to be skried, in what pointe of the Seacompasse they appeare, and what apparent forme, Situation, and bignes they haue, in respect of any daungerous place in the sea, or nere vnto it, assigned. And in all Coastes, what Mone, maketh full sea: and what way, the Tides and Ebbes, come and go, the Hydrographer ought to recorde. The Soundinges likewise: and the Chanels wayes: their number and depths ordinarily, at ebe and fluid, ought the Hydrographer, by obseruation and diligence of Measuring, to haue certainly knownen. And many other pointes, are belonging to perfecte Hydrographie. and for to make a Rutter by: of which, I nede not here speake: as of the describing, in any place, vpon Globe or Plaine, the 32. pointes of the Compass, truely: (wherof scarcely foure, in England, haue right knowledge: bycause, the lines therof, are no straight lines, nor Circles.) Of making due projection of a Sphere in plaine. Of the Variacion of the Compass, from true Northe: And such like matters (of great importance, all) I leaue to speak of, in this place: bycause, I may seame (al ready) to haue enlarged the boundes, and duety of an Hydrographer, much more, than any man (to this day) hath noted, or prescribde. Yet am I well hable to proue, all these things, to appertaine, and also to be proper to the Hydrographer. The chiefe vse and ende of this Art, is the Art of Navigation: but it hath other diverse vses: even by them to be enjoyed, that neuer lacke sight of lande.

... ASTRONOMIE, is an Arte Mathematicall which demonstrateth the distance, magnitudes, and all naturall motions, apparaences, and passions prope to the Planets and fixed Sterres: for any time past, present and to come: in respect of a certaine Horizon, or without respect of any Horizon. By this Arte we are certified of the distance of the Starry Skye, and of eche Planete from the centre of the Earth: and of the greatnes of any Fixed starre sene, or Planete, in respect of the Earthes greatnes ...
OF ASTROLOGIE, here I make an Arte, seuerall from Astronomie: not by new devise, but by good reason and authoritie: for, Astrolgie, is an Arte Mathematicall, which reasonably demonstrateth the operations and effectes, of the naturall beames, of light, and secrete influence: of the Sterres and Planets: in every element and elementall body, at all times, in any Horizon assigned . . .

HOROMETRIE, is an Arte Mathematicall, which demonstrateth, how, at all times appointed, the precise vsvall denominatio of time, may be known, for any place assigned . . .
Appendix No. 8

B

Dr. John Dee and Arithmetical Navigation

Recent researches make it clear that the credit for first grasping the possibilities of arithmetical navigation, for doing the pioneer work on it, and for teaching its potentialities to both navigators and to younger mathematicians lies with Dr. John Dee. As mathematical adviser on navigational problems to the Muscovy Company from its inception in the 1550s he not only made original contributions to the solution of navigational problems but also for some thirty years taught the company’s navigators the theory of the art, and the possibilities latent in mathematics for the solution of its problems. Moreover, it seems clear that it was his teaching, which he reduced to written form for publication, that illuminated the path for the new generations of mathematicians that came to the fore in the 1580s, 1590s and 1600s—Hood, Hues, Harriot, Wright, Briggs, Gunter and Handson—who were to solve mathematically many of the outstanding problems of navigation.

Not only did Dr. Dee devise the circumpolar chart in the 1550s for the use of the Muscovy Company’s navigators in northern waters but, as companions to it, he also calculated a departure table, and designed a compass fly divided off into degrees as well as points. The departure table, of about 1556, survives in manuscript (Ashm. 242, No. 43 Bodleian) and has been described in a recent paper by Professor E. G. R. Taylor. (*John Dee and the Nautical Triangle, 1575*, *Jour. of Inst. of Navigation*, Vol. 8). The manuscript is entitled: *Canon Gubernaticus: An Arithmetical Resolution of the Paradoxall Compass*, and as already stated, and as the extract given below makes clear, was in effect a table for finding difference of longitude resulting from raising or laying one or more degrees of latitude when sailing upon any of the principal rhumbs of the wind.

For each of the seven rhumbs in a quadrant (111°, 224°, 333°, 45°, etc.) the table ran from the equator to lat. 80°, and gave the difference of longitude made as each degree was raised, and the cumulative difference of longitude.

**Dee’s Canon Gubernaticus**

I (i.e. First Rhumb)

<table>
<thead>
<tr>
<th>Latitude</th>
<th>11 D 15 M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Continuate</td>
</tr>
<tr>
<td></td>
<td>Longitude</td>
</tr>
<tr>
<td>D</td>
<td>D  M  S</td>
</tr>
<tr>
<td>1</td>
<td>0  11 56</td>
</tr>
<tr>
<td>2</td>
<td>0  23 53</td>
</tr>
<tr>
<td>3</td>
<td>0  35 50</td>
</tr>
<tr>
<td>4</td>
<td>0  47 48</td>
</tr>
<tr>
<td>5</td>
<td>0  59 46</td>
</tr>
<tr>
<td>6</td>
<td>1  11 45</td>
</tr>
<tr>
<td>etc.</td>
<td>etc.</td>
</tr>
</tbody>
</table>

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Professor Taylor points out that as Dee entered above the title the words 'the diameter 50 ynches', it may be assumed that the actual 'compass' or chart was of this diameter, and that the rhumbs (or some of them) were plotted from meridian to meridian upon it, when their spiral shape would be demonstrated. The final entry in the table represented a course from 79° lat. to 80° lat. on the 7th rhumb (78° 45') and gave a cumulative easting from the equator of 699° 43' 51'', and an actual easting during the single degree change of 27° 36' 31''. Thus the world had been circumnavigated and more on the spiral rhumb.

In the autumn of 1575 Dr. Dee assembled all his navigational teachings into a large volume which he called The British Complement of Perfect Navigation with a view to publication. No patron supported the project which was costly on account of the number of tables and figures, and its limited appeal, and the manuscript is now lost. Dr. Dee's references to it in a surviving manuscript (Vitellius, C.VII. Volume of Great and Rich Discoveries, Brit. Mus.) show that it contained the solution of the nautical triangle. However, the mathematical processes available were far too laborious for navigational practice. Until improved trigonometrical tables and text books had been prepared and published, and instruments such as the Sector invented, Dee's mathematical solutions were impracticable at sea. The long title of the Complement of Navigation says that it teaches 'Paradoxall and Great Circle Sailing', and in her recent paper quoted above Professor Taylor gives examples of the laborious calculations involved in finding the Great Circle bearing and distance between two places using Peter Apian's methods in his Instrumentum Sinuum sev primi mobilis (1524 and 1541) which books were in Dee's library.
Appendix No. 9


‘The use thereof is this, fyrste too knowe howe that the place dooth beare from him, by what wynde or poynte of the compass, and also how farre that the place is from hym, and also to consider the streame, or tide gates, Currents, whiche waye they doo sette or drieue the shippe, and also too consider what dauners is by the waye, as Rockes and sandes, and such other like impediments, and also if that the wynde chaunge or shifte by the waye, to consider which way to stande, and direct his course unto the most aduantage, to attayne vnto the port in shortest time: and also if any stormes doo happen by the waye, to consider how for to preserve the shippe, and the goodes, and to bring hir safe vnto the porte assigned. And also it is moste principally too be considered and foreseene that if they have had by occasion of a contrarye tempest, for to go very much out of the course or way, too knowe then howe that the place dooth then beare, that is to say, by what poynte of the Compass the place doth stande from you: and also how farre it may be from you. Whiche waye too bee knowne is thys: Fyrste too consider by what poynte that the shippe hath made hir waye by, and how fast and swiftly that the shippe hath gone, and to consider how often that the ship hath altered hir course, and how much that shee hath gone at every tyme, and then to consider all thys in your Platte or Carde, and so you maye gue an neere gesse by what poynt or wynde it beareth from you, and also nowe farre it is thyther. And also you may haue a great helpe by the Sunne or Starres, too take the heigth of the Pole aboue the Horizon and also in some place you may gesse by sounding, both by the depth, and also by the grounde. And also it is very meete and necessary to knowe any place, when that hee dooth see it.’

Appendix No. 10

A

Note on Frobisher's Chart of 1576. See Pl. XXXVI.

Frobisher's Chart of 1576 was prepared by William Borough, and was used by Frobisher for plotting his discoveries and magnetic observations on the voyage of 1576. It is now preserved at Hatfield House, being perhaps one of the four 'cartes of navigation written in blanke parchment . . . ruled playne' (See Appendix 10B).

The coasts of England and Ireland are coloured blue, those of France and the smaller islands close to England, red; those of Scotland, Scandinavia, Greenland, and Frobisher's Bay, are green.

The small island in latitude 60° and above the scale is marked 'ice', and was evidently a large ice floe erroneously charted as an island. It is not the origin of the mythical Buss Island; this was supposedly located during the return passage of the third voyage in latitude 57°N by the Emmanuel, 'otherwise called the Buss of Bridgewater'.

The chart was completed a fortnight before Frobisher left the Thames on his first voyage for the discovery of the North-West Passage to Cathay. Pencilled in very faintly are the outline of 'Farry Iland' [the Faroes], 'Podalyn' [?], 'Yse-land' [Iceland], 'Westmony' [a cape on the south-east end of Iceland ?], 'Neome', and 'Frisland' [mythical islands contained in the Zeno map of 1558], 'Labradore' [Greenland] and a few names of Capes.

They were drawn in conjecturally before the voyage and were based on the Zeno map and Portuguese charts of the first half of the century.

Frobisher's 'f l', with the cape named 'Cabó de terra firme', would appear to be a notation for 'Frisland', 'Cabó de terra firme' is Cape Farewell, the southern point of Greenland, named by Davis in 1585, who called Greenland 'The Land of Desolation'. The confusion between 'Labradore,' 'f l', and 'Frisland' on the chart, and Davis's later 'Land of Desolation', also the placing of 'Cabó de terra firme' on the chart on Frobisher's 'f l' all arose from the inability of navigators to determine their longitude, and to the diverse and at the time unknown currents in these regions making their reckonings erroneous. 'Labradore' was the name the early Portuguese explorers in the north-west gave Greenland; 'Cabó de terra firme' was their name for Cape Farewell.

Frobisher's Sound, shown as a strait and called then 'Frobisher's Strait', was plotted more than a degree north of its position.

Davis rediscovered the Sound in 1587 and called it 'Lumley's Inlet', for he did not identify it; this name it retained until the discovery of Frobisher's mines in the nineteenth century, which led to its receiving its original name, with 'Sound' in place of 'Strait'.

The chart is important for its arrows indicating the amount of variation observed by Frobisher and for the position of the observations, and is the earliest
surviving MS. chart to have such notations. It is thus one of the earliest English
scientific records relating to magnetism, and provided data that enabled Robert
Norman to prove the inequality of magnetic variation in *The Newe Attractive*,
five years later.

‘Goyng to *Meta Incognita* [the name Frobisher gave to the land around his
"Strait"], it varieth more in ¼ parte of the last of the way then in ¾ of the first;
and in those partes is found to be sudden’, he wrote.

The magnetic observations mark, incidentally, Frobisher’s track.
Appendix No. 10

B

Bill for Charts and Nautical Instruments for Frobisher's Voyage, 1576.

\[ £ \quad s. \quad d. \]

- Paid for a book of Cosmographic in French of Andreas Thevet\(^1\) 2 4 0
- Paid to Humphrey Cole and others—
  - For a greate globe of metal in blanke in a case\(^a\) 7 13 4
  - For a great instrument of brasse named Armilla Tolomei or Hemisperium\(^b\) 4 6 8
  - For an instrument of brasse named Sphera Nautica\(^c\) 4 6 8
  - For a great instrument of brass named Compassum Meridianum\(^d\) 4 6 8
  - For a great instrument of brasse named Holometrum Geometricum\(^e\) 4 0 0
  - For a great instrument of brasse named Horologium Universale\(^f\) 2 6 8
  - For a ringe of brasse named Annulus Astronomicus\(^g\) 1 10 0
  - For a little standing level of brasse\(^h\) 0 6 8
  - For an instrument of wood a stafce named Balestella\(^i\) 0 13 4
  - For a very great carte of navigation\(^j\) 5 0 0
  - For a great mappe universall of Mercator in prente\(^k\) 1 6 8
  - For three other small mappes prented 0 6 8
  - For 6 cartes of navigation written in blanke parchment whereof 4 ruled playne & 2 rounde\(^l\) 2 0 0
  - For a Bible Englishe great volume\(^m\) 1 0 0
  - For a cosmographical glasse\(^n\) & castell knowledge\(^o\) 0 10
  - For a new World of Andreas Thevett Englishe\(^p\) & French\(^q\) 0 6 8
  - For a Regiment of Medena (Spanishe)\(^r\) 0 3 4
  - For Sir John Mandeville (Englishe)\(^s\) 0 1 0
  - For 20 compasses of divers sorts\(^t\) 3 3 0
  - For 18 hower glasses\(^u\) 0 17 0
  - For a astrolabium\(^v\) 3 10 0


In 1578 amongst 'Implements' supplied to the *Ayde*, Frobisher's flagship, or 'Admiral', were 'runnynge glass, j naught'. *The Three Voyages of Sir Martin Frobisher*, Hak. Soc., Ser. 1, Vol. 38, p. 220, under 'State Papers relating to the outfit of the third voyage'—'Inventorie of the ship *Ayde*'.

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Appendix No. 10

C

Notes on the Charts, Instruments and Books carried on Martin Frobisher’s First Voyage to the North-West, 1576.

THE BOOKS IN FROBISHER’S SHIP’S LIBRARY, 1576

(1) André Thevet, Cosmographie Universelle, Paris, 1575.
(5) Thomas Hacket (trans. of (4)) The New found World or Antartike, London, 1568.
(6) Pedro de Medina, Regimiento de Navigacio, Seville, 1543, 1552, or 1563 or Arte de Navegar, Seville, 1545.
(8) For the daily saying of prayers, and reading from Holy Scripture, and singing of psalms on taking over the night watches, possibly Richard Jugge’s Bishop’s Bible of 1572.

FROBISHER’S NAVIGATIONAL INSTRUMENTS AND CHARTS, 1576

(a) A blank metal sphere on which to work out navigational problems.
(b) An armillary sphere for working out astronomical problems.
(c) A ‘Nautical Sphere’. It is difficult to decide whether this was a globe with rhumb lines engraved upon it, or an instrument like that of Jean Rotz, or the later one of Edward Wright’s, for finding the variation.
(d) A meridional compass for finding the compass variation.
(e) A horizontal plane sphere’, i.e. a bearing plate, mounted with an open sight adjustable for bearings and elevations, the forerunner of the theodolite, for surveying the coastlines; or a form of plane table.
(f) A universal ring or dial, adjustable for latitude and the sun’s declination, for finding the time by the sun.
(g) An astronomical ring for finding the altitude of the sun. Perhaps the same as John Davis’s ‘Sea Ring’, illustrated in The Seamans Secrets, 1595.
(h) A level that held either water or embodied a plumb-bob.
(i) A cross-staff.
(j) A MS. chart, presumably of the North Atlantic.
(k) Mercator’s world map of 1569.
(l) Four blank plane parchment charts for plotting the ship’s position and discoveries.

Two blank circumpolar or ‘paradoxal’ charts for plotting.

(m) Presumably ship’s compasses, as distinct from ‘dividers’, and Flemish and meridional ones, i.e. some with off-set flies, others without.

(n) A large number of glasses were taken to guard against breakages and to check for accuracy.

(o) An astrolabe, possibly, since Dr. John Dee took up his residence in the Muscovy House and spent the spring of 1576 on board Frobisher’s ships giving instruction in the ‘Use of the Instruments of Navigation’, and in ‘Rules of Geometry and Cosmography’, a universal planispheric as distinct from a sea-astrolabe.
Appendix No. II

Thomas Digges's 'Errors in the Arte of Navigation commonly practized', 1576, in Digges, Thomas, A Prognostication everlasting ... Published by Leonard Digges Gentleman. Lately corrected and augmented by Thomas Digges, his sonne, London, 1576.

'Errors in the Arte of Navigation commonly practized.

'Firste all their Chartes are descriyed with streyghte Meridane lynes runninge equidistante or Parallele which error is most manysted to anye that hath tasted but the fyrrste Principles of Cosmographye consideringe they are all great cyrcles & concur in the Poles.

'SEcondly they suppose that runninge vpon any of their poynctes of their cumpasse they should passe in the circumference of a greate circle and therefore in the playne Chartes describe those wyndes with straighth lines, but therein are they greatly abused, for the shippe stenninge the North and the South onlye maketh her course in a greate circle, East or West shee describeth a Parallele, and being styrred on any other meane poynct (the cumpasse beinge truely rectified) shee delineateth in her course a curue or Helicall line, neither straight nor circulare, but myxte of both, and therefore to set forth these wyndes in the Chartes with straighth lines is most erroneous.

'THirdly theyr rule to know the Latitude by the Pole starre adding or subtractinge from his Altitude according to the situation of the Guarde, is also false, and that worsst is cannot be amended, but be it neuer so well rectified to one Clymate yet is it fausle, in all other.

'FOurthly theyr taking of the Sunne with their Ballestile (as they terme it) is most fausle, and whereas some findinge the errour thereof have gone about to remedy the same by cutting of a parte at the ende thinkinge thereby it mighte approche to the Centre of the eye, they increase thereby the error, and make it more fausle. For visus non fit à puncto as they suppose. And this error is muchly the other of the Pole starre and situation of the Guarde for be it neuer so well corrected by section to any one Altitude then shal it be fausle for all other, as to any skilfull in Perspectiue it is easilly demonstrate.

'This Errour I haue alredy reformed demonstratiue & practicè in my booke lately published entituled Alæ Seu Scaele Mathematicæ.

'Also the Rules they have to knowe howe manye leagues they, shall ronne vpon every poynct to raize one degree in latitude, are also meere fausle. For they serch that Arck Itinerall as though it were the Hypotenus a to a righte angled tryangle whose sides are circles of contrary nature, the one a Parallele the other a greate circle, and therefore without all sense seke they by proportion of right lynes to deliuer their quantitie.

'But besydes these errours they haue one great imperfection yet in their arte, and hitherto by no man supplyed, and that is the wante of exact rules to knowe the Longitude or Arckes Itinerall East and West, without the which they can neither truely geeue the place or situation of any Coaste, Harbourough, Rode or Towne, ne yet in saylinge discerne how the place they saile vnto beareth
from them, or how farre it is distant, whereby they are enforced longe before
they come at anye Coaste all night to stryke sayle, no other waies then if they were
uppon it, thereby losinge the benefit of prosperous windes, in such sorte some-
time, that whereas keepinge a true course they mighte have bin quietly at Roade,
they are by contrarye and aduerse tempestes caryed farre of, and so not without
great chardge to the owner, payne to the companye, and perill to the vessell,
are enforced to waste theyr time. Which growth of their ignorâce, that they
neyther haue true Rules too direct theymselfes, the nighest course, ne yet tread-
inge their beaten pathes can assuredlye decide of theyr certayne place. For
reformation of these erroirs and imperfections, newe Chartes, newe Instruments
and newe Rules muste bee prescribed. Wherein I haue prepared in a peculiare
volume for that purpose to entreate, wyshinge in the meane time that sutche as
are not able to refourme these faultes, wyll absteyne to teach our Coûtrye men
moe Erroirs."
Appendix No. 12

Spanish and Portuguese Reports on Drake as a navigator in 1578–9.

(See also Appendix No. 3).

Report by Gaspar de Vargas

'He carries with him a Portuguese pilot who is very skilful [Nuño da Silva, captured 19.1.1578].

'It seems that it is he who governs and directs this Armada. This Portuguese speaks the English language as though it were his own and he is the general's all in all.

'Francis Drake is so boastful of himself as a mariner and man of learning that he told them that there was no one in the whole world who understood the art of navigation better than he. From what the prisoners saw of him during their two days' imprisonment, they judge that he must be a good mariner. He also told them that, since he had left his country he had navigated seven thousand leagues and that, to return thither, he would have to sail as many more.'


Report by Nuño da Silva

'I am . . . a native of Lisbon . . . captain and pilot combined, of merchant ships . . . as I was entering the port of Santiago [Cape Verde Is.] for water and about to cast anchor February, 1578 . . . He captured my ship, took my men out of her . . . He then put forty or fifty Englishmen aboard my ship . . . and took me along because he knew I was a pilot acquainted with the Brazilian coast. Drake took from me my astrolabe, my navigation chart which embraced, however, only the Atlantic Ocean as far as the Rio de la Plata on the west and the Cape of Good Hope on the east, and my book of instructions. He also took the charts of my master and boatswain and divided them among his officers. He caused a chart of the coast of Brazil to be translated into English from the Portuguese, and as we went along the coast he kept on verifying it down to 24° which is as far as the Portuguese charts reach . . . March 10, we reached the coast of Brazil . . . Continuing our voyage south from 13°, Drake kept making soundings, until we reached 39°. The coast is very low and we saw little of it until we sighted land April 5, at 30°. . . .'

