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# THE IBERIAN BASES OF THE ENGLISH ART OF NAVIGATION IN THE SIXTEENTH CENTURY

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by

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It is platitudinous that we live in a scientific age and that we conduct our affairs increasingly in accordance with scientific laws and principles is a characteristic of the age. Science affects not only our physical environment, shaping and controlling our activities to an ever-increasing extent, but also our mind, our psyche, our way of thought and our feelings. If anything can be said to be new in this world it is this scientific outlook or attitude of mind which has led to the scientific conditioning of our environment in the last 500 years. The Renaissance has been defined as the revival of the arts and letters in the 15th century but I find this too narrow a definition, for something else occurred in that century which was quite unprecedented, which was not a reversion to old learning, nor a revival of lost or forgotten accomplishments; it was the birth of a new intellectual technique, of what has come to be known as the scientific method and which is characterised intellectually by a scientific attitude of mind and physically by an extension of man's exploitation of nature by consciously exploiting natural phenomena methodically in order to achieve a certain aim or aims. If we seek for the cause of this phenomenon there seems to be one that is pre-eminent, the need of seamen to be able to determine the position of their ship in the ocean. This need first arose in the 15th century. Solutions were first developed by Portuguese and Spanish scholars and applied by Portuguese and Spanish seamen. They were not complete but they were sufficient for European man, mediaeval man, to break out of the hard shell, the narrow compass of his known world, and to discover lands and seas undreamed of and of dimensions so vast that it took a man three years to return from whence he had set out. In ancient times man had gained control of wind power to propel ships over the sea and in mediaeval times to turn windmills for grinding corn, but in the 15th century he began to use natural phenomena occurring beyond the Earth on which he dwelled to guide and control his movements. For centuries astronomers, the first scientists, had studied the apparent movements of the heavens, very largely in order to determine through the pseudo-science of astrology the influence of the heavenly bodies upon human activities. But in the 15th century seamen started using the apparent motions of the heavenly bodies to direct and control their movements on the surface of the Earth and they required of the astronomers accurate predictions of the apparent motions of the heavenly bodies to enable them to plan their future activities with the reasonable assurance that they would be able to carry them out no matter where they might be at sea or on the surface of the Earth. Astronomy quite suddenly became of immediate practical day-to-day importance in the lives of many men whose safety and whose prosperity depended in the last resort on the accuracy of astronomical observation and prediction. The science of nautical astronomy was born, and it was born in Iberia. For three centuries it dominated astronomy. All the great astronomers of the 15th, 16th, 17th and 18th centuries were pre-eminently interested in positional astronomy, that is to say, the positions of the so-called fixed stars and the motions of the Sun, Moon and planets. They were interested in it for the very practical reason that a ship's position is defined scientifically and known accurately when it is expressed in terms of latitude and longitude, and its latitude and its longitude can be determined only by observation of the heavenly bodies and by prediction of their relative positions and of their apparent motions through the heavens. It was not until the year 1767 that seamen had the means to determine their ship's longitude scientifically within about thirty miles as well as their latitude within about one mile, for it was not until that year that an adequate ephemerides was published, *The Nautical Almanac*, and suitable observational instruments and timekeepers were available for use at sea. These developments culminated in Britain but they were the fruits of some 300 years of effort by many of the greatest minds in history. Men of many nations had made their contribution. It is not my purpose to recount the story of the solution of the problem of finding longitude at sea. I wish to recount briefly the indebtedness of the English to the inventors of the art of navigation and the science of nautical astronomy and the pioneers of the technology of manufacturing precision instruments of measurement for use at sea.