'In the port of Santiago in 32°. . . captured the ship of Juan Griego . . . on the 8th . . . we departed, taking with us the ship, Juan Griego the pilot . . . At Callao he left in her Juan Griego . . . on the 20th the Captain, with a pinnace took a ship bound for Lima . . . Drake took out of her only the bread, some hens and a hog, and the pilot, an old man. Towards noon on the 1st of March we spied the ship laden with silver, called the Cacafuego . . . On the 6th, at night. Drake then let the ship go putting in her three pilots whom he had brought along. . . .'

1 In 1579.
On the 20th a frigate passed close by, which they captured... on board two pilots... Later Drake put the Spanish sailors in the pinnace and let them go, but took with him the ship and one of the pilots named Colcherco with the letters, papers, and maps which he had with him. Among the letters were those from the King of Spain to the Governor of China. These Drake prized highly, saying he would take them to his Queen. Among the maps were the sea cards by which the voyage was to be made. This pilot was acquainted with the China route and Drake consulted with him about matters concerning navigation... [the 6th April] Drake turned her loose [another prize] leaving in her the China pilot and all the others who had been taken except one sailor whom we took along to show us where fresh water would be found... passing the port of Guatulco, on the 13th... Drake put me into the ship in the port whose Captain was Juan Gomez without previously having shown any intention of leaving me anywhere during the voyage... While in Guatulco Drake took out a map and pointed on it how he had to return by a strait which is in 66° and that if he did not find it, then by way of China. He carries three books of navigation, one in French [perhaps Nicolas de Nicolai's translation of Pedro de Medina's manual, L'Art de Naviguer, Lyons, 1554], one in English [either, Eden's translation of Cortes's work, The Arte of Navigation, London, 1561 or, Bourne's Regiment for the Sea, London, 1574], and another, the account of Magellan’s voyage, in a language I do not know [either, Maximilian of Transylvania’s De Moluccis Insulis, Rome and Cologne, 1523, or, Pigafetta’s Le Voyage et Navigation fait par les Espanolz éc isles de Molliucques, Paris, 1525, in translation in a language not known to da Silva]. He carries a book in which he writes his log and paints birds, trees and seals. He is diligent in painting and carries along a boy... who is a great painter; shut up in his cabin they were always painting. He has a map of the world made in Portugal but by whom I do not know, and some other maps which he said had been made in England. The first thing he did when he had captured a vessel was to seize the charts, astrolabes and mariners’ compasses which he broke and cast into the sea... He is a very skilful mariner...’

Appendix No. 13

See Pl. XXXVII.

A Page of Captain Hall's Journal of the Voyage of 1578 to the North-West, Harleian 167, fol. 199r. 'Ye account of the third Voyage to Meta Incognita, made by Mr. Christopher Hall, Mr. of the ship Ayde, and now pilott in the ship Thomas Allyn'.

September. 1578.

no ground at 150. faddom, and then I did hoyste over bord 2 mariners that did dye this night before the ship sayled ENE—

from 4 to 8, the winde at W. little winde the ship sayled East North East—

from 8 to myndight the winde at N.N.W. a good gale the ship sayled East North East—

from myndight to 4 in the morning the winde at N.N.W. by the 2. corse (a) the ship sayled E.N.E. The 25 of September thursday, from 4 to 8. the winde at N.W. & by N a stout gale the ship sayled by the 2 corse (a) East and by North—

from 8 to 12 of clock at None the winde at North west & by N a stout gale, the ship sailed E & by N. from 12 to 4 of clock at afternone the winde at N.W. & by N a stif gale of winde the ship saild E.N.E.

And at the ende of this wache I toke in my fore corse, & sounded & had .70. faddom & fyne softe sand with 3. blackes amongst & some white sand about the red cloth,(b) Silly beeing from me. 8. leages East and by South—

from 4 to 8. the winde at N.W. & by N. the ship sayled East South East, & in the myddst of this watche I sounded & found .70. faddom and fyne soft sand and then I set my fore corse and sayled South East from 6. to 12 of clock at myndnight—

from 12 to 4 in the morning, the winde at N.N.W. the ship sailed East—

The 26. of September friday from 4. to 8. the winde as before, the ship sayled East N.E.—

from 8. to 12 at none, the winde at N & by N. [W] a stif gale, the ship sailed East North East—

from 12. to 4 of clock, the winde at N.W. a fayre gale, the ship sayled N.E.—

from 4 to 8 the winde at N.W. a fayre gale the ship sayled North East—

(a) signifies the ship was sailing with the fore and main courses set.
(b) the piece of cloth dipped in tallow with which the bottom of the lead was 'armed' to find the nature of the bottom.

38—A.O.N.
Appendix No. 14

Instructions to be observed by Thomas Bavin, 1582.

B.M. Add. Ms. 38823, ff. 3v–5v. (By Courtesy of the Council of the Hakluyt Society in whose series of documents on the English voyages to North America, edited by Professor D. B. Quinn, Ph.D., it is to be included).

Lett Bavin carry with him good store of parchments, Paper Ryall, Quills, and Inck, black powder to make yncck, and of all sortes of colours to drawe all thinges to life, gumme, pensyll, a stone to grinde Colours, mouth glue, black leade, 2 payres of brazen Compasses, And other Instrumentes to to [sic] Drawe cardes and plottes.

Also lett him carry with him your Sea Instrumentes, A flate watche Clock, which dothe shewe & devide the howers by the minutes, and such a one as will runne .24. howers or .40. howers without any winding vp and lett the whelles be gylded or silvered, for yt will preserve them from ruste.

Also lett him carry with him .2. Instrumentes thone for the variacion of the Compasse, the other for the declyning of the nedle, noting in every destinct place and elevacion, the declyning of the nedle and the variacion of the Compasse.

Also yf you have with you .3. good Clockes made, as is aforesayd with your universall Dyall you may with them precisely observe the longetude of every place bothe by Sea and land duly observing those instructions I gave you for the same.

Also lett Bavin never go att any tyme without a payer of writing Tables.

And one alweis to atten him with penne Inck and paper and somme others to attend him with an universall Dyall A Crosse staffe and Ephimerides or somme other Calculated Tables to observe the latitude. The instrument for variation of the Compasse the instrument for the Declynacion of the nedle and A sailinge Compasse.

[f.4] Also lett him carry a vniversall Dyall And by that Dyall sett your Clock precisely from tyme to tyme by the Sonne and kepe your Clock in suche precise sort going .3. or .4. Dayes before the 19. day of June next to thend you may thereby observe the Iust protest of the hower of the day when the eclipse of the Sonne shall then & there appear vnto you.

And note the same exactly The which eclipse will appeare to vse att London att .4. of the Clocke and .5. mynutes in the morning the same 19. day of June as the Almanack of this yeare .582. will shewe.

By which observacion you may certainly knowe the true longitude of the place where you shall make this observacion yf the same eclipse shall then and there appeare vnto you.

Also sett downe the sayd eclipse by painture in the very place of your plott where you shall observe the same taking the elevacion of the pole att the same place noting the same downe in figures in the self same place & even there observe bothe the variacion of the Compasse & declyning of the nedle.

And for the more certentie thereof note all the observations of the same eclipse Togither with the latitude of the place in the captains Jornall.
Also by your vniversall Dyall you may alweis finde the variacion of the Compasse att noonetyde by observing how farre your Compass dothe differ from your Just meridian which difference sett downe in the same place of your Carde where you shall observe the same by drawing A doubwe flye Noting also the iuste observacion of the same pole in the same place.

Also lett Bavin in the Discovery drawe to lief one of each kinde of thing that is strange to vs in England by the which he may alweis garnishe his plott As he shall se causse vppon his retourne. As by the portraiture of one Cedar Tree he may Drawe all the woodes of that sorte and as in this so may he doe the like in all things ells.

A[I]so you shall not neede to sett downe any lynce for devision of degrees in any of your first draftes in paper before all your plattes shall be perfectely finyshe for losse of tymce.

Also sett downe in your plattes the places where any oysters moustells with pearle or any other shell fishe shalbe founde.

Also drawe and sette downe the distinct places & countries by drawn plott as also by writing and observe with their iuste latitudes where you [f.4v] Shall fynde any thing worth the noting either like our thinges in Europe or differing from them in any manner of way Noting alweis the differences in Colour or quantetic atloughhe theybe of one sorte As the Newlandes herring ys farre bigger then ours being bothe of one kinde.

Also lett Bavin in his first plottes vse sevral marckes for severall things to be sett downe without alteration, As one for Woodes, another for hills, Another for Rockes, another for shelves, another for the Channel of a Ryver not altering his marckes vntill he shall perfectly finyshe his whole Discovery Noting the Depth of the Shelves by the foote and the depth of the Channells with fathams. As in figures the number of the foote or fathams.

Here followe the particular markes of every thing to be sett downe in the first draughte of his plottes. [Conventional signs]. [f.5]

Adding also to every marck the name of that kinde of thing that it betokeneth as vnder his marck of woodes which serveth for all sortes of Trees without alteration write the name of that kinde of Tree as the same Wood ys of As Cedar yf the wood be of Cedar Trees and Firre yf y be of Firre trees and so of all the rest.

Also devide your plattes of the Countrey into sondrye particular Cardes of 4 shetes of paper Royall alongest by the Sea coste According to the bigges of the Table of your Instrument or as you shall see causse for your best devision of the bondes either by ryvers head landes &c.

In making of your bounds make princypall choice of your marckes vppon the Cost for your better devisions by Sea.

Also becausw you may the better knowe how theise cardes should be rightly Joyned together you may note them vpon the Sea costes beginynge the first towards Cape Florida with a great .A. and the next card with .B. and so to the end of the Crosse row. And then beginne againe in the same order with the rest of your Cardes with a douuble .A. and a douoble .B. Mutlepleyeing your letters as occasyon shall requier Till your whole discovery be perfectly finyshe & sett downe in platt which I wold not have sett down with figures least yt might breede mistaking of the latitude formalye appointed to be noted in them.

Also in the making of this particular Cardes precisely sett downe in figures the iust latitude of every Notatious place to be there. Noted as you shall observe the
same and especially note yt on the particular Carde Aswell within land as vpon
the Sea Cost And also in any case [f. 5r] Omitt not to sett downe the same in
any place where you shall finde any difference of latitude Be yt never so litle.
Also observe alweis one proportion in your skale without alteration be yt of
never so smale an Island or thing worthc the mesuring. For yt you alter your
skale you shall never make your plottes vniforme.
Also by your Instrumentes iustly mesure and sett downe the distances of
Capes hedlandes and hilles the depth & bredthe of havens & bayes & ryvers
placing vpon cache of them in figures their severall elevacions and to vse the
like order within lande for Champions1 Woodes hills dales Lakes pooles &
ryvers. Noting Distinctly the Diversitye of the nature of every kinde of grownde
by yt self.
Also note how the Soyle ys compassed or furnished with hills medowes
woodes or Champions or whether they be garnished with ryvers freshe water
springes or bogges. Setting Downe their height bredthe & distances.
Also sett Downe in your plottes the dyvers sortes of Trees in each of their
particuler places be yt in woodes or otherwise dispersed naming the woodes
by those kinde of Trees that shall most growe therin.
Also drawe to lief all strange birdes beasts fishes plantes herbes Trees and
fruictes and bring home of cache sorte as nere as you may.
Also drawe the figures and shapes of men and women in their apparell as
also of their manner of wepons, in every place as you shall finde them differing.

1 Champaign, open country.
Appendix No. 15

An advertisement of instruments and instrument makers in London in 1582.

'Scales, compasses, and sundry sorts of Geometricall instruments in metall, are to be had in the house of Humfrey Cole, neere vpto the North dore of Paules, and at the house of John Bull at the Exchange Gate: in wood, at John Reades in Hosier Lane, at James Lockersons dwelling neere the Conduit at Dowe gate, and at John Reynolds at Tower Hill. Every figure in this Treatise is drawn according to some Scale, therefore the hauing of scales and compasses, and applying them to those figures, will make the demonstrations, and proofs herein very easie to the readers thereof, though they vsnderstand litlle or nothing in Geometrie. I haue thought good to give advertisement hereof, because many that would prouide such things, knowe not where to haue them.'

Appendix No. 16

Richard Hakluyt on the establishment of a navigational lectureship in London.
From The Epistle Dedicatory of Divers Voyages, London, 1582.


Whiche thing, that our nation may more speedily and happily performe, there is no better meane, in my simple judgemént, then the increase of knowledge in the arte of navigation and breeding of skilfulness in the sea men: whiche Charles the Emperour, and the king of Spaine that nowe is, wisely considering, haue in their Contractation house in Siuell, appointed a learned reader of the sayde art of Navigation, and joyned with him certayne examiners, and haue distinguished the orders among the sea men, as the groomet, whiche is the basest degree, the marriner, which is the seconde, the master the thirde, and the pilot the fourth, vnto the which two last degrees none is admitted without hee haue heard the reader for a certaine space (which is commonly an excellent Mathematician, of which number were Pedro di Medina, which writte learnedly of the art of navigation, and Alonso di Chauze and Hieronimus de Chauze, whose works likewise I haue seene), and being founde fitte by him and his assistants, which are to examine matters touching experience, they are admitted with as great solemnitie and giuing of presents to the ancient masters and Pilots, and the reader and examiners, as the great doctors in the Vniuersities, or our great Sergeantes at the law when they proceed, and so are admitted to take charge for the Indies. And that your worshippe may knowe that this is true, Master Steven Borrows, nowe one of the foure masters of the Queene's nauie, told me that, newly after his returne from the discouery of Moscouie by the North in Queene Maries daies, the Spaniards hauing intelligence that he was master in that discouerie, tooke him into their contractation house at their making and admitting of masters and pilots, giuing him great honour, and presented him with a payre of perfumed gloues, woorth fiue or six Ducates. I speake all this to this ende, that the like order of erecting such a Lecture here in London, or about Ratcliffe, in some conuenient place, were a matter of great consequence and importance for the sauing of many mens liues and goods, which nowe, through grosse ignorance, are dayly in great hazerds, to the no small detriment of the whole realme. For whiche cause I haue dealt with the right worshipfull sir Frances Drake, that seeing God hath blessed him so wonderfully, he woulde do this honour to him selfe and benefit to his countrey, to bee at the cost to erect such a lecture: Whereunto, in most bountifull maner, at the verie first, he answered, that he liked so well of the motion, that he would giue twentie pounds by the yeare standing, and twentie pounds more before hand to a learned man, to furnish him with instruments and maps, that woulde take this thing vpon him:
yea, so readie he was, that he earnestly requested mee to helpe him to the notice of a fitte man for that purpose, which I, for the zeale I bare to this good actio', did presently, and brought him one, who came vnto him and conferred with him thereupon: but in fine he would not undertake the lecture vnless he might haue fourtie pounde a yeere standing, and so the matter ceased for that time: howbeit, the worthie and good Knight remaineth still constant, and will be, as he told me very lately, as good as his worde. Nowe, if God shoulde put into the head of any noble man to contribute other twentie pounde to make this lecture a competent liuing for a learned man, the whole realme no doubt might reapc no small benefite thereby.
Appendix No. 16

B


Right honorable; the famous disputations in al the partes of the mathematices which at this present are held in Paris for the gayning of the lecture which was erected by the worthy scholer Petrus Ramus to the greate increase of those excellent sciences, put mee in mynd to sollicite your honour agayne and agayne for the erection of that lecture of the arte of Navigation whereof I haue had some speach with your Honor, sir Francis Drake, and Alderman Barnes and other. And that you might meet with al inconveniences which might frustrate the expected profit which is hoped for by the erection of the same I send your honour heare the testament of Petrus Ramus newly put out agayne in printe and sent vnto mee by monsieur Bergeron Ramus his executor, wheryby you may see first the exceeding zeale that man had to benefit his countrey, in bestowing 300 livres (which as your honor knoweth) is fiftie pound sterling, vpon establishing of that lecture, bequething not halfe soe much to al the kinred [sic] and frindes he had in the world. Secondly you may note that he being one of the most famous & clerkly of Europe thought those sciences next after diuinitie to be most necessarie for the comun welth, in that he erected a newe lecture of the same, wheras there was one before erected and endued with fiftie pound stipend by the Kings of France. Thirdly that most provident order which the good man by his wil hath taken, is most requisite to be put in execution in England: which is, That every three yeares, there shalbe publike disputations signified to al men by publike writing, wherein yt shalbe free for any man for three monethes space to dispute agaynst the reader for the tyme being, who yf he bee found negligent, or yf any one of the competitours be found more worthy by the opinion of certayne indifferent men of lerninge chosen out of purpose to be judges, that then the vnworthier shal give place to the more sufficient: who soe being placed is bound in three yeares space to read through the course of the mathematickes. Yf by your honors instigation her majestie might be endued to erecte such a lecture in Oxford, and the like for the arte of navigation might be some other meanes be established at London, allowing to ech of them fiftie pounds yearly with the same conditions, in my simple judgement yt wold be the best hundred poundes bestowed, that was bestowed these five hundred yeares in England For it is not vnknowne vnto your wisedome, howe necessarie for service of warres arithmetick and geometric are, and for our newe discoueries and longe voyages by sea the arte of navigation is, which is composd of many partes of the aforesayd sciences. Vnderstanding heeretofore of your honors greate abundance of busines, and your dangeroue sicknes, I thought yt not meet to trouble your honor with such things as I had carefully sought out here in France concerning the furtherance of the westerne discoueries but chose rather to imparte the same with Mr. Carlile, which thinge I also did. But being lately advertised of your recovery (for which I
humbly thank ye almighty God) I was bold to signify vnto your honour my dealing with Horatio Palavisini to become an adventurere in those westerne voyages, and among other talke, alleadged your good disposition to the same, which he hearing of replyed very cheerfully, that yf he were moved thereunto by the lest word from your honor, he wold put in his hundred pound adventure or more. Yf Mr. Carlile bee gon, yet yt might come in good tyme to serue Mr. Frobishers turne, yf your wisdome shold like wel of yt, seing he setteth not fourth as I vnderstand vntil the beginning of may

I vnderstand that the papistes giue out secretly in the towne that there shall shortly come forth a confutation of the defence of the execution of custice [?] in England which was set forth in English and french in London. When yt cometh forth I trust to haue yt with the first . . . Those that favour the Spanish here in the towne haue spread al abroad these two or three Dayes that Monsieur is dead: which is nothing soe. Thus leving other matters & aduertisementes of importance to them vnto whom they appertayne, with remembrance of the continuance of my humble dutie to your honor, and your worthy and vertuose sonne in lawe I leve you to the merciful protection of the Almighty. Paris the first of April 1584. Don Antonio his captaynes of his fleet are not yet departed from Paris, but looke every day to depart.

Your honors most humble
Richard Haklut.

Endorsed: To the right honorable SIR
Francis Walsingham principall secretarie
to hir Maiestie giue these.
At the Courte
[in another hand]
Primo Aprilio 1584
From Mr. Hakluite the preacher at Paris.
Appendix No. 16

Richard Hakluyt on the results of Sir Walter Raleigh's employment of Thomas Harriot, the mathematician, to solve navigational problems, and to instruct him and his sea captains in the art of navigation, 1587. (See also Appendix No. 30.)


Ever since you perceived that skill in the navigator's art, the chief ornament of an island kingdom, might attain its splendour amongst us if the aid of the mathematical sciences were enlisted, you have maintained in your household Thomas Harriot, a [young] man pre-eminent in those studies, at a most liberal salary, in order that by his aid you might acquire those noble sciences in your leisure hours, and that your own sea-captains, of whom there are not a few, might link theory with practice, not without almost incredible results. What will shortly be the outcome of this excellent and most prudent departure of yours, even those whose judgement is no more than moderate will undoubtedly be able to divine with ease. This one thing I know, and that is that you are entering upon the one and only method by which first the Portuguese and then the Spaniards at last carried out to their own satisfaction what they had previously attempted so often at no slight sacrifice.
Appendix No. 16

D

Mathematical Navigation and the relationship between Dr. Dee, Thomas Hariot, Sir Walter Raleigh and Captain John Davis.

'The fresh experience of the happie and singuler skilfull pilotte and Captain Master John Davis to the northwest (towarde which his discoverie your selfe have thrice contributed with the forwardest) hath shewed a great part to bee maime Sea . . .'


In the British Museum copy of El viaje que hizo Antonio de Espejo en el anno de ochenta y tres [1583] . . . Paris, 1586, the title-page bears in John Dee's hand the inscription 'Joannes Dee; A° 1590, Ianuarij 24 Ex dono Thomas Hariot, Amici mei.'
Appendix No. 17

A

Instructions concerning the delivery of the lectures on Astronomy and on Geometry at Gresham College, laid down in 1597 and adhered to throughout the seventeenth century.

The standard authority on the Gresham Professors is: Ward, J., The Lives of the Professors of Gresham College (1740).

The following extracts give Ward's opinion of the contribution of Gresham College to the arts and sciences. They also give the most important instructions concerning the time and manner of delivery of the lectures on geometry and astronomy.

WARD ON THE CONTRIBUTION OF THE GRESHAM PROFESSORS TO THE ADVANCEMENT OF SCIENCE:

'The reader will find here many things, which give no small light to the state of learning in England for more than a century past. The writings of the professors... the improvements in several arts and sciences, which have been owing to them, might be thereby seen in their order. And as these, among a variety of other subjects, relate to mechanics, statics, anatomy, chymistry, geometry, astronomy, and navigation, than which nothing can be of greater service to trade, the benefits, which the city of London has received from their labours will appear to have been very considerable...’ Vol. i. Preface, p. ii.

INSTRUCTIONS CONCERNING THE LECTURE ON ASTRONOMY AND GEOMETRY

In January 1597 it was laid down:

'The solemn lectures of astronomy and geometry are to be read... either of the said lectures twice every week, on Friday astronomy, on Thursday geometry, between the hours of eight and nine in the forenoon, and two and three in the afternoon; whereof the lectures in the forenoon to be in Latin, and the lectures in the afternoon to be in English.1 Touching the matter of the said solemn lectures, the geometrician is to read as followeth, viz. every Trinity term arithmetique, in Michaelmas and Hilary terms theoretical geometry, in Easter term practical geometry.2 The astronomy reader is to read in his solemn lectures, first the principle of the sphere, and the theoriques of the planets, and the use of the astrolabe and the staf, and other common instruments for the capacity of mariners; which being read and opened, he shall apply to use, by reading geography, and the art of navigation, in some one term of every year.' p. viii.

1 It was agreed, after much debate, to have the lectures in both languages so as to render them more useful to all sorts of hearers, foreigners as well as natives.
2 Michaelmas term was from October to November; Hilary term was from January to February; Easter, April to May; Trinity term was from July to August.
Appendix No. 17

B

A list of the Gresham Professors of Astronomy and Geometry from 1597 to 1631.

The following table is compiled from Ward's A List of the Professors of Gresham College in their several Faculties. It is corrected to New Style Calendar, for he took his year from 25 March and Old Style.

<table>
<thead>
<tr>
<th>Astronomy</th>
<th>Chosen</th>
<th>Resigned</th>
<th>or</th>
<th>Died</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edward Brerewood</td>
<td>Mar. 1597</td>
<td>Nov. 1613</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thomas Williams</td>
<td>Nov. 1613</td>
<td>Mar. 1619</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Edmund Gunter</td>
<td>Mar. 1619</td>
<td></td>
<td></td>
<td>Dec. 1626</td>
</tr>
<tr>
<td>Henry Gellibrand</td>
<td>Jan. 1627</td>
<td></td>
<td></td>
<td>Feb. 1636</td>
</tr>
</tbody>
</table>

Geometry

(a) Henry Briggs    | Mar. 1597 | Aug. 1620 |     | Jan. 1631 |
(b) Peter Turner    | Aug. 1620 | Feb. 1631 |     |         |
(c) John Graves     | Mar. 1631 | Nov. 1643 |     |         |

(a) First Savilian Professor of Geometry at Oxford from 1620–31.
(b) Second Savilian Professor of Geometry at Oxford from 1631.
The first Savilian Professor of Astronomy at Oxford was John Bainbridge.
(c) Second Savilian Professor of Astronomy at Oxford.
Appendix No. 18

A

MS. chart of the N.E. Atlantic from the Soundings to the Azores, on Mercator’s Projection. See Pl. LXI.

No. 52 in Maps, Charts, and Plans, No. 2, Hatfield House. This MS. chart bears a striking resemblance to Edward Wright’s engraved chart of the Azores in the 1599 edition of Certaine Errors.

It is on vellum and in a state of perfect preservation and vividly coloured. The coastlines are tinted, Ireland with red-brown, England and the Channel Islands bright blue-green, France sienna, Spain yellow, Portugal emerald green, the Azores dull green.

The compass roses are all brilliantly illuminated, the mother roses with red, yellow, blue, and two shades of green, the periphery half flies with red, blue, and yellow (N. & E. ones), or red, blue, yellow, and brown (S. one), or red, yellow, blue and two greens (W. one). The rhumbs are drawn in in the manner approved by Cortes in red, green, and black.

The lines of soundings are of interest. It will be noted that they run along parallels of latitude.

The mother rose is labelled at each rhumb from N. through E. to S. with letters indicative of the establishment of the various ports.

The appropriate establishment letter is placed against ports and capes from Finisterre to St. Malo and Chichester (not named) to Cardigan Bay in Wales (not named).

This is in accordance with Bourne’s wishes and Hood’s practice, except that on his surviving charts he did not give establishments on the English coasts.

The notations for variation are similar to Edward Wright’s ‘V.C. 6.30’ or indicating ‘compass variation (‘variatio compassi’) 6° 30’ East,’ (orient), ‘V.C. 4v occ.’ indicating ‘compass variation 4° West’, (occident).

The note in Latin below Pico in the Azores reads in translation very similarly to Edward Wright’s note on the 1599 chart.

The longitude scale is clearly drawn and boldly lettered and would appear to agree with Wright’s as regards the prime meridian—‘the western-most point of Africa’.

The feature that puts this MS. chart in a class by itself and akin to Wright’s is its latitude scale. It is on Mercator’s projection.

The distance between 37° N and 40° N is 2.30 in., between 49° N and 52° N, 2.78 in.

The variation off Start Point (Dartmouth) is 9° 30’ E,

in lat. 48° N, long. 6° it is 7° E,

N. of C. Finisterre 7° 12’ E,

W. of C. Finisterre 6° 15’ E, as in Wright’s,

S. of St. Michael’s 5° 20’ E,
APPENDIX NO. 18A

In lat. 47° 30' N, long. 346° 1' E.

'Variatio compassi nulla' occurs between lat. 37°-39° N in long. 346° precisely where Wright on his 1599 chart stated it to be zero.

Off the coast of Flores variation is 4° W as on Wright's.

The border is blocked in blue and white, the latitude and longitude scales in pink and yellow.

The 40th and 50th parallels are drawn in, and every 5th meridian.

It has every appearance of belonging to the close of the sixteenth century. It would appear to be the oldest MS. chart on Mercator's projection extant.

In an old inventory at Hatfield, a list entitled 'The register of all the platts contained in his booke', no. 20 is entitled 'Platt of the Sea Coastes Cart. 21', and this number is found in the same hand on the chart described above. The oldest dated chart in the collection seems to be 1604: No. 20. Platt of the Sea Coastes of England, by T.S.? 1604.

It is possible that this Azores chart was presented to Lord Burghley as an example of the new chart projection covering the area he was most interested in, the approaches to England and Spain and the strategically vitally important Azores. Possession of the Azores became essential to Spain for the security of her homeward bound Mexican and New Spain convoys as soon as Drake's and other English seamen's activities in the West Indies in the '70s threatened their safe passage. Hawkins, Drake, and Lord Burghley were always considering plans for participating in the Portuguese resistance to seizure of the Azores after their capture by Spain in 1582. The Azores were to Spain in the 1580s and '90s as Iceland was to England in 1940-5, and resumed their old importance between 1943 and 1945 with the institution of the Allied supply convoys from the United States and Caribbean to North Africa and the Mediterranean. This was marked by the establishment of Allied bases in the Azores in 1943.

In Wright's chart 'E' off 'Vshant', 'Arcason', 'Bayon', and 'C. Finister', are establishment letters evidently put in by the engraver or copyist. This feature and the various similitudes mentioned, and the agreement of the variation notations leave little doubt that it is a chart of the 1590s, and raise the question, was it the original of Wright's engraved chart of 1599?
Appendix No. 18

B

Captions on the Chart of the Voyage of the Earl of Cumberland to the Azores 1589, by Edward Wright in the first edition of Certaine Errors, 1599. This is the first English engraved chart on Mercator’s projection. See Pl. LVIII.

Wright’s Explanations on the Chart run as follows:

Top left-hand corner

The Meridians in this Chart are every where aequidistant: yet in all places, is kept the same proportion of Longitude, and latitude, that is in the globe: the degrees of latitude, increasing in the same proportion, wherewith the parallels, and consequently the degrees of longitude decrease in the globe: so as in all places, this Chart agreeith with the globe. It was thought more reasonable, to begin the longitude from the westemost part of the maine continent of Africa, Asia, and Europa, then from any small Islands, as the Canaries, or the Azores, especially seeing those reasons fail, which Ptoleme, and Mercator to begin their account from hence: whereof the one knew no land more westerly then the Canaries: the other thought the true and magnetical meridian agreed in one at the Azores only.

The difference of longitude betweene the Rocke and S. Michaels, we make to be about XV degr. agreeable to the often experience of English Navigators, who (for the most part) haue made the distance betwixt those places, to be about two hundred and thirty English leagues, though some would haue that distance to be lesse. But they may easily erre half a score leagues in a hundred, because the way of finding distances from east to west at sea is for the most part conjectural, in assestimating how much way the ship maketh, in saying. The latitudes and courses of the Islands Azores each from other, we obserued as followeth; The latitude of Fayall towne, 38 degr. 54 min. The latitude of Gratioosa 39 degr. 15 min. The latitude of Tercaera, 38 degr. 45 min. The latitude of S. Maries Iland, 37 degr. 15 min. The latitude of S. Michaels, 38 degr. The latitude of Dingleacush in Ireland, 52 degr. 12 min. The course from the eastermost part of Gratioosa to Pico, is Southwest and by south, Tercaera beareth from the same place southeast and by east. Riding at anker in Fayall roade, we sawe the Ile of Gratioosa by the west end of S. George Iland. S. Georges Iland lieth westwards from Tercaera. The moûtaine Pico lieth east southeast southerly, from the towne of Fayall. The letters V C signifie the variation of the compasse which how much it is, the numbers adioyned do declare, whereof the first sheweth the degrees, the second the minutes. The syllables or. or occ. shew whether the variation be orientall, or occidentall. About the longitude of 346 degrees and a halfe, betwixt the Islands of Fayal and Flores, it seemeth there should be no variation of the compasse.

[Bottom left-hand corner]

In the Iland Pico there is an exceeding high mountaine of the same name: the height whereof is almost three Italian miles vpriyght. The top of it is for the most part scene aboue the clouds.

[Middle, bottom]

The beginning of Longitude is taken from the westemost part of Africa.

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Appendix No. 19


He is addressing Lord Charles Howard, Earl of Nottingham, the Lord High Admiral.

'And here by the way most humbly crav'g pardon, and alwayes submitting my poore opinion to your Lordships most deep and percing insight, especially in this matter, as being the father and principall fauourer of the English Naviga'gion, I trust it shall not be impertinent in passing by, to point at the meanes of breed-ing vp of skilful Sea-men and Mariners in this Realme. Sithence your Lordship is not ignorant, that ships are to little purpose without skilful Sea-men; and since Sea-men are not bred vp to perfection of skill in much lesse time (as it is said) then in the time of two prentiships; and since no kinde of men of any pro-fession in the common wealth passe their yerers in so great and continuall hazard of life; and since of so many, so few grow to gray heires: now needfull it is, that by way of Lectures and such like instructions, these ought to have a better education, then hitherto they have had; all wise men may easily judge. When I call to minde, how many noble ships haue bene lost, how many worthy persons haue bene drenched in the sea, and how greatly this Realme, hath bene impover-ished by losse of great Ordinance and other rich commodities through the igno-rance of our Sea-men, I have greatly wished there were a Lecture of Navigation read in this Citie, for the banishing of our former grosse ignorance in Marine causes, and for the increase and generall multiplying of the sea-knowledge in this age, wherein God hath raised so generall a desire in the youth of this Realme to discouer all parts of the face of the earth, to this Realme in former ages not known. And, that it may appeare that this is no vaine fancie nor deuis of mine, it may please your Lordship to vnderstand, that the late Emperour Charles the fift, considering the rawnesse of his Sea-men, and the manifolde shipwrackes which they susteyned in passing and repassing betwene Spaine and the West Indies, with an high reach and great foresight, established not onely a Pilote Major, for the examination of such as sought to take charge of ships in that voyage, but also founded a notable Lecture of the Art of Navigation, which is read to this day in the Contractation house at Siuil. The readers of which Lecture have not only carefully taught and instructed the Spanish Mariners by word of mouth, but also have published sundry exact and worthy treatises concerning Marine causes, for the direction and incouragement of posteritie. The learned works of three of which readers, namely of Alonso de Chauzez, of Hieronymo de Chauzez, and of Roderigo Zamorano came long ago very happiely to my hands, together with the straight and seuere examining of all such Masters as desire to take charge for the West Indies. Which when I first read and duely considered, it seemed to mee so excellent and so exact a course, as I greatly wished, that I might be so happy as to see the like order established here with vs. This matter, as it seemeth, tooke no light impression
in the royall brest of that most renowned and victorious prince King Henry the eight of famous memory: who for the increase of knowledge in his Sea-men, with princely liberalitie erected three severall Guilds or brotherhoods, the one at Deptford here vpon the Thames, the other at Kingston vpon Hull, and the third at Newcastle vpon Tyne: which last was established in the 28. yeere of his reigne. The chiefe motiuies which induced his princely wisdome hereunto, himselfe expresseth in maner following. Vt. magistri, marinarij, gubernatores, & alij officiarij nauium, iuuentutem suam in exercitacione gubernationis nauium transigentes, mutilati, aut aliquo alio casu in paupertatem collapsi, aliquo releuamen ad eorum sustentationem habeant, quo non solum illi reficiantur, verumtiam alij iuuenes moueantur & instigentur ad eandem artem exercendam, ratione cuius, doctiores & aptiores fiant nauibus & alij vasis nostris & aliorum quorumcunque in Mare gubernantis & manutenendis, tam pacis, quam belli tempore, cum opus postulet, &c. [In order that masters, mariners, pilots, and other ship’s officers, spending their youth in the management of ships, disabled or by some ill fortune reduced to poverty, should have some relief for their maintenance whereby not only may they be sustained but other young men may be moved and encouraged to exercise the same skill, and so become more skilled and proficient in pilotage and maintenance of ships and other craft at sea, both our own and any others in peace or war, as necessity arises, etc.] To descend a little lower, king Edward the sixt that prince of peerelesse hope, with the advise of sage and prudent Counsaille, before he entred into the Northeasterne discouery, advancement the worthy and excellent Sebastian Cabota to be grand Pilot of England, allowing him a most bountiful pension of 166.li.vj.s.vij.d. by the yeere during his life, as appeareth in his Letters Patents which are to be seene in the third part of my worke. And if God had granted him longer life, I doubt not but as he delt most royally in establishing that office of Pilote Maior (which not long after to the great hinderance of this Common wealth was miserably turned to other priuate vses) so his princely Maiciestie would have shewed himselfe no nigard in erecting, in imitation of Spaine, the like profitable Lecture of the Art of NAVIGATION. And therefore when I considered of late the memorable bountie of sir Thomas Gresham, who being but a Merchant hath founded so many chargeable Lectures, and some of them also which are Mathematicall, tending to the advancement of Marine causes; I nothing doubted of your Lordships forwardnes in settling and establishing of this Lecture; but rather when your Lordship shall see the noble and rare effects thereof, you will be heartily sory that all this while it hath not bene erected. As therefore our skill in NAVIGATION hath hitherto bene very much bettered and increased under the Admiralty of your Lordship; so if this one thing be added thereunto, together with seuere and straight discipline, I doubt not but with Gods good blessing it will shortly grow to the hiest pitch and top of all perfection: which whensouer it shall come to pass, I assure my selfe it will turne to the infinite wealth and honour of our Countrey, to the prosperous and speedy discouery of many rich lands and territories of heathens and gentiles as yet vnknown, to the honest employment of many thousands of our idle people, to the great comfort and rejoicing of our friends, to the terror, daunting and confusion of our foes.'
Appendix No. 19

B

Richard Hakluyt on the art of navigation in the Epistle Dedicatoire and on pages 866–8 in the third and last volume of the second edition, 1600, of his Principal Navigations.

He is addressing Sir Robert Cecil, principal Secretary to the Queen.

‘And for an appendix vnto the ende of my worke, I haue thought it not impertinent, to exhibite to the grave and discreet judgements of those which haue the chiefe power in the Admiraltie and marine causes of England, Certaine briefe extracts of the orders of the Contractation house of Stiuil in Spaine, touching their government in sea-matters; together with The streight and seuer examination of Pilots and Masters before they be admitted to take charge of ships, aswell by the Pilot mayor, and brotherhood of ancient Masters, as by the Kings reader of The lecture of the art of Navigation, with the time that they be enioynd to bee his auditors, and some part of the questions that they are to answere vnto. Which if they finde good and benefical for our seamen, I hope they wil gladly imbracc and imitate, or finding out some fitter course of their owne, will seke to bring such as are of that calling vnto better governement and more perfection in that most laudable and needful vocation.’

‘The examination of the Masters and Pilots which saile in the Fleete of Spaine to the West Indies: Written in the Spanish tongue by Pedro Dias a Spanish Pilot taken by Sir Richard Grimaile 1585.

‘First they make suit unto the Pilot maior (who at this present is called Alonço de Chiaues) that he would admit them to examination, because they are naturall Spaniards, and sufficient for the same.

‘Hereupon the Pilot maior commandeth the party to be examined, to giue information that he is a mariner, and well practised in those parts, about which hee desireth to be examined. And then immediately he bringeth fieue or sixe pilots before examined to giue testimonie that he is a good mariner, and sufficient to become a pilot, that he is a Spaniard borne, and that he is not of the race of the Moores, Jewes or Negroes.

‘Hauing made this information, hee presenteth it vnto the Pilot maior. And the Pilot maior seeing the information to be good, willeth the kings publique reader of navigation (who is now Roderigo Zamorano) to admit him to his lectures. Whither there doe resort fourteene or fifteene persons that desire to be examined: and they come to a certaine house which the kings reader hath appointed vnto him for the same purpose, at eight of the clocke in the morning: and then they stay two houres, and two houres likewise in the afternoone: in one of which houres Zamorano readeth vnto them, and in the other they aske one another many particulars concerning the art of navigation in the presence of the said kings reader: and him that answereth not to the purpose the sayd reader instructeth more perfectly, and telleth him how every thing is. And this exercise continueth two months, during which time the examinates must not faile to bee present twice in a day, as is aforesaid.

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And having heard the kings reader those two moneths, they resort then vnto The hall of examination which is in the Contractation house, where there are assembled the Pilot maior and divers other pilots, to the number of 25 at the least; who all sitting there in order, the Pilot maior demandeth of him that would be examined, of what part of the Indies he desireth to be examined: Thereto the exanimate answereth, that he would bee examined concerning Nueva Espanna, or of Nombra de Dios and Tiere Firma. And others that are not experienced in those partes, crave to be examined of Santo Domingo, Puerto rico, and Cuba.

Then the Pilot maior commandeth the exanimate to spread a sea-chart vpon the table, and in the presence of the other pilots to depart or shewe the course from the barre of Sant Lucar to the Canarie-Islands, and from thence to the Indies, till he come to that place whereof he is to bee examined, and then also to returne backe to the barre of Sant Lucar in Spaine, from whence he departed. Also the Pilot maior asketh him, if when he saileth upon the sea, hee be taken with a contrary wind, what remedie he is to vse, that his ship be not too much turmoiled upon the sea? And the exanimate answereth him aswell as he can.

Then one of the other pilotes opposeth him about the rules of the Sunne and of the North-starre, and how hee ought to use the declination of the Sunne at all times of the yeere: when the exanimate is bound to answere in euery thing that hee demandeth. Then another asketh him of the signes and markes of those lands which lye in his way to that hauen whereof he is examined. And then another demandeth, that if his mastes should be broken by tempest, what remedy hee would use? Others ask him, if his ship should take a leake, to the hazarding of the lives of himselfe and his company, what remedy he would find to stop the same with least danger? Others ask him, what remedy, if his rudder should chance to faile? Others oppose him about the account of the Moose and of the tides? Others ask him if a Pirate should take him and leave him destitute of his Chart, his Astrolabe, and his other instruments serving to take the height of the Sunne and of the starre, what course hee would take in that extremitie? Others demand other questions needfull for a mariner to know, which desireth to be a pilot. Unto all which the exanimate is very attentive, and answereth to euery particular.