Before I do that I would like to explain why I find this subject worthy of study. It is because the basis of modern civilisation is shipborne commerce, because the basis of ship-borne commerce is accurate navigation, because, out of the struggle to develop the means to navigate accurately, emerged our modern scientific and technological civilisation. If this seems at first too sweeping a claim for the role of navigation in our society let me remind you that it was not until the astronomical method to determine longitude at sea — lunar distance — had been developed in the middle of the eighteenth century that astronomers turned their attention to the physics of the universe. Then they were prompted to do so primarily as a result of speculations arising from their lunar observations made in the course of perfecting navigation. Until then the problem of «guiding a ship engulfed» claimed virtually all their attention. By then the scientific inventions made to enable seamen to navigate world-wide combined with the world-wide discoveries which they had made had stimulated an intellectual revolution — the scientific revolution of the seventeenth century — which, by the 1760s was already manifesting itself physically in the form of the industrial revolution. From such small beginnings as I shall now recount grew such great events.

There is something particularly appropriate to my theme that it was an Englishwoman, Philippa, daughter of John of Gaunt, Duke of Lancaster, who, marrying John I of Portugal at Oporto in 1487, gave birth seven years later to the Infante Henrique, Prince Henry the Navigator. It is appropriate because it was the ambition and driving force of this prince which sent medieval Portuguese seamen down to the pitiless Atlantic coast of the Sahara, and which forced them, in search of winds favourable for their return, out into the Atlantic. Here, because the ocean was of vast extent, was subject to powerful but unknown currents and as bottomless as it is featureless, they had imperative need of a new technique of navigation to verify their reckoning of where they were. It was developed from the oldest of the sciences, astronomy. By 1460, the year in which Prince Henry died, a new science, the science of nautical astronomy, had been initiated and had begun to be applied as an aid to the seaman anxious to know where he was in the featureless ocean.

The art of oceanic navigation was a new art in the history of western man. It was but in its infancy when the Prince died, for the first record of an astronomical observation — of the Pole Star — taken to determine the position of a seaman is one of 1454 near the Gambia River. Of course men had used the stars before at sea to guide them, but never before had western seamen used them to determine the distance they had sailed and, hence, their position in the ocean by instrumental measurement of their altitude.

Measurement is one of the characteristics of science. It was the practice of determining position at sea by astronomical measurement which made oceanic navigation basically a scientific art, for the instrumental human physiological and mathematical limitations upon the accuracy of the measurements made application of the science largely, at first, an art — the greater the scientific limitations the greater, of necessity, is the art of the scientist.

When first brought forth the observational and mathematical techniques of nautical astronomy where severely limited were, by modern standards, crude; their application, therefore, called for great innate or acquired navigational skill in the navigator — skill akin to that of the artist working to a purpose in any other difficult medium or with tools of strictly limited performance. But this crudity of scientific equipment and technique should not detract from the intellectual brilliance and originality of the initial concept — of the idea of measuring the ever changing altitude of the stars and, later, of the Sun, with sufficient precision to enable a ship's position in the ocean to be known. Time and again I read in histories of science, of astronomy, of navigation, that finding a ship's position at sea in terms of her latitude was a simple business, that the real problem, the tough nut to crack, was that of finding a ship's longitude at sea. In this connection, finding the time at sea of a ship's point of departure or at a distant observatory, with which the local time on board the ship (easily found at sea, we are repeatedly told) could be compared in order to find the difference in time and hence the longitude of the ship, was, according to many otherwise well-informed writers, the only serious problem in the history of navigation. But this is simply not true — the history of navigation is a history of a succession of intellectual feats of the first order, and how to find a ship's latitude is one of them.

To the modern seaman, equipped with a sextant reading to seconds of arc, with a nautical almanac predicting the positions of astronomical bodies to within fractions of a minute of arc several years ahead, and with tables of trigonometrical functions and of logarithms to calculate with, it is relatively easy to determine a ship's latitude accurately and also, provided he makes his observation of the Sun's altitude well before or well after noon, the local or ship's time, and, with a watch, to carry it forward or back. But this has been practicable for barely two hundred years. Before that all these so-called simple tasks were relatively difficult, if not impossible. I know one distinguished astronomer who wrote that finding noon at sea was perfectly simple because noon was when the Sun was due south and at its highest altitude. But the seaman knows, and of course this eminent astronomer knew had he thought, that at midday the Sun's passage across the heavens is, for an appreciable time, to all intents and purpose horizontal for it is then at the top of its daily arc and moving (apparently) directly in a horizontal line from east to west. In short, it is impracticable for a seaman (or anyone else) to determine the time of noon accurately from the Sun's noon altitude! So accurate time determination in a ship at sea was for centuries the reverse of easy, it was, in fact, a very difficult business, indeed it could not be done until the second quarter of the 18th century. Even today it is only relatively easy compared with, for instance, the business of determining a ship's longitude at sea astronomically or with a chronometer.