After they haue all asked him so much as they think expedient, they bid him depart out of the hall, to the ende that every one of them may seuerally bee sworne upon a booke, that they will speake the trueth. Then they put into a certaine vessell of siluer standing there for the same purpose so many beanes, and so many peason as there are pilots within the hall: and euery one putting his hand into the vessell in order, he that thinkest the partie examined to be sufficient, taketh up a beane, and he that thinkest him not sufficient, taketh up a pease. After all that all have taken out what they please, the Pilot maior looketh what voyces the exanimate hath: and if he finde him to have as many voyces for him as against him, he commandeth him to make another voyage: but if he hath more voyces for him then against him, then they give him letters testimoniall of his examination signed by the Pilot maior, by the kings reader, and the secretary, and sealed with the seal of the Contractation house. And vpon the receipt of these letters testimoniall, the new pilot giueth a present unto the Pilot maior, and the kings reader, for their golues and hennes, euery one according to his abilitie, which is ordinarily some two or three ducats.

And then he may take vpon him to be pilot in any ship whatsoever, vnto that
place for which he was examined: and if he finde in the Indies any ship vnder the charge of a pilot not before examined, hee may put him out of his office, and may himself take charge of that ship for the same wages that the other pilot agreed for.

'The pilots wages for making a voyage outward and homeward is according to the burthen of the ship. If she be of 100 tunnes, he hath 200 or 250 ducats: and if shee bee of 400 or 500 tunnes, he taketh for his wages 500 or 550 ducates: and if she be bigger, he hath a greater allowance: ouer and besides all which, he hath every day while he remaineth on land, fourre reals for his diet. And the greater shippes are always committed vnto the more ancient pilots, because they are of greater experience and better skill, then the yonger sort which newly take vpon them to be pilots.

'The pilot vndertaketh no farther travell nor care, but in directing the course or navigation: for the masters of the ships take charge of the freighting and preparing their ships, and to pay the mariners, and to doe all things needesfull for the ship; for the pilot commeth not vnto the shippe, untill the visitours come to visite the same, to see whether hee hath all things necessary for the voyage.

'The visitours are fourre men which are appoynted by the king, and these are men of great vnderstanding: and they come to visite the shippes before they take in their lading, to see whether they be well prepared to make the voyage. And after the ships bee laden, they returne againe to visite them the second time, to see whether they haue all things necessary, according to the orders of the Contractation house: and whether they haue all their mariners, victuals, poudre, shot, and ordinance, and all other things necessary for the voyage. And if they want any thing, they charge them upon grievous penalties, to provide the same before they set out of the hauen.

'The ships that goe to the Indies are wont eche of them to have with them a Notarie, whose charge is to keepe a note of remembrance of all the marchandise which is laden in the ship, and to take the marks thereof, thereby to deliver the commodities in the ship to their particular owners, after they haue finished their voyage, and he serueth likewise to make wille, and other instruments, which are wont to be made by a Notarie, if any man chanceth to fall sicke. And his wages in eche voyage is as much as the wages of two mariners.

'The Generall of the fleetes vseth continually, after hee is arrived in the Indies, to send into Spaine a barke of Auiso, to aduertise the king of the state of his arriuall; And after the fleetes be ready to come home, he dispatcheth another pinnesse of Auiso to certifie them how the fleetes are now ready to set saile, with other particularities. There goe with the fleetes two great ships, the one as Admirall, the other as Viceadmirall, of the burthen of 400 or 500 tunnes, which carry nothing but victuals and souldiers for the wafting of the rest of the fleete, and these are payed out of the marchandise which come in the fleete, after the rate of one in the hundred, and sometime at one and an halfe in the hundred . . .

Furthermore, that no Master nor Pilot may carry any Chart, nor Astrolabe, nor Crosse-staffe, nor regiment, without they bee signed and sealed by the Pilot maior Alonso de Chieues, and the Cosmographer the kings reader Rodrigo Zamorano . . .

Written by me Pedro Dias borne in the Isle of Palma one of the Canaries, vpon the request and gratification of M. Richard Hakluyt, in February 1586.' (Vol. III, pp. 866–68).
Appendix No. 19

C

Richard Hakluyt on Sir Thomas Smith's contributions to the improvement of the teaching and practice of navigation, 1614.

'Your erecting of the Lecture of Navigation at your owne Expenses, for the better instructing of our Mariners in that most needful art: your setting downe of better orders in dispatching forth of our East Indian flotes: your employment with extraordinarie entertainment of skilfull Mathematicians and Geographers in the South and North partes of the world: This your providence and liberalitie is like, in time, to worke many speciall good effects.'

Richard Hakluyt's Dedication of The Dialogues in the English and Malaiane Languages... by Augustus Spalding, London, 1614, to 'the truly Honorable and right worthy Knight, Sir Thomas Smith, Governor of the East India, Muscovia, Northwest Passages, Sommer Islands Companies, and Treasurer for the first Colonie in Virginia'.
Appendix No. 20


(One of the two earliest descriptions published of arithmetical navigation.)

In 1614 the first explanations of arithmetical navigation to be published appeared in London. The fullest was in Ralph Handson's appendix to his translation of Pitiscus's Trigonometry, the simplest was in The Newe Attractive, printed for John Tapp by T.C., London, 1614, and published shortly after Handson's Trigonometry. In this the declination and other tables of the second, 1585, and later editions were omitted. Borough's treatise Of the Variation of the Compass, bound with it, was also edited. Borough's concluding remarks of Chapter eleven of the 1581 and later editions (given below) were omitted: 'But I hope such as intende hereafter to write of Nauigation, will either frame their rules, precepts, and Instruments, with regard to the Variation, as herein I haue shewed, or els ease them selues of that travaile, for as good none as unprofitable'. In their place was put: 'But letting that pass, let these few following examples make knowne to the Judicious, what is fittest to be conceaued in their experimentall practices.' There follow six and a half pages of 'Certaine briefe and necessarie propositions, nauticall to be performed Arithmetically by the tables of sines, Tangents, and Secants.' Following these are tables of natural sines, tangents and secants.

'The principall thing that is chiefly to be considered in the art of navigation', explains the opening paragraph of the propositions, 'is to knowe directly, or so neare as Art may performe, the true pricke or place, of the ships being at any distance in the time of her voyage, which may be done to a certain neereness, though not precisely many waies: but Arithmetical Calculation being the most perfect, is therefore most to be regarded. For the knowledge of which pricke or place of the ship, things are principally to be desired and knowne (viz.) difference of Latitude, departure fro the meridian, or difference of Longitude, the true course that your ship hath made good her way ypon,\(^1\) and the distance or number of leagues of way that she hath gone, of which any two being gien you, may by the tables of Sines Tangents and Secants, find eyther of the other two. For by the difference of Latitude and course is found the distance. And againe, by the difference of Latitude and distance, is found out the course: also by the course and difference of Lat. is knowne the departure from the Meridian, and consequently the difference of Longitude. For the better understanding whereof, these few expositions following will sufficiently instruct you.'

'Proposition 1'

'The difference of Latitude, and distance gien to find the course.'

'As the leagues of difference of latitude is to the whole sine, so is the leagues

\(^1\) It is to be remarked that Tapp here uses the terms 'true course' and 'made good' in the modern sense, namely, the mean compass course steered, corrected for variation and for the effects of leeway, currents or tidal streams, the resultant course 'made good' being expressed in terms of angle from the true meridian.

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of your distance to the secant of your courses, distance from South or North."

In other words  \( \frac{d.\ \text{lat}}{R} = \frac{\text{dist}}{\sec (\text{Co})} \) where \( R = 1 \)

\[ \therefore \frac{\text{d. lat.}}{1} = \frac{\text{dist}}{\sec (\text{Co})} \]

\[ \therefore \sec (\text{Co}) = \frac{\text{dist}}{\text{d. lat.}} \]

Tapp gave for an example a difference of latitude of 20 leagues and distance of 36 leagues south-westerly, so that the working resolved itself into

\[ \sec (\text{Co}) = \frac{36}{20} \times 10,000 \text{ (the whole sine)} \]

\[ = 18,000 \]

\[ = \text{Secant of } 56^\circ 15' \]

\[ \therefore \text{Course was 5 points West or South, or 'S.W. and by W.'} \]

'Proposition 2'

'The difference of Latitude and course being known, to find the departure from the Meridian, and consequently the Longitude.'

'As the whole sine is to the leagues of difference of Latitude: so is the tangent of the courses distance from South or north, to the leagues of departure from the Meridian.'

Tapp gave:

\[ \text{d. lat. } = 1^\circ \]

\[ \text{co. } = \text{SW & by W} \]

\[ = 56^\circ 15' \]

\[ \therefore \text{Formula } = \frac{1}{\text{d. lat.}} = \frac{\tan (\text{Co})}{\text{dep.}} \]

\[ = \text{dep. } = \text{d. lat.} \tan (\text{Co}) \]

\[ = 20 \tan. 56^\circ 15' \]

\[ = 20 \times 14.966 \]

\[ = 299.320 \]

\[ = \frac{299.320}{10,000} \]

\[ = 29.9320 = 90' \]

\[ = 1\frac{1}{4}^\circ \text{ of a great circle} \]

'This devide by the minutes that make a degree in the Latitude, where you find yourselfe to be, it gyues you the difference of Longitude in the said parallel.

'Proposition 3'

'The course and difference of latitude giuen to finde the distance.'

'As the whole sine is to the minutes of difference of Lat. so is the Secant of the courses distance from South or north to the miles of distance.'

i.e., \[ \frac{1}{\text{d. lat.}} = \frac{\sec (\text{Co})}{\text{dist.}} \]

\[ \therefore \text{dist. } = \text{d. lat. sec. (Co)} \]

'Example.'

'The difference of Latitude one degree or 60. miles, and the courses distance, 56.d.15.m. from South to West to finde the distance, I multiplie 18. [secant of
by 16. [60]. the minutes of difference of Lat. whose product 1080000.
divided by 10000. the whole sine, the quotient thereof is 108 miles, or 36.
leagues that the ship hath sailed upon that course to alter one degree of Latitude.'

'Proposition 4'

'By course and departure from the Meridian, to finde the difference of Latitude.'

The formula for this was given as:

\[ \frac{1}{\text{dep.}} = \frac{\tan \,(\text{Co})}{\text{d.lat.}} \]

\[ \therefore \text{d.lat.} = \text{dep.} \times \tan \,(90-(\text{Co}) \text{ which is to-day expressed as } \text{d.lat.} = \text{dep.} \times \cot \,(\text{Co}) \text{ where } '\cot' = \text{Cotangent}. \]

Tapp gave:

\[ \text{dep.} = 90 \]
\[ \text{Co} = 56^\circ \, 15' \]

\[ \therefore \text{d.lat.} = 90' \times \tan \,(33^\circ \, 55') \]
\[ = 90 \times 6723 \]
\[ = \frac{605070}{10000} \]
\[ = 60' \]
\[ = 1^\circ \text{ of latitude.} \]

After this proposition Tapp continued:

'These few Propositions are sufficient for the examining and correcting of a
dead reckoning, upon any course or distance whatsoever: but first for the better
knowledg the said dead reckoning, it is necessary to have this following Table,
either alwaies by you, or els perfect in your memory, which give you (1) for each
point and half point, the degrees and minutes that belong to it. (2) the leagues
and parts of a league that raise or lay a degree upon each point. (3) the leagues,
and the points of leagues that you depart from the former Meridian in raising
or laying a degree, upon each said point and \( \frac{1}{2} \) point.' He then included a table
for raising and laying one degree of latitude, and continued:

'How to finde the angle of position ypon a Trauaerse of seurall points.'

S.W.  8 L.    to bring all these into one direct course, with the difference of
S.W.S. 10 L.  Latitude and Longitude, whereby is knowne the true angle of
S.S.E. 11 L.  position, you must wokre for each point severally, first for the
E.S.E.  9 L.  difference of Latitude according to that proportion that each
point requires for the raising or laying of a degree . . . and
departure from the Meridian . . . and set them downe in order one under the
other . . .

<table>
<thead>
<tr>
<th>Points of dist.</th>
<th>Leags.</th>
<th>min. of</th>
<th>Departur from</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.W.</td>
<td>8</td>
<td>17 1/2</td>
<td>5 2/3 Westerly</td>
</tr>
<tr>
<td>W.S.W.</td>
<td>10</td>
<td>11 1/7</td>
<td>9 3/7 Westerly</td>
</tr>
<tr>
<td>S.S.E.</td>
<td>11</td>
<td>30</td>
<td>4 Easterly</td>
</tr>
<tr>
<td>E.S.E.</td>
<td>9</td>
<td>10 3/5</td>
<td>8 1/5 Easterly</td>
</tr>
</tbody>
</table>

Add all southerly mins. of latitude together = 69
Add all westerly departures together = 14 2/3
Add all easterly departures together = 12 1/3
Add all one from the other = 2 1/2 L.W.'
'So by this worke haue you 2. things knowne, viz. difference of Lat. and departure from the Meridian, thereby to finde the other 2. (viz.) course and distance, for which 2 other propositions will gie you satisfaction.'

'Proposition 5'

'By difference of Latitude and departure from the Meridian to finde the course.'

The formula he gave was:

\[ \text{dep.} = \frac{\text{d. lat.}}{\tan (\text{Co}) \text{ from E. or W.}} \]

\[ \therefore \tan (\text{Co}) \text{ from E. or W.} = \frac{\text{d. lat.}}{\text{dep.}} \]

or \[ \cot (\text{Co}) = \frac{\text{d. lat.}}{\text{dep.}} \]

'Proposition 6'

'The difference of Latitude, and the departure from the Meridian being knowne to finde the distance.'

'Square the miles of difference of Latitude, and the miles of departure from the Meridian, addde both the squares together, and from the product extract the square roote, which root the distance.'

'Example'

'The difference of Latitude 69 miles, the square thereof 5761. the departure from the Meridian 7\frac{1}{2} miles, the square thereof 112\frac{1}{4} both added together 5873\frac{1}{4} whose square roote 76 miles or 25 leagues is the distance required.'

'But this way is not in my judgement altogether so true as the working by the Table of Sines and Secants. for by this it is 25 and by the other as is shewed in the 3 Props: it is but 23, which I hold the truest.'

'Whoseuer desireth more exquisitnes in this kinde of Arithmetical sailing: let him practise S. Petiscus his doctrine of Triangles, lately translated into our vulgar tongue, by Mr. R. Handson for the benefit chiefly of our English Marinerers, and other practisers in the Mathematickes.'

'Finis'

Then followed 'A Cannon of Triangles: or The Tables, of Sines, Tangents and Secants, The Radivs assumed to be 100000.'

---

1 Tapp's mathematics were the cause of the discrepancy, \[ \therefore 69^2 = 4761, (7\frac{1}{2})^2 = 56\frac{1}{4}, \]

sum = 4817\frac{1}{4} of which the square root is 69 (nearly), or 23 leagues.
## Appendix No. 21

*Transcript from Sir Thomas Roe's Journal, 1615.*

B.M. Add. MS. 6115, fo. 9 recto. See Pl. LXVII.

<table>
<thead>
<tr>
<th>1615</th>
<th>Observations according to ye Table of course</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>It is Necessary that shipping be ready in the downes to take opportunity of wynd by the 20th of January, that they may fale with the Cape of Good Hope before the dead of wynter, whereby men may have some leasure of Refreshinges, and the sicke may recover in the warme seasons; for in the wynter the ayre is sharpe, and Rawe, and those that daylie wade, and are often wet, endainger their healths; and if the Roote Nangin be of value, it must be gathered in that Season, for when the sapp returns the roote is withered in the ground, and dring up shrinkes, and Comes to Nothing; besides the Season wilbe better to get aboute the Cape, subiecte to foule weather, and thereby they shall haue tyme enough to staye at the Isles of Comoro, for new refreshyng, which is necessarie; that men may come stronge, and in healtke, among their enemyes, for it is doubtfull that the Trade with the Mogull, must be mayntayned with Armes. I wish the Coast from the Cape as high as Mozambique were discouered it is very probable that is good matter, and doubtlese brave harbours. The Portugall hath trade for gould in a River, not far from Mozambique, and the people make fiers to any shipping they see, to invite them to commerce; This were done easily by two pinnaces (who might with great hope leave some men on that Coast) which after might goe into the Indies, and serve the Company to transport goodes from harbor to harbor, in Japan, Sumatra, Coromandell, or Java:</td>
</tr>
</tbody>
</table>

6. This day we lost sight of the Lizard, and begann our Course for the Cape of Good Hope:  

26. On this day in the Morning wee saw the Mayne of Barbary, making that for Fortauintura. and then stood away, S.W.b.S: till Noone, and saw land N.W. for the Canarye 8 leaues off; then we stooed SSW all night:  

27. At 6 in the Morning Cape Bugador bare E by S: 4 leaues off: wharby wee found 30 lea. error in westerly way: this Cape lyeth in 26 latt: 353° 50'. long: differing from the Meridian of the Lizard 6° 10'. by Mercators projection, but I suppose
<table>
<thead>
<tr>
<th>March</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations according to ye Table of course</td>
</tr>
</tbody>
</table>

it is layd 20 lea. to much to the E: the Canarye Islands in the same error: The land to the Sowthward trendeth SSW for steering SW by S. I could not cleare the land in 24 howers: So that when on the 26 day, wee tooke our selues to bee betweene the Island, we were, betweene the Mayne and Forteuentura: a sandy shoure 16 fadome: 4 lea: off: and steering that day 6. howers SW by S: we could only discerne land in the Topp for the Canarye: wheras had we bene with the Islandes, we should with that Course from Forteuentura haue shott faire out by the Canarye: The 24th at Noone the Mayne bearing E: in 26° 5 leaugs off wee shaped our Course: From the Cape Bugador, ther is a Currant that setts swift S.S.W. for from the 28 day to the 31th of March we had little wynd, yet by observation we rayssed euerey day aboue a degree, wherby I conclude the Current setts about two leaugs a watch, and more, aboord the shoare.

Aperill:

5: This day the sunne was in our Zenith crossing ye paralell at Midnight
Appendix No. 22

A

Sir William Monson on the advantage of a lighthouse at the Lizard, 1622.¹

Sir John Killigrew of Arwenack petitioned in May 1619 for permission to build a lighthouse on the Lizard. His declared aim was philanthropic; secretly he hoped to derive a good revenue from a compulsory levy on all ships, except fishermen, passing the Lizard. He got his patent in June 1619 but without the powers of levy. He at once fell foul of the local wreckers and of Trinity House, who resented the infringement of its rights.

The light was of coals burnt on a tower of brick and lime. By 1622 it would appear to have flickered out as a result of this opposition. However, Killigrew revived the scheme and, on the grounds of its utility, received a patent in December 1622 empowering him to receive a levy from ships passing the Lizard. But the opposition of Trinity House, who saw in it an infringement of its rights; of the Customs, who resented having to levy it; and of the shipowners, who had to pay it, rendered the scheme abortive. Monson here gives his views on the light:

'First, it may be alleged that ships coming in with our Channel seek not our coast in the night but in the day, and therefore needless.

'Secondly, that men do commonly fall with our coast about Plymouth or Dartmouth, and that many times men seek not the Lizard, either outward or homeward.

'Thirdly, that the Channel is there so broad that men may sail as well by night as day.

'Fourthly, the advantage that pirates will take by a light there placed.

'An answer to these objections:

'In time of war I hold it dangerous to maintain a light upon our coast, but in time of peace I think it very necessary, by the reasons following.

'The art of navigation is not so certain that a man can assume to himself what land he shall fall withal, or the time, and therefore seeing it is undetermined, it were fit men should be furnished with as many other helps as can be devised. But in my own particular I have oftener fallen with the Lizard in my return from the southward than with all other lands.

'There is no man that hath lain boyltinge at sea any time but will be glad to make a land, for a good landfall is a principal thing desired coming for our coast, and men shall be the more emboldened to bear in with the coast when they shall know a light upon the Lizard that will appear to them seven or eight leagues, for I have been informed it hath been so far descried.