Precisely the same thing is true about determining a ship's latitude at sea. Once upon a time, how to do this was an entirely novel intellectual and therefore difficult problem — it was something that no-one — not just no seaman — had ever attempted before. Indeed, in the words of the Elizabethan scholar Thomas Digges, who was writing in a different context, it could be said of the pioneer Portuguese navigators of the mid-fifteenth century: «They neyther have true Rules too direct theymselves, the nighest course, ne yet treadinge their beaten pathes can assuredlye decide of theyr certayne place. For reformation of these errours and imperfections, newe Chartes, new instruments and newe Rules must bee prescribed» (1).

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(1) T. Digges, *A Prognostication everlasting*..., London, 1576, in *The Addition*.

And this is what must have been said, in so many words, to Prince Henry the Navigator as his pilots pressed south down the African Atlantic coast at his behest. For this is exactly what was done; but not, be it noted, at the sound of a trump, all at once, nor easily, nor perfectly, but laboriously and imperfectly.

To devise new charts, new instruments and new rules was a formidable technological task for experienced hydrographers and for craftsmen skilled in working in miniature in metal and wood — to say nothing of the novelty of the problem of training pilots in astronomical techniques. The pilots had to be taught by astronomers to use new gadgets, novel tabulated figures and abstract rules designed to ensure their proper use, with sufficient skill to inspire them to launch out into the ocean knowing all the time that there is nothing, in the words of the sixteenth century Spanish scholar, Martin Cortes, — «more difficulte than to guyde a shyppe engoulfed, where only water and heaven may be seene» (2).

Up to the midle of the fifteenth century, the pilot had been very well served with instruments of pilotage. The portolan chart was drawn on parchment, the coastlines having been laid down by estimated distances and magnetic compass bearings, and the whole surface was overlaid with a radial pattern of compass roses and of their radiating directional or rhumb lines for indicating direction between places. It was completed with one or more scales of leagues and miles for measuring the distance between places. A couple of dividers enabled the pilot to read off and plot on it direction and estimated distance sailed, data arrived at by the use of the magnetic compass, and a sand-glass (or running glass as the English called it); a *tavoleta di marteloio* or traverse table helped him to calculate courses and distances, if winds were not favourable; and a manuscript *roteiro* or book of sailing directions told him the distances in leagues and the courses to be followed; it gave him also times of high and low water, safe anchorages, dephts of water and sometimes the nature of the sea bed.

The oldest surviving Portuguese sailing directions appear to have been compiled in the 1460s or '70s. Parts of them, through the compiler of the oldest surviving French sailing directions, Pierre Garcie, who drew on them in the 1480s, eventually reached the English some forty years later in their first printed *Rutter for the Sea*, of 1528 (3). This, reprinted several times, continued to be the only printed sailing directions in English for almost forty years. But this is to anticipate developments.

Because the outward courses of the Portuguese pioneer navigators lay in southerly and southwesterly directions it was for an independent check to his estimated distance made good south or south-west that the Portuguese

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(2) M. Cortes, translated by R. Eden, *The Arte of Navigation*, London, 1561. The Spanish edition was written in 1545 and published in Seville in 1551.