'If men do not now covet to see the land until they come as high as Plymouth or Dartmouth, which I will suppose to be the Bolt [Bolt Head], yet when they shall know of a light placed upon the Lizard they will rather covet to shape their

course for the Lizard, where a light shall appear to them, then for any other headland that shall have no such mark. And what a comfort a ship in distress shall find by this light it is to be imagined by example of a traveller on land losing his way in a dark cold night and espying a light in a cottage, or hearing a ring of bells, by either of which he may be directed.

‘In the year 1589, I being at sea with my Lord of Cumberland, we sent home a Spanish prize to the value of a hundred thousand pounds, they coming for our Channel, and in distress, bore in with the land, thinking she had been shot in as high as Plymouth, but it happened that she was a little short of the Lizard and forced into Mounts Bay; there, two days after her coming to an anchor, she was cast away. A light from the Lizard at that time had saved a hundred men’s lives and 100,000 l. worth of wealth, for if she had known herself to be so nigh the Lizard the wind was so large as she might have gotten about the land with the foresail, and I dare say there was as good mariners on board her as that time could afford.

‘The year before this I remember Mr. Cavendish, in his return in his voyage about the world, falling with our Channel. Somewhat short of the Lizard he was taken with so great a storm as he could not make the land, and hath confessed to me he endured more hazard and trouble in two nights upon our coast than in his long navigation. Divers other mischances I could allege, together with the late several wrecks that have been in Mounts Bay, which is sufficient to prove the necessary convenience of a light to be placed on the promontory of the Lizard, so it be carefully performed and maintained with fuel as I am informed now it is.

‘And for answer of the breadth of our Channel about the Lizard, I say how broad soever the Channel is yet ships must put in with the shore, and no man but will be glad of the light and knowledge of a land in such a case.

‘I conclude my poor opinion that neither the spaciousness of the Channel coming in by day only with our coast, nor falling to the eastward of the Lizard, or the objection of pirates sufficient reasons to hinder the proceeding of so pious an undertaking as the light to be maintained on the Lizard, which intendeth, with good approbation, the safety and lives of his Majesty’s subjects, together with the wealth of the kingdom and increase of his Highness’s customs.

‘For that divers times men are mistaken of the land when they fall with it, by which mistaking many ships have perished, but the light will not only give knowledge of a land, but what land it is from whence they may shape their course.

‘If it be objected the Lizard and Scilly, the Gulf [Wolf Rock] and Land’s End lie east and west, so that seeking the Lizard they are in danger to fall with the others, therefore they haul not with it in the night.

‘In answer to that, whereas in the first objection it may be said they commonly fall not with the Lizard, but with the land about Plymouth or Dartmouth—which I will suppose to be the Bolt—if it be so and that they be assured of such a landfall, I say they may as well miss Scilly and the Gulf and fall with the Lizard, as to miss the Lizard and fall with the Bolt, the course being, but one or two points difference, and but three or four leagues betwixt them in distance.

‘If it be danger of haul in with the Lizard because of Scilly and the Gulf, as perhaps some will allege, I say the like danger is in hauling in with the Bolt, in respect of the Eddystone, that lieth more dangerously than the Gulf because it lieth in the course.

‘But suppose a man does haul eight leagues to the westward or eastward of the
Lizard, he shall have sight of the light and know certainly where he is. So that if he should be mistaken sixteen leagues in his reckoning he shall be helped by the view of the light.

‘If it happen that a man fall between Scilly and the Land’s End with a southerly wind, or in the night, or in a fog that they cannot descry land, if they escape the Gulf, which, as I have said, is no more dangerous than the Eddystone, they shall be more safer than hauling in with the shore as high as the Bolt, for they shall have sea room, and know certainly where they are by their sounding, for that side only affords ooze. As hauling betwixt the Lizard and the Bolt with a southerly wind, which is an embaying wind and commonly brings fogs and storms, a man shall be in danger to be put to the shore; therefore it may appear it is more safety to seek the Lizard, if a light be placed upon it, then to seek further into the Channel having no help but only art to help them.

WILL. MONSON.’
Appendix No. 22

B

Sir William Monson on 'The Convenience of a Lecture of Navigation'. [c. 1624].

In Naval Tracts of Sir William Monson, Vol. 4, N.R.S., Vol. 45, pp. 391–396 is printed Monson's Tract on the need for a public lectureship in navigation. Monson's Tracts were originally drawn up for publication in 1624. His reasoning is similar to Hakluyt's and he held high hopes of the practical value of applying mathematics to navigation, writing 'I am of opinion that there is no error the mariner finds at sea, either in card, star, instrument, or compass but upon his information may be reduced by the skilful mathematician and made perfect. If not suddenly yet time may work it by following such instructions as shall be prescribed by them.'

He concluded, 'Besides the common good we shall receive by this lecture, it will concern gentlemen to study the art of navigation, who, seeing the pleasure and the necessity of it, will make them forward in actions by sea which will be a great strength and stay to the kindom.'
Appendix No. 23

The Readership of Navigation to the Mariners at Chatham in the early 1630s.

In 1677 Robert Sliter petitioned the Navy Board to renew the stipend formerly allowed to a mathematician to teach mariners in the service of the Crown navigation and the use of mathematics generally.

He wrote: 'It appears by the records in the Clerk of the Cheques Office at Chatham, that in former time [by 1631] there was a stipend allowed to a mathematician for reading a mathematical lecture to his Majesty's servants relating to his navy and instructing them in the art of navigation and other parts of the mathematics, thereby to render them the more serviceable to the King and country...’ Rob. Sliter [1677].

See Knight, C., 'Navigation instruction in 1677', M.M., Vol. 16. The first holder appears to have been John Basset (fl. before 1633), whose Nautical Discourse refuting errors contained in Polter's Pathway to Perfect Sayling (1605) was published by Henry Bond, his successor as 'Reader of Navigation to the Mariners in Chatham Dockyard'. Bond probably succeeded Basset in 1633. Bond was in turn succeeded by Richard Burley. The lecture lapsed during the Civil War.

Appendix No. 24

A typical advertisement by a teacher of mathematics and navigation.

(Robert Hartwell’s advertisement in his 1623 edition of Robert Recorde's
The Ground of Arts.)

ARTS MATHEMATICALL

In Fleetstreete, neere the Cundite, within Hanging Sword Court, is taught by
Robert Hartwell Practitioner in the Mathematices, these Arts, Sciences, and
Faculties here-vander expressed.

In whole Numbers and Fractions.

The extraction of Rootes, viz. 
Square, Cube, 
Sursolid,

Arithmetick.

Of Astronomical or Physicall Fractions.
Of Proportions.
The Rules of Acquation, with Cosse,
or Algebra.

Principles with Practise and Demonstration.

Measuring of Land, and Reducing of Plots or Maps to any proportion.

Geometry

Plotting of Countries with diuers and 
sundrie instruments.
Measuring of any superficiall or solid content.

The doctrine of Triangles.

Plaine and 
Sphericall

With Vse of the Tables of
Sines,
Tangents,
Secants, and
Logarithmes.

Description, Demonstration, and vse of 
Instruments, viz.

Quadrant, Theodelite, plaine 
Table, Circumferenter, Pantometer, 
Circular Scale, M. Gunter’s Sector, and 
proportionall Ruler (by him) converted

Navigation

Principles thereof, with the making and 
vse of sundrie Instruments fitting that
Art. The vse and projection of Maps and
Charts.

Vse and demonstration of

The Sphere or Globe both 
Celestiall Globe in plaine by M. D. Hood.
All sorts of Astrolabes, and M. Blagraues Iewell.

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APPENDIX NO. 24

Dialling of all sorts, viz. 
\{ 
  \text{Fixed and Instrumentall} 
\} 
as well \{ 
  \text{Geometrically. Arithmetically. as Instrumentally.} 
\}

Accompts for 
\{ 
  \text{Merchants by order of Debitor and Creditor. Retaylers of all sorts.} 
\}

Perfecting of Accompts in Controuersie 
\text{Fide Seā} 
\text{Vide.}
Appendix No. 25

The names of the Several Instruments Captain Thomas James provided and bought for the Voyage of 1631–32 in his intended Discovery of the North-West Passage into the South Sea.

from The Strange and Dangerous Voyage of Captaine Thomas James, London, 1633.

The Preparations to the Voyage . . . the better to strengthen my former studies in this businesse, I seake after Journals, Plots, Discourses, or what-euer else might helpe my understanding.

I set skilfull workemen to make me quadrants, Staues, Semicircles, etc. as much, namely, as concerne the Fabricke of them: not trusting to their Meccanick hands to diuide them, but had them diuided by an ingeniose practitioner in the Mathematickes. I likewise had Compasse-needles made after the most reasonabolest and truest wayes that could be thought on: and by the first of April, everie thing was ready to be put together into our hopfull Ship . . . [p. 4.]

(Fol. Q r & v). The Names of the suerall Instruments, I prouid and bought for this Voyage.

A Quadrant of old seasoned Pearettee-wood, artificially made: and with all care possible diuided with Diagonals, cuen to minutes. It was of four foote (at least) Semidiameter.

An Equilaterall Triangle of like wood; whose Radius was fiue foote at least; and diuided out of Petiscus Table of Tangents.

A Quadrant of two foote Semid. of like wood: and with like care proiectd.

The Sights, Centers and everie other part of them lookt to, and tryed with conuenient Compasses: to see if they had been wrongd or altrd. And this continually, before they were made vse of.¹

Staues for taking Altitudes and Distances in the heauens.²

A Staffe of seuen foote long, whose Transome was foure foote; diuided into equal parts by way of Diagonals, that all the figures in a Radius of tenne thousand might be taken out, actually.

Another of sixe foote, neere as conuenient: and in that manner to be vscd.

Masters Guntervs Crosse-Staffe.

Iacobs Staues, proiectd after a new manner, and truly diuided out of the Table of Tangents.

Two of Master Davis Backe-staucs: with like care made and deuided.

Of Horizonall Instruments.

Two Semicircles, two foote Semidiameter: of seasoned Pearetree wood: and diuided with Diagonals to all possible exactnesse.

Sixe Meridian Compasses, ingeniously made; besides some doozens of others, more common.

Foure Needles in square boxes, of sixe inches Diameter, and other sixe, of three inches Diameter.

¹ The above instruments were for use in surveying.
² These were for finding latitude and longitude.
Moreouer, foure speciell Needles (which my good friends Master Allen and Master Marre gaue me) of sixe inches diameter, and toucht curiously with the best Loade-stone in England.

A Loade-stone to refresh any of these, if occasion were; whose Poles were marked, for feare of mistaking.

A Watch-Cloke of sixe inches Diameter and another lesser Watch.

A Table euery day Calculated; correspondent to the Latitude, according to Master Gunters directions in his booke; the better to keepe our Time and our Compasse, to judge of our Course.

A Chest full of the best and choicest Mathematicall bookes that could be got for money in England; as likewise Master Hackluite and Master Purchas, and other books of Journals and Histories.

Study Instruments, of all sortes.

I caused many small Glasses to be made; whose part of time, I knew to a most insensible thing: and so diuided and appropriated the Logg-line to them; making use of Wilbrordus, Snellius his numbers of feete answering to a Degree: and approved of by Master Gunter.

I made a Meridian-line of 120. yards long: with sixe Plumb-lines hanging in it: some of them being about 30. foot high, and the weights hung in a hole in the ground to avoyde winde. And this to take the Sunnes or Moones comming to the Meridian. This line wee verified, by setting it by the Pole it selfe, and by many other wases.

Two paire of curious Globes; made purposely: the workeman being earnestly affected to this Voyage.
Appendix No. 26

Notes on the chart of winds and currents in the North and South Atlantic.

The chart is drawn on Mercator's projection. See Pl. LXV.

Soundings. The fine dotted line round the coasts indicates portions of the 100-fathom line. In the areas enclosed by this line, or between it and the coastline, the water is less than 600 feet deep. Ships in such water were in 'soundings'.

Winds and Weather. All information on winds and weather is printed in italics. The average limits of the trade wind zones are shown in broken lines.

The Doldrums. These are located between the equator and about 15° N. In the northern summer the belt is located north of 5° N, but in winter it lies between the equator and 5° N. The movement follows the sun in its declination. From January to March when off the South American and African coasts the Doldrums may extend 100 miles south of the equator. Winds are usually light and variable, but squalls, which reach gale force occasionally, and calms are frequent. Heavy rainstorms, accompanied by thunder, are a regular feature, but seldom last long. Conditions are apt to be worst at night; and worse on the African than the American side.

The N.E. Trades which prevail in the south-eastern part of the North Atlantic stretch south and south-west of the Canaries as far as the Doldrums. The winds are steady in direction and speed, averaging 10–12 knots. In the northern part the winds tend to be more north than east, and in the southern more east than north. Along the north edge of the Doldrums the wind is easterly. The weather of the Trades is seldom troublesome, and alters little from summer to winter. The rainfall is small and gales uncommon.

Between the Sargasso Sea and the coast of the U.S.A. the weather is much the same as in the Trades, except that winds are less steady and blow from the south-east and south; hurricanes occur in the West Indies from July to October.

The unsettled weather belt in the North Atlantic lies north of a line joining Cape Hatteras and Cape Finisterre, and varies in width from 500 to 2,000 miles. Along the south fringe of the belt winds are usually south-westerly or westerly. Further north in the centre of the belt, the winds become less steady and more stormy, especially from October to April. From May to September winds are much less strong and storms infrequent. Quiet periods of up to two or three weeks occur, during which light winds from most directions may be experienced. In such weather the westerly belt is found at this season about the latitude of Newfoundland.

Along the northern edge of this unsettled weather belt, the winds are steadier and blow mainly from the north and north-east. Although these winds are seldom so strong or constant as the westerlies, they are dangerous in summer owing to drifting ice especially off Newfoundland and south Greenland.

Seasonal shift of the wind belts in the North Atlantic. All three of these wind belts shift a few degrees north and south with the seasons. From January–March the Doldrums are practically over the equator, from July–September they are in about latitude 15° N off the African coast and 10° N off the South American coast. The Cape Verde Islands which are well inside the Trades in winter are just on the north edge of the Doldrums in summer. The unsettled
weather belt does not move north or south with any regularity, but it averages 500–750 miles farther north in summer than in winter.

**Local winds in both North and South Atlantic.** Within 5–10 miles of land the prevailing winds are affected by land and sea breezes, especially in summer and in low latitudes, a phenomenon observed by the first English navigators to the Guinea coast (1550s). The sea breeze strengthens on-shore winds and weakens off-shore winds between noon and dusk; land breezes have the opposite effect from midnight till dawn. Close to high land strong squalls are generally experienced, especially in the approaches to fjords or other inlets. In such areas, the local winds usually blow up or down the inlets.

**The S.E. Trades,** which prevail in the north-eastern part of the South Atlantic, stretch roughly north of a line São Salvador–Lüderitz Bay as far as the Doldrums. The winds are steady in speed, averaging 12–14 knots, and direction, from between E.S.E. and S.S.E. In the N.W. part of the belt the winds tend to be more easterly than southerly, and in the S.E. part more southerly than easterly. In the southern winter the S.E. Trades cross the equator and are deflected to the south, even S.W., off the Guinea coast. The N.E. Trades do not cross the equator.

Ignorance of the wind system off the Guinea coast committed the first English adventurers there to toilsome return voyages against persistent head winds. Later, failure to take account of the southerly wind system off the South African coast often condemned ships bound round the Cape of Good Hope to months of windward work—much of it in the tropics!

The weather in the S.E. Trades region is seldom troublesome and alters little from summer to winter. The rainfall is small, and north of 25° S gales are practically unknown. Towards the South American coast and between the latitudes of São Salvador and the Rio de la Plata, winds are less steady, and blow mainly between north and east. Although the weather is fine, rainy and unsettled spells are common during the winter months.

**The unsettled weather belt in the South Atlantic.** In the southern winter this belt lies roughly south of a line joining the Rio de la Plata and the Cape of Good Hope; in summer it lies 300–400 miles farther south. The belt varies in width from 500 to 2,000 miles. In the north part of the belt, as far south as the Falkland Islands winds are mainly N.W. or westerly, moderate to strong in summer, strong to gale force in winter. The stormiest zone lies south of a line joining the Falkland Islands and the Cape of Good Hope. From April to October it is unusual for this belt to be free from storms for more than a few days at a time; from November to April the storms are less severe and intervals between them longer.

The further south in this belt, the more unsettled is the weather and less steady the winds; but north of the limit of polar pack ice the prevailing direction remains westerly.

**Ocean currents** are broad permanent movements of the surface waters. The general direction of these currents is fairly constant throughout the seasons and is shown on the chart by arrows. The strength of the currents at any given time is much influenced by the wind that is blowing. Where the drift or amount of movement is stated to be, for example, 0–25 miles per day, the lower figure applies if the wind is calm or blowing in the reverse direction to the current arrow, and the higher figure if a gale is blowing in nearly the same direction as the current arrow. Where there are no current arrows on the chart there is usually no current and winds are variable. Moderate or strong winds experienced in these localities cause a drift to leeward of from 6 to 12 miles per day.
Appendix No. 27

The sailing powers of Elizabethan and Early Stuart ships.

The speed of a sailing ship through the water varies under different conditions of wind and sea. As a rough guide to the performance of Elizabethan and Early Stuart ships it can be reckoned that the average ship made two knots in a light breeze, four knots in a fresh breeze and six knots in a strong breeze, provided she had not been sufficiently long at sea for barnacles and marine growth to become so thick on her bottom as to check her way appreciably.\(^1\) Leeway, unless the wind was abaft the beam, amounted to about 1 ½ to 2 points, say, 15° to 25°. Current. The speed of currents was not known, unless ascertained by log, log-line and half-minute glass from an anchored vessel, as was done sometimes, or from a ship's boat held stationary by a kettle lowered into the depths below the surface current.\(^2\) Some idea of the effect of a current on a ship's track can be gathered from the following table showing the deflection caused by currents of 1 and 2 knots setting across the track:

<table>
<thead>
<tr>
<th>Current across track</th>
<th>Speed of Ship</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 knots</td>
</tr>
<tr>
<td>1 knot</td>
<td>2½ points</td>
</tr>
<tr>
<td></td>
<td>(30° approx.)</td>
</tr>
<tr>
<td>2 knots</td>
<td>4 points</td>
</tr>
<tr>
<td></td>
<td>(45°)</td>
</tr>
</tbody>
</table>

Deflection

What may be taken as typical speeds made good on an Atlantic voyage are those made by John Davis in the Lion (400 tons) with the Liomenes (250 tons) in company, on his first voyage to the Far East, 1598. Between England and the Madeiras he made good a speed of about 3 ½ knots (in April); between the Madeiras and the Cape Verde Islands, running straight before the N.E. trades and with the Canary current, he made good about 5 knots; between the Cape Verde Islands and Brazil, on a passage which involved crossing the Doldrums, in May and June, he made good 2 knots (Robert Dudley crossing from Cape Blanco to Trinidad in January 1595 made good 5 knots); from Fernando Noronha to the Abrollos Rocks Davis made good, with the assistance of the Brazil current, about 2 ½ knots; and from the Abrollos Rocks to Saldanha Bay probably 4½ to 5 knots running before the westerlies and with the South Atlantic drift.

In his northern voyages a decade or so later William Baffin made good about 3 knots.

\(^1\) Reports of the voyage of Mayflower II, under the command of Captain Allan Villiers, in 1957 substantiate the general accuracy of these estimates. For details of design research for Mayflower II, see Bibliography, under Baker, W. A.


A kettle was a large iron pot.
Appendix No. 28

A

The Calendar as used by Elizabethan and Early Stuart Navigators.

THE CALENDAR

(1) 'The Julian calendar, old style.' Throughout the Middle Ages, and in some countries for much longer, the calendar in use was that known as the Julian because it was originally introduced by Julius Caesar in 45 B.C. This style of reckoning is now known as the old style (O.S.), in contradistinction to the new style (N.S.), that is to say, reckoning by the Gregorian calendar introduced by Pope Gregory XIII in 1582.

'The Julian calendar set up a common year consisting of 365 days, while every fourth year was to contain an extra day. The sixth calends of March (24 February) was doubled, and the year therefore described as annus bissextilis. This latter device was intended to rectify, at regular intervals, the accumulated discrepancy between the calendar year of 365 days and the solar year, calculated by the astronomers at $365\frac{1}{4}$ days. The mistake was made, however, of counting in the current year when deciding which was 'every fourth year', so the bissextile years occurred in what we should call every third year. Thus an error rapidly accumulated, until the Emperor Augustus got rid of it by ordaining that twelve successive years should consist of 365 days only. The next bissextile or leap year was A.D. 4, and thereafter, as long as the old style lasted, every fourth year, in the modern sense, was a leap year.

'In the course of the Middle Ages various scholars interested in chronology pointed out that the calendar year was increasingly divergent from the solar year. The reckoning of the latter at $365\frac{1}{4}$ days was a slight overestimate, and by the sixteenth century this annual error had caused, cumulatively, a discrepancy of ten days. It was not, however, until 24 February 1582, that a Bull of Pope Gregory XIII ordered the use of a reformed calendar. This met the immediate trouble by cutting ten days out of the year 1582, so that 15 October followed immediately upon 4 October, while future difficulties were to be avoided by making only the fourth of the end-years of successive centuries a leap year, with occasional exceptions, at A.D. 2000, 4000, etc., to put right the slight over-correction thus made. The year was to begin on 1 January.

' . . . Broadly speaking, Catholic states adopted the new style in the sixteenth century, Protestant states early or late in the eighteenth century, Russia, the Balkan States, and Greece in the twentieth century . . . In Great Britain and Ireland the change was effected by 'Chesterfield's Act' (24 Geo. II, c. 23), passed in March 1751, which decreed that throughout the Dominions of the British Crown the following 1 January should be the first day of 1752 and 2 September 1752 should be followed by 14 September . . . A difference of dating [by the old style] may amount to 10, 11, 12, or 13 days according as the document is written after 1582, 1700, 1800, or 1900 . . . From Elizabeth's reign onwards, English correspondence with the Continent often gives both forms of date . . .

'for example $^{12}_{22}$ Dec. 1635'.
(2) '1 January. The historical year, the year now used by historians, begins on 1 January . . . In the sixteenth century it found favour . . . throughout most of the continent of Europe. In Scotland it become the official beginning of the year 1600 following 31 December 1599. In England and Ireland the change was not effected until the day after 31 December 1751, which became 1 January 1752 . . .'

(3) 'The Use of 25 March after Christmas as the opening of the year . . . came into common English use late in the twelfth century and so continued to 1752 . . . From about the middle of the seventeenth century the practice of the continental countries, which had gone over to a year beginning with 1 January, and of Scotland, influenced Englishmen. For official purposes Englishmen continued till 1752 to use the old reckoning from 25 March, but they were wavering in their allegiance and found it convenient to give a double indication for the period between 1 January and 24 March; we commonly meet this in the form 29 February 1675 . . . Where no double indication is given, it is usually safe for the historian to assume that an Englishman writing in England reckons from 25 March; but . . . from the latter half of the sixteenth century the printed almanacs started their year with 1 January, using the modern historical year.'

The preceding excerpts (1), (2) and (3) on the calendar are from Cheney, C. R., *Handbook of Dates for Students of English History* (1945). Reproduced by courtesy of the author and of the Council of the Royal Historical Society.
Appendix No. 28

B

NAUTICAL DATING

The Elizabethan and Stuart navigator, while he adhered to the Julian calendar and, except when consulting his almanac, reckoned the new year to begin on the 25th March after Christmas, counted his day, while he was out of sight of land, from noon to noon. This was because he fixed his position, normally, by observation of the sun's meridian transit at noon, and kept his reckoning from then until his next fix, 24 hours later. The result was that his date after noon and up to midnight, was one day ahead of the date on shore, where the date ran from midnight to midnight. When, however, the navigator was in waters of pilotage he logged his entries in accordance with the midnight to midnight date system used by landsmen. This was because he was fixing his position by terrestrial objects; and might go into harbour and out on the same day by shore dating.
**Appendix No. 29**

**Nautical Time-keeping and Watch-keeping.**

*Time measurement.* Up to the close of the sixteenth century English navigators frequently recorded the time of day of an occurrence in terms of the bearing of the sun, entering in their journals an ‘East Sun’ instead of ‘6 o’clock in the morning’, or a ‘South-East sun’ instead of ‘nine o’clock in the morning’. They were continuing the long-established nautical practice of finding the time of day by taking a bearing of the sun with the compass, and of expressing the time in terms of the rhumb upon which the sun bore instead of in hours and minutes.

(See Appendix No. 3 for further remarks on this and its use with tidal predictions and the moon.)

In the same period generally, and in early Stuart days always, the passage of time was measured at sea by half-hour or one hour intervals by the emptying of a sand-glass, and it was probably marked by the striking of a bell each time the glass emptied and was turned, for bells inventoried as watch-bells already formed part of a ship’s furnishings in the fifteenth century.

(See Appendix No. 10 for hour (watch) glasses supplied to Frobisher in 1579, and ‘runnyng glasses’ supplied in 1578).

Shakespeare, always remarkably accurate in nautical matters, refers to the nautical hour glass in Scene 1, Act 2 of *All’s Well that Ends Well*:

> Or four and twenty times the pilot’s glass
> Hath told the thievish minutes how they pass.

‘A [printed] Survey-Book containing all the Rigging ... Furniture and Stores belonging to his Majesties ships’ the *Royal James*, the *Royal Katherine*, and *Harwich*, No. 2265 in the Pepysian Library, has the following entries:

> ‘Boatswain his Sea store:

<table>
<thead>
<tr>
<th>Glasses</th>
<th>Compasses</th>
<th>Watch</th>
<th>Watch</th>
<th>Hour</th>
<th>Minute</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>18</td>
<td>12</td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This shows that in the later Stuart era (post 1660), the passage of time was measured in ‘whole watches’ (periods of four hours) and ‘half watches’ (periods of two hours) as well as in half-hours. The early Tudor evidence available is insufficient for it to be stated as a fact that this was the invariable practice in those times also though it is highly probable. The half-minute glass was for use with throwing the log for measuring the ship’s speed.

By the latter half of the sixteenth century the twenty-four hour day was divided into five four-hour and two two-hour watches. The passing of the first half hour of a watch was probably already indicated by one stroke on the watch-bell, of the second by two strokes and so on until at ‘eight-bells’ the watch ended.

*The watches.* The watch from eight at night to midnight was (and is) known as the ‘first watch’; the ‘second watch’, today termed the ‘middle watch’, was from midnight to four in the morning; the watch from four to eight in the
morning—today called the ‘morning watch’—was termed the ‘day watch’ or ‘morning watch’; the watch from eight in the morning to noon is today called the ‘forenoon watch’, and the watch from noon to four in the afternoon, the ‘afternoon watch’. The period from four to eight hours after noon was divided into two two-hour periods, today termed respectively the ‘first’ and ‘last dog watches’, in the Royal Navy, and the ‘first’ and ‘second dog watches’ in the Merchant Navy. In Elizabethan days the watch from four to six at night was termed the ‘look-out watch’.

Division of the ship’s company into watches and ‘squadrons’ for watchkeeping. At sea the ship’s company was divided into two parts, ‘the one’, explained Mainwaring in his manuscript Seamans Dictionary of 1623, ‘called the starboard watch, the other the larboard watch’. Today the same system is followed but the ‘larboard watch’ is termed the ‘port watch’.

The master was in charge of the starboard watch, the first mate or ‘his right-hand mate’ was in charge of the larboard watch. These watches worked turn and turn about ‘to watch, trim sails, pump and do all duties for four hours’, that is to say they worked the ship ‘watch and watch’.

In harbour and in roads however, the ship’s company, Mainwaring informs us, watched only ‘quarter watch’, that is to say, only ‘one quarter of the company’ kept watch at a time.

Captain Smith, in his Sea Grammar of 1627 explains ‘How they divide the company at sea, and set, and rule the watch.’

The Boatswain having, at the captain’s or Master’s command, called up the ship’s company ‘the Master being chiefe of the starboard watch doth call one, and his right hand mate on the larboard doth call one, and so forward till they be divided in two parts, then’, he explained, ‘each man is to chuse his Mate, Consort or Comrade’, continuing, ‘and then divide them into squadrons [today known in the Royal Navy as first and second parts of the watch.] according to your number and burthen of your ship as you see occasion; these are to take their turns at the Helme, trim sails, pumpe, and doe all duties each halfe, or each squadron [of a watch] for eight Glasses or four hours, which is a watch [that is, during periods of ‘quarter watch’ only a squadron of a watch was on duty], but care would bee had’, advised Captain Smith, ‘that there be not two Commodores upon one watch because they have the more roome in their Cabbins to reste.’ That is to say, care had to be taken to ensure that two men, sharing one of the box bunks commonly provided for sleeping quarters, were each in a different squadron or parts of a watch so that each had the bunk to himself when not on duty. Just as ‘the Captaine and masters Mates, Gunners, Carpenters, Quertermasters, Trumpeters,’ etc. lived ‘abast the Mast’, so, explained Captain Smith, ‘the Boatswaine, and all the Yonkers or common Sailers under his command lived ‘before the Mast’. Having divided the ship's company into watches and squadrons the next thing to do, Captain Smith continued,

‘is, to messe them four to a messe, and then give every messe a quarten Can of beere and a basket of bread to stay their stomachs till the kettle be boiled, that they may first goe to prayer, then to supper, and at six [eight] a clocke sing a Psalme, say a Prayer, and the Master with his side [the starboard watch] begins the [first] watch, then all the rest may do what they will till midnight”; and then, he explains, ‘his Mate with his larboard men with a
Psalme and a Prayer relieues them till foure in the morning, and so from eight to twelve each other, except some flaw of winde come, some storme or gust, or some accident that requires the helpe of all handes, which commonly after, such good cheere in most voyages doth happen.'

Curiously enough it appears to be Thomas Hariot, the mathematician, who gives in his *Mathematical Papers*, of between 1590 and 1616, but probably before 1595 (Vol. VII, p. 21, Add. MSS. 6783) on a page entitled 'Notes ab. the offices of a ship', the earliest explanation of the rotation of the watches. On the right-hand lower corner of the page he scribbled:

The watch from 4–8 at night is divided into two partes.

The first? [the word is illegible] parte frō 4 to 6 they call the *look out*.

These two partes are as two watches, that the same men may not have the first watch.

If the first watch beginnes at 8 at night, then they get the watch.
1. Watch
2. Watch
Day watch or morning watch.

and he added a circular diagram to illustrate the system where watch 'a' starting with the first watch, 8 p.m. to midnight, is shown to finish with the 6 p.m. to 8 p.m. watch on the following day, and to follow this with the 'middlewatch'.

*The rotation of the watches at sea*

The starboard watch starts the cycle by taking the first watch on the first day at sea, and completes it by taking the 'last dog watch' beginning twenty-two hours later.

The larboard watch takes the middle watch on the first day at sea, and starts the new cycle 20 hours later by taking the first watch. The second cycle is completed by the larboard watch taking the 'last dog watch'. The third cycle is started by the starboard watch taking the first watch on the third night.

<table>
<thead>
<tr>
<th></th>
<th>Midnight</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First Watch</strong></td>
<td><strong>Middle Watch</strong></td>
</tr>
<tr>
<td>8 Bells</td>
<td>4 a.m. 8 Bells</td>
</tr>
<tr>
<td>8 Bells</td>
<td>8 p.m.</td>
</tr>
<tr>
<td><em>Last Dog Watch</em></td>
<td></td>
</tr>
<tr>
<td>8 Bells</td>
<td>6 p.m.</td>
</tr>
<tr>
<td><em>Look-out Watch</em></td>
<td></td>
</tr>
<tr>
<td>8 Bells</td>
<td>4 p.m.</td>
</tr>
<tr>
<td><em>Afternoon Watch</em></td>
<td></td>
</tr>
<tr>
<td>8 Bells</td>
<td>8 a.m.</td>
</tr>
<tr>
<td><em>Forenoon Watch</em></td>
<td></td>
</tr>
<tr>
<td>8 Bells</td>
<td>8 Bells</td>
</tr>
<tr>
<td><em>Noon</em></td>
<td></td>
</tr>
<tr>
<td>8 Bells</td>
<td></td>
</tr>
</tbody>
</table>
### The Striking of the Watch-bell in Ships

<table>
<thead>
<tr>
<th>First Watch</th>
<th>Second Watch</th>
<th>Day or Morning Watch</th>
<th>Forenoon Watch</th>
<th>Afternoon Watch</th>
<th>Look-out Watch</th>
<th>Second or Last Dog Watch</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 Bells</td>
<td>8.00 p.m.</td>
<td>Midnight</td>
<td>04.00 a.m.</td>
<td>08.00 a.m.</td>
<td>Noon</td>
<td>4.00 p.m.</td>
</tr>
<tr>
<td>1 Bell</td>
<td>8.30 p.m.</td>
<td>00.30 a.m.</td>
<td>04.30 a.m.</td>
<td>08.30 a.m.</td>
<td>12.30 p.m.</td>
<td>4.30 p.m.</td>
</tr>
<tr>
<td>2 Bells</td>
<td>9.00 p.m.</td>
<td>01.00 a.m.</td>
<td>05.00 a.m.</td>
<td>09.00 a.m.</td>
<td>1.00 p.m.</td>
<td>5.00 p.m.</td>
</tr>
<tr>
<td>3 Bells</td>
<td>9.30 p.m.</td>
<td>01.30 a.m.</td>
<td>05.30 a.m.</td>
<td>09.30 a.m.</td>
<td>1.30 p.m.</td>
<td>5.30 p.m.</td>
</tr>
<tr>
<td>4 Bells</td>
<td>10.00 p.m.</td>
<td>02.00 a.m.</td>
<td>06.00 a.m.</td>
<td>10.00 a.m.</td>
<td>2.00 p.m.</td>
<td></td>
</tr>
<tr>
<td>5 Bells</td>
<td>10.30 p.m.</td>
<td>02.30 a.m.</td>
<td>06.30 a.m.</td>
<td>10.30 a.m.</td>
<td>2.30 p.m.</td>
<td></td>
</tr>
<tr>
<td>6 Bells</td>
<td>11.00 p.m.</td>
<td>03.00 a.m.</td>
<td>07.00 a.m.</td>
<td>11.00 a.m.</td>
<td>3.00 p.m.</td>
<td></td>
</tr>
<tr>
<td>7 Bells</td>
<td>11.30 p.m.</td>
<td>03.30 a.m.</td>
<td>07.30 a.m.</td>
<td>11.30 a.m.</td>
<td>3.30 p.m.</td>
<td></td>
</tr>
<tr>
<td>†</td>
<td>†</td>
<td>†</td>
<td>†</td>
<td>†</td>
<td>†</td>
<td>†</td>
</tr>
<tr>
<td>8 Bells</td>
<td>Midnight</td>
<td>04.00 a.m.</td>
<td>08.00 a.m.</td>
<td>Noon</td>
<td>4.00 p.m.</td>
<td>6.00 p.m.</td>
</tr>
</tbody>
</table>

[Names of Watches in square brackets above are modern]

* Watch begins.
† Watch ends.
Appendix No. 30

Thomas Hariot’s Contribution to the Art of Navigation. (See also Appendix No. 16C.)

Thomas Hariot, who was born in 1560 and died in 1621, is frequently referred to as one of the most brilliant mathematicians of his age. None of his navigational works having been published, nor, until recently, critically examined, it has been difficult to form an opinion of Hariot’s contributions to the art of navigation. However, within the last few years the researches of Professor E. G. R. Taylor and of Mr. D. H. Sadler, the Superintendent of H.M. Nautical Almanac Office, have made it possible to assess some of Hariot’s mathematical achievements in the art of navigation. The Hariot navigational data contained in the following summary of his navigational work is derived primarily from Taylor, E. G. R., ‘Hariot’s instructions for Raleigh’s voyage to Guiana, 1595,’ J.I.N., Vol. 5, and Taylor, E. G. R., ‘The Doctrine of Nauticall Triangles Compendious. I. Thomas Hariot’s Manuscript’; Sadler, D. H., ‘II. Calculating the Meridional Parts’, J.I.N., Vol. 6, and from transcripts of Hariot’s work kindly provided by Professor Taylor.

Some time after Hariot came down from Oxford in 1579, Walter Raleigh, eight years his senior in age, set him up in his house in the Strand as his mathematical and scientific adviser, with particular reference to the problems of navigation. Since the age of sixteen Raleigh had been an active service soldier. He had, however, found time to be a member of Oxford University and of the Inns of Court; he was a voracious reader, a gifted writer, an acquaintance of all those most influential at Court and in the Council. In the late seventies his half-brother, Humphrey Gilbert, was busy with schemes for the colonization of North America. In 1578 Raleigh commanded his first ship (with a Portuguese pilot) on Gilbert’s abortive colonizing expedition of that year. It was three years since Thomas Digges attached to his Prognostication his Errors of Navigation drawing attention to the outstanding problems and errors in the art. (See Appendix No. 11.) Raleigh who, on the death of Gilbert in 1583, was to continue his half-brother’s schemes of colonization, evidently engaged Hariot at this time to solve the problems and correct the errors of current navigational practice as summarized by Digges, and as, no doubt, experienced by himself in ‘78. Raleigh’s object, of course, was to ensure that his schemes of colonization should not miscarry through failure of the ships to arrive at their destination, and subsequently toply between England and the colony with certainty and despatch.

It would appear that Hariot first set about refining the technique of celestial observations at sea and correcting the declination tables of the sun and the rule of the North Star. By 1584 he had compiled a navigational manual, apparently on these lines, which he entitled Arcticon, and which he evidently used as a source book for instructing Raleigh, and the sea-captains and masters in Raleigh’s service, in the refinements in the art of navigation resulting from his researches. Raleigh, as an investor in Davis’s voyages in search of the North-West Passage (1585–86–87), was also directly concerned with their success. Consequently Davis’s knowledge of mathematical navigation can be linked with Hariot, through Raleigh, as well as with Dr. Dee.

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Hariot's *Arcticon* has unhappily been lost. However, a later summary of a part of it, in Hariot's hand, survives in the form of 'Instructions for Raleigh's Voyage to Guiana, 1595' evidently prepared at Raleigh's request to refresh his and his navigators' navigational knowledge. (B.M. Add. MS. 6708). In this paper Hariot embodied tables for ensuring that the latitude should be found with the greatest possible accuracy as a result of observing with a cross-staff or with a back-staff the sun's meridian altitude, and with a cross-staff the Pole Star; and that the ship's course should be checked and corrected for variation approximately every twelve hours.

Concerning sun sights Hariot dealt with:

(a) Instrumental parallax of the cross- and back-staff.
(b) Instrumental refraction.
(c) Atmospheric refraction.
(d) Solar parallax.
(e) Dip.
(f) Declination tables of the sun.
(g) Effect of longitude on declination; and
(h) Gave examples of working out meridian altitude sights.

In this connexion he included tables of:

(i) Corrections for instrumental parallax.
(ii) Corrections for dip.
(iii) The sun's declination, on a four-year cycle.

Concerning Pole Star observations Hariot dealt with:

(a) The regiment of the Pole Star and the polar distance assumed.
(b) The effect of latitude on the Regiment.

He also (i) included a regiment of the Pole Star based upon a corrected and up-to-date polar distance, and incorporating (ii) a correction for the effect of latitude. He also gave examples of working out Pole Star sights.

In the text Hariot recommended the use of the cross-staff for taking celestial observations, emphasizing that unless the butt of the staff were held always at the same place on the cheek—he recommended the edge of the eye socket—an observational error would result. Notwithstanding, a parallax error still remained, the result of the line of sight being eccentric to the centre-line of the staff on which the scale was drawn. Hariot's table of the 'parallaxis of the staff' was designed to correct this error. He had checked its accuracy with observations by Raleigh, Jacob Whiddon his principal captain, and John Douglas his master.

In the example given below of one of Hariot's examples of a sun sight it will be seen that his navigator used a 90° back-staff and corrected it for 'parallax of the staff'. He was evidently assumed to be using a 90° back-staff, as originally designed by John Davis and illustrated in *The Seamans Secrets* of 1595, for this type was subject to parallax of the staff.

Hariot pointed out that the crude coloured glass often affixed to the upper edge of the transom of a cross-staff for observing the sun's centre induced an error in the form of refraction. His remedy was to recommend observing the sun's upper limb by covering the sun with the transom, and to deduct 16° — the sun's semi-diameter—from the observed altitude.

The effect of atmospheric refraction Hariot stated was, in his opinion, too small to be taken into account by seamen. Like Kepler he held that the stars

41—A.O.N.
have no appreciable parallax. The parallax of the sun he rather overestimated; nevertheless this too he considered could be ignored by navigators. As no observations could be taken of a body low in the sky Hariot's statements were approximately correct, since refraction, for instance, would not normally exceed 3'.