(3) D. W. Waters' *The Rutters of the Sea*, New Haven, 1967, App. 6.

pilot first felt the need. Now, while it is today virtually a glimpse of the obvious to anyone interested in the subject to use in the northern hemisphere change in the altitude of the Pole Star as just such a check, it was by no means so obvious in the first half of the fifteenth century. For one thing the Pole Star was not, as now, less than 1° from the north polar point in the heavens, it was then about 4° away. As a result, at any given place in the northern hemisphere its altitude changed by about 8° in the course of a day. Now 8° is a sufficiently large change of altitude to obscure the obviousness of selecting the Pole Star as an aid to position finding at sea, particularly as the north polar point being invisible in the heavens it was impracticable, by looking at the Pole Star itself, to determine its angular distance above or below the north polar point or whether it was at that altitude. Even when the star had been selected, how and when to observe its altitude was still a very real practicable problem exacerbated by the fact that as yet no one had devised a measuring instrument of sufficient accuracy to measure small angular changes in celestial bodies when seen from on board a ship. Indeed, the first observations seem to have been made on shore. The earliest record — already referred to — is that of 1454 by Ca' da Mosto, a Venetian pilot in Portuguese service. He recounts how, after leaving the Canaries, the ships sailed south for 200 miles then standing in toward the land, coasted, sounding continually, until off the River Gambia, «The Pole Star was about the third of a lance above the horizon».

The Pole Star having been selected as a position-finding aid, the problem remained how was the navigator to find the altitude of the pole from the star's observed altitude, notwithstanding its 4° circumpolar diurnal motion? And then, how was this observation to be used to help him? To answer this question first, it was decided that he was to take the altitude of the Pole Star as observed at Lisbon as his astronomical datum; that after he had sailed south for some days he was to measure the altitude of the Pole Star when it was in the same position relative to the pole as it had been when measured at Lisbon; that he was to find the difference between the two altitudes and, on the basis of there being $16\,^2/_3$ leagues in a change of altitude of 1°, was to multiply the angular difference by $16\,^2/_3$ in order to determine the linear distance sailed from Lisbon. To help the navigator — as the pilot now became — to determine the altitude correctly for comparison he was told the various altitudes of the Pole Star as seen from Lisbon at eight different points on its circumpolar track, as indicated by the bright star *Kochab*. While the Pole Star is in the tail, *Kochab* is at the head of the constellation of the Little Bear. As *Kochab* was about 15° from the Pole its position relative to it was readly discernible — in the head, at the feet, on the right or on the left hand, etc. So *Kochab*'s position relative to the pole was to be used as an indicator of the Pole Star's position relative to the pole. The Rule of the Pole Star was the first of the new rules which the pilot had to master; the second was the linear length of a degree already described. This «altitude» sailing had been thought up, developed and taught for Atlantic navigation by 1460 for, in that year, Diogo Gomes, sailing to Guinea, recorded using a quadrant to observe the altitude of the Pole Star, which he «marked on the scale of the quadrant». The crucial feature of altitude navigation was that it gave a linear check in a north-south direction to the navigator's plotted position on his portolan chart and to his delineation of the African coastline as he charted it on his way south. Thus, altitude sailing had very far-reaching results, for it stimulated the integration of celestial angular measurements with terrestrial linear measurements, a prerequisite of scientific hydrography.

As experience was gained in navigation and hydrography by the use of altitude sailing the charts revealed that the length of a degree had been seriously under-estimated. By the 1480s, probably, a figure of 17 $^{1}/_{2}$ leagues of four miles to the league, equivalent to twenty English leagues of three miles, had been adopted; though this was still an underestimate of about 7% it had the navigational advantage, because it was an under-estimate, of helping to ensure that a pilot did not underestimate the number of leagues to be sailed to make a landfall and thereby risk coming upon the coast unexpectedly. As the Portuguese progressed down the African coast and as they found more islands in the eastern Atlantic the navigators felt the need for a more adaptable Rule of the Pole Star than that based on its altitudes at Lisbon. Therefore a more sophisticated rule was evolved. This gave the star's altitude in degrees and fractions of a degree above the pole or, in other words, the correction to be applied to the observed altitude of the Pole Star to reduce it to the altitude of the North Pole. As before the so-called *Guard Kochab* was used as the indicator of the Pole Star's position relative to the pole. This new rule was a very important development: it was the first step towards making nautical astronomy of universal utility. At first, of course, it was used by a navigator to measure his angular distance from other points of departure than Lisbon. However, as the equator was approached in the 1460s, the Pole Star sank too close to the horizon to be usefully observable. The navigator had, perforce, to be taught to observe the Sun when it was on the meridian at noon on successive days in order to find its difference of altitude. While it was one thing to take the Sun's altitude at noon in June and count any difference in altitude over a period of several days at sea as the result only of the distance sailed «south or south-west» (as the Rule put it) in the interval, around the period of the equinoxes, in March and September, the Sun's meridian altitude changes about $^{1}/_{2}{}^{o}$ daily when seen from the same place, because of its change in declination. Therefore the navigator had soon to be taught about the daily changes in quantity and direction of solar declination. This was doubly necessary when, by 1471, the equator had been crossed for the new stars seen in the southern hemisphere had not been charted. Only the Sun could be used to check positions south of the equator.