Hariot considered that dip constituted an error large enough for correction according to whether the observation were made from the poop, waist, or chains. His table of dip—which presumably antedates Wright's—was consistently a little high:

**Hariot's Table of Dip—1595**

Dip of the Horizon

<table>
<thead>
<tr>
<th>Height of the eye above the water in pases</th>
<th>Surplus of the horizon in minutes</th>
<th>Equivalent in feet</th>
<th>Dip from the modern formula $0 = \frac{0.98}{\sqrt{h}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>5</td>
<td>2.2</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>10</td>
<td>3.1</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>15</td>
<td>3.8</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>20</td>
<td>4.4</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>25</td>
<td>4.9</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>30</td>
<td>5.4</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>35</td>
<td>5.8</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>40</td>
<td>6.2</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td>45</td>
<td>6.6</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>50</td>
<td>7.0</td>
</tr>
</tbody>
</table>

From his observations Hariot made the maximum declination of the sun to be 23° 31', and the precession of the equinoxes to be 14'–15' annually. In his declination tables, as in all the others, he was careful to give, in red ink, the arithmetic difference between successive entries, so as to facilitate interpolation. This was particularly useful because, as he emphasized, the declination tables having been calculated for a given meridian, interpolation became necessary when the observer was not on the given, or prime meridian used—Hariot put the distance at 71' or 30 minutes E or W of the chosen prime meridian and allowed longitude by dead reckoning to be sufficiently accurate for this purpose.

**Part of Hariot's Table of SolarDeclination, 1595 March**

<table>
<thead>
<tr>
<th>Day</th>
<th>1593</th>
<th>1594</th>
<th>1595</th>
<th>1596</th>
<th>1600</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G. M.</td>
<td>G. M.</td>
<td>G. M.</td>
<td>G. M.</td>
<td>Southerly</td>
</tr>
<tr>
<td></td>
<td>0 24</td>
<td>0 30</td>
<td>0 36</td>
<td>0 18</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0 24</td>
<td>0 24</td>
<td>0 24</td>
<td>0 12</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0 24</td>
<td>0 17</td>
<td>0 11</td>
<td>0 24</td>
<td>0 29</td>
</tr>
<tr>
<td></td>
<td>0 23</td>
<td>0 24</td>
<td>0 24</td>
<td>0 24</td>
<td>0 53</td>
</tr>
<tr>
<td>11</td>
<td>0 47</td>
<td>0 41</td>
<td>0 35</td>
<td>0 23</td>
<td>0 24</td>
</tr>
<tr>
<td></td>
<td>1 11</td>
<td>1 23</td>
<td>1 23</td>
<td>1 23</td>
<td>1 16</td>
</tr>
<tr>
<td>12</td>
<td>1 34</td>
<td>1 28</td>
<td>1 22</td>
<td>1 40</td>
<td>1 40</td>
</tr>
</tbody>
</table>
APPENDIX NO. 30

One of Hariot’s examples of the determination of latitude by a meridian altitude observation of the Sun:

A ship being 900 leagues [45'] west of England on 18 March 1595:
Meridian alt. of the higher edge of the sun by the back-staff \[79.35'\]
Parallaxis of the staffe \[1.35'\]
Surplus of the horizon \[0.5'\] to be abated \[1.56'\]
Semi-diameter of the Sun \[0.16'\]
True meridian alt. of same is \[77.39'\]
Declination in the Regiment of the Sun \[2.56'\]
Part proportional to be added for 900 leagues \[0.3'\]
True declination northerly \[2.59'\]
Abate because zenith is more northerly \[74.40'\]
Altitude from equinoctial \[15.20'\]

In explaining Pole Star observations Hariot pointed out that both Cortes’s rule—still the standard one in England—based on the 3½° polar distance of nearly a century before, and his diagram showing that it was 4° 9' (in 1545 when he wrote his manual) were incorrect. The precession of the equinoxes had reduced the 3½° polar distance of the Rule by about ½°; and Werner, the German astronomer from whom Cortes had got the 4° 9' polar distance, had been in error. In pointing out the effect of precession Hariot was not original; in recalculating and tabulating the Rule on the basis of a smaller polar distance, which he took to be 2° 55', he was. So was he in incorporating in it a correction for the effect of latitude caused by the use of plane instead of spherical triangle formulae in arriving at the corrections to be applied for the various positions of the guards.

Early in the century Pedro Nuñez, and as recently as 1576 Thomas Digges, had pointed out these causes of error. Hariot was the first man to remedy their effects.

### Hariot’s Regiment of the North Star, 1595

<table>
<thead>
<tr>
<th>Altitude of the Pole</th>
<th>E(A)</th>
<th>W</th>
<th>NE(A)</th>
<th>SW</th>
<th>N(A)</th>
<th>S</th>
<th>NW(A)</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1 27</td>
<td>1 19</td>
<td>2 50</td>
<td>2 46</td>
<td>2 33</td>
<td>2 34</td>
<td>1 0</td>
<td>0 48</td>
</tr>
<tr>
<td>20</td>
<td>1 30</td>
<td>1 16</td>
<td>2 52</td>
<td>2 44</td>
<td>2 33</td>
<td>2 34</td>
<td>1 5</td>
<td>0 43</td>
</tr>
<tr>
<td>30</td>
<td>1 34</td>
<td>1 12</td>
<td>2 53</td>
<td>2 41</td>
<td>2 33</td>
<td>2 34</td>
<td>1 11</td>
<td>0 36</td>
</tr>
<tr>
<td>40</td>
<td>1 36</td>
<td>1 6</td>
<td>2 54</td>
<td>2 36</td>
<td>2 33</td>
<td>2 34</td>
<td>1 19</td>
<td>0 27</td>
</tr>
<tr>
<td>50</td>
<td>1 45</td>
<td>0 59</td>
<td>2 55</td>
<td>2 28</td>
<td>2 32</td>
<td>2 35</td>
<td>1 29</td>
<td>0 16</td>
</tr>
<tr>
<td>60</td>
<td>1 52</td>
<td>0 51</td>
<td>2 54</td>
<td>2 16</td>
<td>2 32</td>
<td>2 35</td>
<td>1 41</td>
<td>0 14</td>
</tr>
</tbody>
</table>

Note: The letter A signifies add to the observed altitude of Polaris. The difference columns are marked red in the original table. The bearings are those of the ‘guards’ of the Lesser Bear as shown by an accompanying diagram in the original.
One of Hariot's examples of a Pole Star sight:

Another example or praesident upon an East guard.

Apparent altitude of the starre by the lesse staffe \[42.30'\]

Parallaxis of the staffe \[0.32'

Surplus of the Horizon \[0.5'

\}{ } to be abated \[0.37'

Therefore the true altitude of the starre \[41.53'

The allowance against 40 because it is next under an East guard to be added \[1.39'

Therefore the altitude of the Pole \[43.32'

By that altitude of the Pole seek a precise allowance.

Against 40 you have the same allowance as before \[1.39'. The difference for the next underneath is 6 minutes which multiply by the odd \[3.32' or 4 because the minutes are more than half a degree and the summe will be 24 which hath two tennes and therefore 2 minutes are to be added to the allowance above \[0.2'

Therefore the allowance is \[1.41'

Which add as by the title & the true altitude of the starre

Then the precise altitude of the starre is \[43.34'

The cumbersome arithmetic of the interpolation, which in fact could have been done by inspection, is worth remark.

Under the heading of 'How to know your course to any point assigned... etc.' Hariot dealt with the problems of direction-finding. After discussing the course errors arising from neglect of variation, and the hydrographical faults resulting from lack of regard for variation, Hariot introduced a new method of determining variation by means of amplitudes, the bearing of the sun at sunrise and sunset. The equal altitude method of finding variation was by no means easy at sea, while the meridian transit method was imprecise. In contrast, given a clear horizon at sunrise or sunset, an accurate compass bearing of the sun could always be taken. Compared with the calculated true bearing of the sun the result gave the compass error—the variation. Hariot calculated the amplitudes for each whole degree of declination up to \[24°\, and for each degree of latitude up to \[54°, and the differences (in red ink in the original) in minutes. He thus provided Raleigh's navigators with a far more certain way than hitherto of finding variation, and a far easier one, as the extracts from Hariot's tables and examples show.

### PART OF HARIOT'S TABLE OF AMPLITUDES

<table>
<thead>
<tr>
<th>Dec. Lat.</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>10</td>
<td>6</td>
<td>88</td>
<td>11</td>
<td>34</td>
</tr>
<tr>
<td>47</td>
<td>10</td>
<td>17</td>
<td>89</td>
<td>11</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>10</td>
<td>29</td>
<td>91</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>49</td>
<td>10</td>
<td>42</td>
<td>93</td>
<td>12</td>
<td>15</td>
</tr>
</tbody>
</table>

As an example of its use Hariot gave, amongst others, the following:

You are SW. of the Lizard in the height of \[48°\ on 10th Feb. 1595. The Sun rises at \[7° S. of E. by the meridian compass. The Book of the Sun's
Regiment gives the declination at noon, 10°.58'. The day before it was 21' more, so at sun-rise it was a fourth part of 21' or 5' more, and the correct figure is 11°.3'. Since 11°.0' is near enough, look up in the table of amplitude for 48 lat. and 11 declination. It is 16° 33'. Therefore the variation is 9° 1 E. of N.

It is presumed that after dealing with variation Hariot dealt with the chart and its problems; but the papers are no longer extant. However, among the Pepworth MSS. at the British Museum, is a manuscript by Hariot entitled The Doctrine of Nauticall Triangles Compendious. Although it is undated there is internal evidence that it was completed in the latter part of 1594. This manuscript is devoted chiefly to the calculation of meridional parts. It seems certain that the work was original and independent; and it is equally certain that many years before the integral calculus was introduced or logarithms invented', to quote Mr. Sadler, Hariot 'discovered the extremely complex and far from obvious method of calculating meridional parts from the integral formula'. This was genius! Mr. Sadler also considers that Hariot had completed, not much later than 1590, a table of meridional parts—what the author referred to as his Canon Nauticus—for every minute of arc, calculated by the simple addition of secants for every minute. Thus Hariot would seem to have completed an accurate table of meridional parts several years before Wright, and independently of him. From the text of Hariot's Doctrine it would appear that he had also drawn a chart on Mercator's projection by the time he completed the manuscript—that is, probably by the end of 1594. However that may be, Hariot opened his manuscript with a recalculated 'Rule to Raise or Lay a Degree of Latitude' in tabular form, and with the resultant departure.

Then follow definitions of the nautical triangles in terms of difference of latitude, difference of longitude, and distance. As, explained Hariot, this triangle was always right-angled, if any three terms (save three angles) were given the remainder might be known. But on the plane chart, because difference of longitude was treated as departure the difference of longitude element, he pointed out, 'came greater than it ought'. It was this that was the cause, he continued, of errors far graver than most navigators appreciated. He then set about explaining how this defect of the plane chart could be remedied. 'A Theorem'; in which he does so, expresses the spacing of the parallels necessary to ensure that the nautical triangle gives the correct difference of longitude or departure. The spacing, he stated, was to be found tabulated in his Canon Nauticus, or engraved 'compendiously upon my stave'. In other words Hariot had not only prepared a table of meridional parts, but, anticipating Gunter, had also projected a line of meridional parts upon his cross-staff. In his Tractatus de Globis of 1594 Hues had formulated for the first time in print the six standard cases of the nautical triangle. In his manuscript Doctrine Hariot not only set them forth but followed them with their trigonometrical solution. For example:

'This proposition promised being sufficient to express the nature of the nauticall triangle; the method for practice I order thus:

1. Meridian segment and \( \angle \) and the thing \( \int \) sought is \( [\text{Difference of latitude and course}] \)
2. The line of distance.
3. The difference of longitude.

[Here follow the remaining five cases of the two elements known]
Harriot gave the trigonometrical solutions in the following form:

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole sine</td>
<td>Degress of ye segment of ye meridian.</td>
<td>Secant of ye angle of direction.</td>
<td>Degrees of distance</td>
</tr>
<tr>
<td>10,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole sine</td>
<td>Aequall degrees answerable to the unequall of the Meridian</td>
<td>Tangent of the angle of direction</td>
<td>Degrees of longitude or arc of a parallel</td>
</tr>
<tr>
<td>10,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note.—The exact layout and notation of the parts of Harriot’s tables reproduced has not in each case been followed.

In short, Harriot expressed the trigonometrical solution of the Mercator’s nautical triangle in terms of simple proportion. For instance 1 above is:

\[
\frac{(\text{II})}{(\text{I})} \cdot \frac{(\text{IV})}{(\text{III})} = \frac{\text{diff. lat.}}{\text{dist.}} = \frac{\text{dist.}}{\text{sec. (Co.)}} = \text{diff. lat.} = \text{dist. cos. (Co.)}
\]

and 2 above is: \[
\frac{\text{d. long.}}{\tan{(\text{Co.})}}
\]

where \(d.\ m.\ p.\) = difference of meridional parts.

Although Harriot never published anything on navigation, it is probable that Ralph Handson in publishing, in the appendix to his *Trigonometrie* of 1614, the mathematical solutions to the nautical triangle, was in fact making public some of the original work Harriot had taught Raleigh’s select circle of mariners twenty years and more before. There can be little doubt that, fostered by Raleigh, Harriot developed mathematical navigation—but for the exclusive use of Raleigh’s navigators. To what extent Harriot was indebted to Dr. Dee’s pioneer work is obscure. But it is significant that in 1590 Dr. Dee spoke of Harriot as ‘Amici Mei’ (See Appendix No. 16 D).

In his *Doctrine* Harriot gave his formulae for calculating his table of amplitudes; and he also sketched out three instruments for taking solar and one for stellar sights. The first was on the lines of the 45° back-staff illustrated by Davis in his *Seamans Secrets*, first published in 1595, and was, Professor Taylor suggests, the prototype design of this instrument. Its disadvantage was that, although it enabled the observer to sight the sun’s shadow and the horizon simultaneously, it could not be used when the sun was more than 45° above the horizon. Harriot tried to get over this disadvantage by employing wooden quadrants, and his next two sketches are of instruments using this principle. Each makes use of a pin at right angles to the quadrant, and affixed to the apex to cast the shadow on the arc of the quadrant, which was held away from the observer, and fitted with a cursor. The stellar instrument was a ‘quadrante for the starres’. All these designs, as Harriot admitted, had the old disadvantage, namely, that observations had to be made, preferably at the top of a surge, ‘as by your old sea staffe’, and ‘in three acts of seeing at the time of observation to certify it good. That is: seeing the starre, horizon, and starre, or horizon, starre and horizon’.

It was Davis who solved the problem of designing a satisfactory 90° back-staff, as he himself claims in *The Seamans Secrets*. Harriot, however, had got hold of a good idea in his back-quadrants, in that they did ensure that the shadow cast should always be of the same size and, given an arc of small radius, sharp.
Nevertheless it was Davis who exploited this arrangement successfully in his later 90° back-staff or quadrant, perfected, as Waymouth's drawings show, by 1604.

After the Guinea voyage of 1595 Hario appears to have taken no further interest in navigational problems. He had achieved much. Nevertheless, in an appraisal of the contributions of Englishmen towards greater precision in the art of navigation as generally practised in the late sixteenth and early seventeenth centuries, Hario's achievements, on present available evidence, cannot figure prominently. Knowledge of them was currently confined to so small a circle of initiates, that Hario's practical contribution to the general fund of navigational knowledge at that time seems likely to have been small, particularly as the mathematical processes involved were too laborious for most seamen.

The soundest conclusion would appear to be that others working in the field of navigational research independently of Hario, concurrently or within a very few years, discovered, as he had done, how to apply the science of mathematics to their problems in order to obtain practical solutions and, unlike Hario, made public their discoveries. Secretly he could justly claim to have combined the astrolabe and cross-staff into a shadow-quadrant, to have corrected the tables of solar declination and of the polar distance of the Pole Star, and to have developed a true chart.
Appendix No. 31


Another way of reckoning, which I have seen used by several good English navigators, which seemed to me very sound as compared with the reckonings ordinarily made.

It is necessary to have a board 3 feet high by 15 inches wide, divided into 13 parts lengthways and five in width; in the first column the hours are entered, from 2 to 12 and again from 2 down to 12, making 24 hours in the 12 divisions [as shown in Pl. LXVI].

In the second column are marked the number of knots, in the third the fathoms, and in the fourth and fifth the rhumbs of the wind on which the ship is sailing.

It is necessary to have a line which is not too thick so that it will run out the more easily, at the end of which must be put a small, flat board of chestnut wood measuring about a foot long by six inches wide, weighted on the bottom with little strips of lead, with a small wooden tube, attached by a thin cord to the two bottom corners of the board, and another small piece of wood in the shape of a peg which fits into the tube quite easily. It is this which makes the board stay upright in the water astern of the ship, only becoming un-pegged as one hauls the board from the water. [The arrangement is, in fact, incorrectly drawn].

The line attached to the board must have some 8 to 10 fathoms of stray line between the board and the first knot, whose length is not taken into account; it can be more or less equal to the distance between the point from which the board is cast, which is always at the stern, and the point where it enters the sea, and extends to the first knot; a man must hold the line, another a small sand-glass, measuring a half-minute, which can be taken as the time it takes to count to 80 without hurrying. At the instant that the first knot passes through the hands of the man who cast the line, while letting it run out freely according to the speed of the ship, have the small sand-glass turned until it has finished running out at which moment the line must be held, and the paying out or veering of it stopped. Hauling it in, see how many fathoms there are out between the first knot and the hand of the man hauling the line, after that count all the knots which have run out into the sea while the sand-glass was running. Note how many knots and that [as] the space between each makes 2 miles of passage run in two hours, there are 7 fathoms between each knot. Every two hours by night as well as by day the board must be cast into the sea, and do not forget after 24 hours have passed to make your reckoning, adjusting your figures in order to know how many miles, reduced to leagues, one will have done, there being 3 miles per league.

For example, as one must reckon in this account, I find that in 24 hours we have sailed and veered the line every two hours, and that the vessel goes more or less according to the strength of the winds or tides; if it changes there will be more or fewer knots veered according to the course of the ship. Suppose it
is desired to calculate how far the vessel has gone, all the numbers of knots in
the first column of the board are added up; this will make 44 knots, and thirty-
six and a half fathoms at 7 fathoms to the knot, making five fathoms; add the
total; 44 knots and five make 49 knots, multiplying by two makes 98 at two
miles per knot, reducing them to leagues gives 32 leagues, three-quarters and a
little more, at 3 miles to the league. This is what the vessel will have run in
24 hours. One must not forget to take the height at every opportunity, to check
the way or route, and to keep count in the paper journal. By this means one knows
that the vessel is on her course, and the lee way, and where she is, the distance that
remains, the place where it is hoped to go to, and what route must be followed
to get there, and I say that 8 vessels which have been in company for 500 leagues
have said almost to within an hour and a half, that a sounding should be made,
which was found correct.
Appendix No. 32

Early development of logarithms.

In 1614 Napier published *Mirifici Logarithmorum Canonis descriptio* because he believed that his invention would lead to the simplification of trigonometrical problems. The product of two trigonometrical functions can be expressed as a sum (or difference) of two other functions, e.g.

\[ 2 \sin A \sin B = \cos (A - B) - \cos (A + B) \]
\[ 2 \sin A \cos B = \sin (A + B) + \sin (A - B) \]

and so on. In such computations, \( \sin 90^\circ \) occurs frequently. Since sines were still regarded as lengths—the lengths of certain lines drawn in a circle of suitable radius, the necessary accuracy was attained by making the radius very large, e.g. \( 10^7 \), (or \( 10,000,000 \)). This is equivalent to saying that \( \sin 90^\circ = 10^7 \). Napier made the logarithm of \( \sin 90^\circ \), i.e. of \( \log 10^7 \), equal to zero. It follows from this that the logarithm of a number greater than \( 10^7 \) would be negative. [Actually he wrote: Unde sinus totius \( 10000000 \) nullum seu o est logarithmus, et per consequens, numerorum majorum sinu toto logarithmi sunt nihilominores (*Descriptio*. Lib. 1. Cap. 1. p. 4)]. [For the mathematically minded, Nap. log\( y \): a log, \( \log_e \left( \frac{a}{y} \right) \) which becomes Nap. log\( y = 10^7 \log_e \left( \frac{10^7}{y} \right) \), if \( a \), the radius, or whole sine, is \( 10^7 \).]

The usual rules for logarithmic computation, which every schoolboy learns, do not hold for Napier's logarithms. Certain relations however do persist, e.g. if Nap. log \( \sin 90^\circ \), i.e. Nap. log \( 10^7 \) is zero, as Napier suggested, then it easily follows that in any triangle:

Nap. log \( \sin A \) − Nap. log \( \sin B \) = Nap. log \( a \) − Nap. log \( b \). At this point Briggs comes into the picture. He went to see Napier in 1615 and suggested the logarithm of the whole sine should be zero, but that the logarithm of the 10th part of the whole sine (5 degrees 44 min. 21 sec.) should be \( 10^{10} \). Napier had already contemplated making a change and suggested that zero should be the logarithm of unity and \( 10,000,000,000 \) the logarithm of the whole sine. This would make the logarithms of all numbers greater than unity positive.

A combination of the two suggestions, namely making log 1 = 0 and log 10 = 1 has the effect of making 10 the base of the system. But neither Briggs nor Napier had any idea of the base of a logarithm, i.e. they did not approach the subject from the relation, if \( a^x = N \) then \( \log_a N = x \), or in words, the logarithm of \( N \) to the base \( a \) is \( x \). The first man to grasp this was John Wallis (*Arithmetica definitorum*, 1655) and it was popularized by the Bernoullis, Professors of mathematics at Basle.

The logarithms which Napier published in his *Descriptio* contain 7 figures. They are the true values of the logarithms of numbers multiplied by \( 10,000,000 \). Napier promised to show how to construct logarithms but when his book appeared (*Mirifici Logarithmorum Canonis Constructio*, 1619) he had been dead a year. Briggs began constructing a new set of common or decimal logarithms. He computed the logarithms of 1 to 1000 to 14 places. This is the *Logarithmorum Chilias Prima* (1617). He then embarked upon the colossal task of computing the
logarithms of all the numbers from 1–100,000. His *Arithmetica Logarithmica* (1624) gives the first 20,000 and also the last 10,000 to 14 places of decimals. The logarithms of the intervening numbers, 20,000–90,000 were calculated to 10 decimal places by Adrian Vlacq, a Dutch bookseller, who published these together with Briggs’s results in his *Arithmetica Logarithmorum* (1628). This work has been translated into English [*Logarithmicall Arithmetike*, or Tables of Logarithms]. It contains also logarithms of sines, tangents and secants at intervals of 1 minute.

The rapid adoption of logarithms during the early decades of the 17th century was due to the enthusiasm of Briggs. Wright translated the *Descriptio* in 1618. The appendix (probably due to Oughtred) contains the statement that \( \log 10 = 2302584 \) i.e. \( \log_e 10 = 2302584 \). This is the first appearance of a natural logarithm, i.e. to base \( e \).

In 1619 Speidell published his *New Logarithms*. Gunter published (1620) the first calculated Briggsian (or common) logarithms.
Appendix No. 33

Holders of the Office of Lord High Admiral, 1540–1640

The office originated in 1360 by the appointment of an Admiral of the North, West and South with jurisdiction in all maritime causes, but the appointments were spasmodic. However, from 1391 the appointments became continuous with the title of Admiral of England. The first Lord High Admiral was appointed in 1540. The office was first placed in commission in 1628.

Lord High Admiral

<table>
<thead>
<tr>
<th>Date</th>
<th>Name and Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1540–42</td>
<td>John (Lord) Russell, afterwards (1550) 1st Earl of Bedford.</td>
</tr>
<tr>
<td>1543–47</td>
<td>John Dudley, Viscount Lisle, afterwards (1547) Earl of Warwick and Duke of Northumberland (1551).</td>
</tr>
<tr>
<td>1547–49</td>
<td>Thomas Seymour, Lord Seymour of Sudeley.</td>
</tr>
<tr>
<td>1550–54</td>
<td>Edward Fiennes de Clinton, Lord Clinton and Saye, afterwards (1572) 1st Earl of Lincoln.</td>
</tr>
<tr>
<td>1554–58</td>
<td>William Howard, Lord Howard of Effingham.</td>
</tr>
<tr>
<td>1558–85</td>
<td>Edward Fiennes de Clinton, Lord Clinton and Saye, afterwards (1572) 1st Earl of Lincoln.</td>
</tr>
<tr>
<td>1585–1619</td>
<td>Charles Howard, Lord Howard of Effingham, afterwards (1596) Earl of Nottingham.</td>
</tr>
<tr>
<td>1628–38</td>
<td>In Commission.</td>
</tr>
<tr>
<td>1638–40</td>
<td>Algernon Percy, 10th Earl of Northumberland.</td>
</tr>
</tbody>
</table>
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For Navigational MSS. and works printed before 1640
see Index pp. 625–628.

Select List of Secondary Sources and of Original Sources first
published after 1640

This list collects the most useful of the books and articles which were
first published after 1640 and which are referred to in shortened form in
the notes to chapters or in the appendices, or which have been consulted in
the preparation of the text and illustrations but are not specified in the notes or
appendices.

Hakluyt Society publications are listed separately.

The following abbreviations are used in the notes and bibliography:

Arch. = Archaeologia.
Cal. S.P. = Calendar of State Papers.
E.H.R. = English Historical Review.
Econ. H.R. = Economic History Review.
M.M. = The Mariners Mirror, Journal of the Society for
      Nautical Research.
N.R.S. = The Navy Records Society.

ANON. Ensayo de Bibliografía Marítima Española. Instituto Nacional del Libro
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nautical subjects under various headings (e.g. navigation) and with numer-
ous facsimile reproductions of title-pages, texts, and illustrations.

1928.

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A brief discussion of the longitude problem in 1622.


Reviews early studies in magnetism.


A valuable work on the compilation of dates and the calendar, with an excellent bibliography on books dealing with special aspects of the subject, such as almanacs.


Valuable for its reproduction of charts of the sixteenth century of the Atlantic and the elucidation of the cartographical faults arising from errors of longitude.


An interesting and well-documented account of Hawkeridge's career, and of his voyage of 1625. It is this paper that established the correct date of his voyage in search of a North-West Passage.


A guide to identifying some sixteenth- and seventeenth-century charts.


Reconstructs the ships of the first successful settlement but includes a telescope in error.


An interesting study of English commercial relations with Spain and the New World and the facilities afforded Englishmen desirous of trading with these territories.


Norwood’s journal edited with a valuable introduction.


This is a detailed and authoritative study of ‘Guessing Speed and Distance’, and of ‘Logging’, based chiefly on continental sources.


Description with diagrams of a reconstruction of Hudson’s ‘Halfe Moon’.


Contains a particularly lucid account of early hydrographical developments.


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Traces the development of the sea-quadrant and rule of the North Star.


A very valuable study of Hariot's MS. instructions prepared to refresh Raleigh's and his captains' navigational knowledge. It shows Hariot to have been far in advance of contemporary teachers of navigation.


An able review of Hariot's paper of 1594 or earlier on the calculation of meridional parts, using Clavius's seven-figure tables of the trigonometrical function of 1586. It discusses also his earlier Canon Nauticus (table of meridional parts, (no longer extant); his definition of the nautical triangle in terms of different latitude, different longitude, and distance; his projection of his Canon Nauticus upon the 'yard' of his cross-staff thirty years before Edmund Gunter; his trigonometrical solution of the six standard cases of the nautical triangle; his formula for computing the true amplitude of the Sun; his attempts to eliminate instrumental error by improvements in design, attributing the principle of the shadow staff in the form of a back-staff to Hariot. It discusses Hariot's planisphere or 'Mercator's chart' and Wright's table of meridional parts of 1593 (or earlier); it describes Wright's charts of 1599 and 1610 and Mercator's of 1569 and their method of use when plotting. It shows that Hariot was one of the originators of mathematical navigation.

For II ('Calculating the Meridional Parts') see Sadler, D. H.


Discusses and explains Dee's mathematical solution of the nautical triangle.
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TENISON, E. M. Elizabethan England, Vols. 1–11 and 'Portfolio of Charts'. Privately printed; volumes are still being issued.

A magnificent source book particularly on Anglo-Spanish relations and Spanish culture.


A first-class, admirably illustrated book containing extensive bibliographical information on cartographers and their products, and hydrographers, charts and chart-folios.


The chart is reproduced.


A valuable illustrated article on anchor varieties and developments.


A very valuable study, fully documented and with many illustrations.


Contains an appendix by Atkinson on the 'Use of Instruments most useful in Navigation' and describing, amongst others, single, and sliding Gunter's Scales.


A brief, authoritative, illustrated history of time measurement.


Reviews developments in ship design for oceanic voyaging.


Notes on the earliest references to the Lubber's Point.


— (ed.) The True and Perfecte News of the Woorthy and Valiante Expoytes, Performed and Doone by that valiant knight Syr Frauncis Drake not onely at Sancto Domingo, and Carthage, but also nowe at Cales, and vpon the Coast of Spayne, 1587 by Thomas Greepe. Hartford, Conn., 1955.
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Gives a valuable review of education in England in the sixteenth and seventeenth centuries.


A valuable study on the growth of cartography in the Low Countries in the sixteenth century. Contains a brief biography of Michel Coignet.


Contains amongst others a reproduction of the original chart of the west coast of South America and Mexico, with an inset of the Strait of Magellan, used or drawn immediately after Thomas Cavendish's voyage of circumnavigation. It is dated 1588.

WHALL, W. B. *Shakespeare's Sea Terms Explained*. Bristol, 1910.

The author draws attention to the uncanny accuracy of Shakespeare's nautical expressions and analogies, giving examples.


The most authoritative work on the early history of Trinity House, though pedantic in style. Ruddock's studies (see above) are particularly valuable in substantiating statements by Whormby.


A valuable and illuminating study of the growth of the Bordeaux wine trade and of the routes, pilotage, and defence measures involved.


A standard work.


A valuable and the most authoritative work on its subject.


Gives a lucid account of the extent and the expansion of English maritime trade from medieval times to the eighteenth century.


An interesting discussion of the question.


A scholarly illustrated study of the purpose of the oblique meridian found in the sixteenth and seventeenth centuries.

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A valuable piece of research on its subject.


A valuable essay on its subject.

WRETTS-SMITH, W. 'The English in Russia during the second half of the Sixteenth Century', Transactions of the Royal Historical Society, 4th Ser. iii.

Hakluyt Society Publications

The publications of the Hakluyt Society form a vast store of original material relating to the art of navigation in the sixteenth and seventeenth centuries, reproduced in very readable form. Each volume is ably edited with an introduction and explanatory notes, and contains reproductions of original charts, illustrations, etc.

Those listed below contain much material on the art of navigation as practised by English seamen in Tudor and Stuart days, and many learned notes elucidating nautical expressions and practices now outmoded. A few of the volumes of foreign voyages have been included in this list because of their relevance to English navigational practice in Elizabethan and early Stuart times.

Note: The year against a volume indicates the year for which each publication was issued.

The number preceding a volume indicates its serial number.

The First Series comprises the first hundred volumes, numbered from 1 to 100, issued for the years 1847–98.

The Second Series comprises the volumes issued since 1899, also numbered from 1.

The Extra Series comprises volumes of collections of voyages issued in addition to the annual volumes.

First Series


13. A True Description of Three Voyages by the North-East. [Undertaken by the Dutch 1594–6; translated from the Dutch by William Phillip, 1609.] (Ed. C. T. Bete.) 4 Maps, 12 Pl. 1853 [2nd Ed. = No. 54].


23. Narrative of a Voyage to the West Indies and Mexico. [Champlain's voyage of 1599-1602.] (Ed. N. Shaw.) 4 Maps, 5 Pl. 1858.


38. The Three Voyages of Sir Martin Frobisher. [To the N.W., 1576-8.] (Ed. R. Collinson.) 2 Maps, 1 Pl. 1867.

52. The First Voyage around the World by Magellan, 1518-1521. (Ed. Lord Stanley of Alderley.) 2 Maps, 5 Pl. 1874.

54. The Three Voyages of William Barents to the Arctic Regions, in 1594, 1595, and 1596. (2nd Ed.) (Ed. K. Beynen.) 2 Maps, 12 Pl. 1876. (1st Ed. = No. 13).

56. The Voyages of Sir James Lancaster, Knt., to the East Indies. [With Abstracts of Journals of Voyages to the East Indies during the Seventeenth Century, and the Voyage of Captain John Knight, 1606, to seek the North-West Passage.] (Ed. C. R. Markham.) 1877. (2nd Ed. = Series II, No. 85).

57. The Hawkins' Voyages. [During the reigns of Henry VIII, Queen Elizabeth, and James I.] 2nd Ed. (Ed. C. R. Markham.) 1 Pl. 1877. (1st Ed. = No. 1).

59. The Voyages and Works of John Davis, the Navigator. (Ed. A. H. Markham.) 2 Maps, 15 Pl. 1878.

63. The Voyages of William Baffin, 1612-1622. (Ed. C. R. Markham.) 8 Maps, 1 Pl. 1880.


79. Tractatus de Globis, et eorum Usu. [Hues's work of 1592 in translation.] (Ed. C. R. Markham.) To which is appended:

Sailing Directions for the Circumnavigation of England. [From a 15th-century MS.] (Ed. J. Gairdner.) 1 Map, 1 Pl. 1888.

86. The Journal of Christopher Columbus. [1st Voyage, 1492-93; and Documents relating to the Voyages of John Cabot and Gaspar Corte Reale.] (Ed. C. R. Markham.) 3 Maps, 1 Pl. 1892.

88-89. The Voyages of Captain Luke Foxe, of Hull, and Thomas James, of Bristol. [In search of a N.W. Passage, 1631-32, with narratives of earlier voyages to the N. West.] (Ed. Miller Christy.) Vol. 1, 2 Maps, 2 Pl.; Vol. 2, 3 Maps, 1 Pl. 1893.


Vol. 2 [The Expedition of Captain Jens Munk to Hudson Bay, 1619-20.] (Ed. C. C. A. Gosch.) 4 Maps, 2 Pl. 1896.
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SECOND SERIES


34. *New Light on Drake.* (Relating to the voyage of circumnavigation.) (Ed. Z. Nuttall.) 3 Maps, 14 Pl. 1914.


56. *Colonising Expeditions to the West Indies and Guiana, 1623–1667.* (Ed. V. T. Harlow). 6 Maps, 2 Pl. 1924.


43—A.O.N.

**Extra Series**

A reprint of Purchas's great work, lavishly illustrated with reproductions of contemporary charts, portraits, etc. Indexed.
Chart Reproductions

Hakluyt Society Publications

The following reproductions of sixteenth- and early seventeenth-century charts are contained in the Hakluyt Society publications indicated below. This list is by no means exhaustive. Numerous other sketches, route, and exploration maps are contained in the various publications; those listed below are charts of the greatest navigational interest. The Volumes are contained in two Series numbered from 1 to 100.

First Series

No.
6. Virginia, Discouered and Discribed by Captayn John Smith (1612).
7. The World, After the map by Robert Thorne of 1527.
   Also in Extra Series, ‘Principal Navigations’, Vol. 2.
   Chart of North-East America and North-West Passage, by
   Michael Lok, from Hakluyt’s Divers Voyages touching the Discovery of
   America, 1582.
   Also in Extra Series, ‘Principal Navigations’, Vol. 7.
13. Nova Zembla, Weygats, and the North Coast of Russia, by Gerrit
    de Veer, 1598.
    Dutch chart of North Russia, ‘Samojeden ende Tingoesen Landt’,
    by Isaac Massa, 1612.
16. Chart by Jodocus Hondius, c. 1590, showing the routes of Drake and Caven-
    dish round the World.
   Also in Extra Series, ‘Principal Navigations’, Vol. 11.
25. The Londe of Java or Australia, from the MS. Boke of Ictrographie, by
    Jean Rotz, 1542.
27. Hudson’s Bay and neighbouring coasts, by Henry Hudson, c. 1611.
    Chart of Hudson’s Voyages, by J. Hondius, c. 1611.
43. The West Indies, from Juan de la Cosa’s MS. map of the World, 1500.
52. Pigafetta’s MS. chart of Magellan’s Strait, c. 1525. Coloured.
54. As in Series I, No. 13.
    Chart of the Northern Coasts and Waters of the World, by Willem
    Barentsz., 1598.
55. MS. Chart of India, from the portolano by Fernão Vaz Dourado, c. 1573.
59. In separate cover, with descriptive text: Chart of the World, called by Shake-
    speare ‘The new map with the augmentation of the Indies’, 1600.
62. MS. Chart of the Malay Peninsula, from the portolano by Diogo
    Homem, 1558.
63. MS. autograph chart of Baffin’s Fourth Voyage to the North-West,
   1615. Coloured.
73. MS. chart of the coasts of Northern Europe and Nova Zemlya, by
    William Borough, c. 1578.
   Also in Extra Series, ‘Principal Navigations’, Vol. 3.

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86. The North-East Coast of America, on the MS. chart of Sebastian Cabot, 1544.
The North-East Coast of America, from Juan de la Cosa's MS. map of the World, 1500.
The New World on the Cantino MS. chart, c. 1502.
89. Capt. Thomas James's chart of 1631 of the North-West Passage, from his Strange and Miraculous Voyage, 1633.
96. The King Christianus His Forde. Cuningshams Forde. Brade Ransons Forde. The Coast of Groineland. All by James Hall, in his Report to the King of Denmark on the voyage of 1605.
MS. chart of the North Atlantic and the Arctic Regions, probably by James Hall, c. 1605.
97. Chart of Davis Strait and Hudson's Strait, by Captain Jens Munk, from Navigatio Septentrionalis, 1624.

Second Series

23. Coast of Mexico near San Juan de Ulúa, after Bautista Antoneli, 1608. MS. Coloured.
San Juan de Ulúa, after Bautista Antoneli, 1608. MS. Coloured.
28. The Straits of Magellan and of San Vincente, by Bartolomé and Gonzalo de Nodal, 1621.
44. Part of Diego Ribero's MS. chart of the World, 1529.
56. MS. map of Guiana, probably by Sir Walter Raleigh, c. 1595.
Also in Extra Series, 'Principal Navigations', Vol. 10.
60. MS. chart of the coast of Guiana, by Gabriel Tatton, c. 1613.
62. Central America and the West Indies, on a MS. chart by Diogo Homem, 1558.
76. Map of the New World, from a map of the World by Rumold Mercator after Gerard Mercator, 1587.
77. John White's chart of Virginia and Florida, c. 1585.
Part of John Dee's chart of North America, 1580.
Both also in Extra Series 'Principal Navigations', Vol. 8.
79. The North Atlantic on an Italian chart of c. 1508.
The Middle Atlantic Coasts on an Italian chart of c. 1508.
The coasts of West and South Africa on an Italian chart of c. 1508.
83. The World, from Sir Humphrey Gilbert's A new passage to Cataia, 1576.
Also in Extra Series, 'Principal Navigations', Vol. 7.
Sir Humphry Gylbert Knight his Charte.
Part of John Dee's chart of North America, 1580.
86. West Africa, from the Diogo Homem Atlas, 1558.
89. Twenty-six MS. charts and sketches of the coast of Western Europe, & the Mediterranean and Black Sea, Brazil, Africa, and southern 90. and eastern Asia, from O Livro de Francisco Rodrigues, c. 1510-15.

Extra Series

Vols. 1–12, The Principal Navigations . . . of the English Nation.

4. Eastern Africa and Southern India, from Linschoten’s East and West Indies, 1598.

5. MS. sailing chart of the Mediterranean, Aegean and Adriatic Seas, 1564, by Jacobo Rosso.


Other Chart Reproductions

In addition to the Hakluyt Society’s reproductions of charts listed above, excellent reproductions of charts, many in facsimile, of the sixteenth and seventeenth (and earlier) centuries will be found in the following publications. The list is not exhaustive.


MS. Charts of the fourteenth to seventeenth centuries. Stevenson, E. L., Portolan Charts, their Origin and Characteristics (1911).

MS. charts (Portuguese) of fifteenth to seventeenth centuries. Cortesão, A., Cartografia e cartógrafos portugueses (1935).


Notes on Collections of Sixteenth- and Seventeenth-Century Navigational Instruments in the British Isles

The National Maritime Museum, Greenwich, England, contains the finest collection of navigational instruments on view to the public, particularly astronomical ones, globes, and manuscript charts.

The Science Museum, South Kensington, London, contains a few navigational instruments and the best collection of nautical sand-glasses.
There are also excellent models of ships of the sixteenth and seventeenth centuries.

The British Museum contains the finest collection in England of manuscript and printed charts. These can be viewed only by accredited students. Selected charts are frequently on view to the public, as are selected astronomical instruments of which the museum has a small but exquisite collection.

The finest English planispheric and sea-astrolabes are both preserved in the collection of the Department of Natural Philosophy, University of St. Andrews, Fife. The oldest and one of the best preserved sea-astrolabes known is preserved in the Albert Institute, Dundee, Forfar.

Many instruments, including a sea-astrolabe, are preserved and admirably catalogued and displayed in the Museum of the History of Science, Oxford.
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