Because the altitude of the Pole is, as we now all know, equal to the latitude of the observer, the new Rule of the Pole Star, which was codified by the 1480s with a polar distance of 3 $^{1}/_{2}{}^{o}$ for the Pole Star, enabled a navigator to measure his angular distance north of the equator, to all intents and purposes, from the centre of the earth. The equator was a far more useful datum than some arbitrarily selected port such as Lisbon, because it could be used as a point of comparison irrespective of the port of departure and as a datum for recording the angular position of places in a form of general utility to navigators. And so latitude sailing was devised (4). In its train it brought a host of intellectual and technological problems before it was perfected.

The technique the navigator was now taught, certainly by the 1480s, was to find his latitude daily, keeping his record of courses and estimated distances sailed also to enable him to determine, in conjunction with his observed latitude, the distance he had probably made good in an east or west direction. To reach a destination, he was taught he should sail to its parallel of latitude but 100 leagues or so to the east or west of it, then «run down the latitude» (which he could check observationally) until he sighted his landfall.

It was at this time, in the 1470s, that the Portuguese navigator was also introduced by astronomers to the concept of solar declination, the change in the Sun's noon altitude caused, as we now all know, by the 23 $^{1}/_{2}$° tilt of the Earth's polar axis and its annual revolution around the Sun. They had to prepare for their navigators' use at sea, solar declination tables. The earliest printed one surviving is for the year 1483. With this table the navigator could now determine his latitude from a solar observation at noon.

But much more was needed to make latitude sailing practicable. For one thing calculation of the latitude of a ship from a meridian altitude observation of the Sun is not a straightforward operation; it is not only complicated by the Sun's declination, which changes, at constantly changing rates, between 23 $^{1}/_{2}$° N. and 23 $^{1}/_{2}$° S. in the course of the year, but also by the position of the observer on the earth's surface — whether he is north or south of the equator and whether he is north or south of the Sun or has it vertically overhead when he observes it at noon.

So rules, a Regiment of the Sun as they were called, had to be evolved telling the navigator what sort of sum to do — which corrections he had to add and which subtract — in order to determine his latitude from his meridian altitude observation of the Sun. Very practically the rules were based upon the direction of his shadow on the deck and, in due course, these rules, like that of the Pole Star, were illustrated for clarity — for the first time by the Spanish scholar Pedro de Medina, in his *Arte de Navegar*, of 1545 — quite a long time later, but still when barely a handful of the English were sailing by latitude.

Customarily, astronomers had tabulated their observations and pre-

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(4) The publication at this time of Ptolemaic *maps* incorporating latitude scales (the first) contributed in all probability to the concept of «latitude sailing».

dictions of the Sun's annual path through the heavens in terms of its angular position in the ecliptic, expressed as degrees (up to 30) and minutes in one of the Twelve Signs of the Zodiac. This was because they were handier this way for astrological use. But for the navigator this form was quite useless because what he wanted to know was the Sun's angular distance north or south of the equator. So it was in this latter form that the first known solar declination tables were prepared by astronomers for the use of seamen.

At first declination was given only to the nearest 1°, in a single table covering the four year solar cycle occasioned by the year being 365 $^1/_4$ days (almost) and not 566 days long. This table was probably the work of the Portuguese astronomer José Vizinho using tables prepared by the Hispano-Jewish astronomer, Abraham Zacuto as part of his great *Almanack Perpetuum* which he had compiled from 1473 to 1478 in Salamanca and which was first printed in Leiria in 1496.

But what of the problem of instruments for taking astronomical observations on board ship?

The first devised was the quadrant, probably with an altitude scale only, such as is known to have been used by Diogo Gomes in 1460; by 1481 an astrolabe had been used. This was probably first made from a sheet of brass for the navigator's use on Vasco da Gama's epic voyage to India. For this voyage, to match the hoped-for improved accuracy of the specially designed instruments, Zacuto also prepared quadrennial solar declination tables — almost certainly the first — to the nearest minute of arc for the years 1497-1500.

Out of these pioneer instruments was evolved by the 1540s the heavy cast brass sea — or mariner's astrolabe of characteristic form; and, probably from the Arabian *Kamal* brought back by Vasco da Gama, the far more accurate, versatile and handy seaman's cross-staff, measuring to degress and minutes of a degree — in contrast to the early astrolabes' $^1/_2$° or, at best, $^1/_4$° — of arc, had been invented by the Portuguese by 1514.

As for training, we know that Vasco da Gama's navigators were taught by Zacuto himself — the most brilliant astronomer in Iberia and, I believe, in Europe at the time. For instruction in astronomical theory the Portuguese used the thirteenth century *De Sphaera*, by the Englishman John Halifax of Holywood. They almost certainly employed initially a Castillian version as the basis for translation into Portuguese. Thus the navigator was taught about the curvature of the earth, and learnt definitions of necessary astronomical terms, such as Zenith. By this means too he became acquainted with the Ptolemaic theory of the heavenly spheres and the mechanics of the (apparent) motions of the celestial orbs. The oldest surviving of these manuals, the *Regimento* preserved in Munich, was printed about 1509, but the first edition probably came out in the 1490s.

But it was one thing to teach a navigator the theory of celestial mechanics, and of position-finding on earth and how to observe and calculate the latitude of his ship and quite another to enable him to put this to regular practical use. For this he had to know, in terms of latitude, where he was and where he was going. And so what can well be termed the first scientific gazeteers were prepared — and I emphasise that they were prepared for seamen to use at sea. They gave the latitude of places, at first to the nearest degree and only of places south from Cape Finisterre — the Iberian seaman's most northerly landfall; then, as instruments of observation were refined to measure more accurately and astronomical tables were improved to match the increased instrumental accuracy, the table of latitudes was also improved giving positions to the nearest minute of latitude; they were extended in scope also as the navigators, with their improved tables, instruments and rules, voyaged farther, until the gazeteers extended virtually around the world.

To simplify the navigator's task of latitude sailing at a time when mathematical tables were rarely available and tables of the trigonometrical functions were inaccessible, a Rule to Raise or Lay 1° of latitude was devised. This told him how many leagues he had to sail on the respective points of the compass to change his latitude by 1° — it was a very necessary table for running down the latitude. It was yet another of the new tables called for and especially prepared for latitude sailing.

But the navigator also needed new charts, for the portolan type chart no longer met his navigational needs. In order to plot his position on his chart he now needed an additional scale, of latitude. By 1500, a latitude scale is found on a Portuguese chart which yet survives. The scale has been superimposed upon the portolan chart which is of the north-east Atlantic and the Mediterranean and the disconcerting fact emerges that, as a result, while the scale is correct in the middle latitudes it is several degrees in error at the northern and the southern ends of the scale. Clearly, the hydrographers were now faced with the problem of integrating observed and «estimated» latitude positions more scientifically.

When a latitude scale was added to a portolan-type chart of the Atlantic ocean, discrepancies between «estimated» latitudes, position found by compass bearing and estimated distance, and observed latitudes became even more apparent. The causes were various, amongst others, the deflection of the magnetic compass needle by variation from true north and the distortion given to the representation of the earth's curved, globular surface, by drawing it as a plane surface on which parallels of latitude and, in effect, the converging meridians of longitude, were drawn as equidistant parallel straight lines. To overcome the variation factor an oblique meridian was introduced, probably, by Pedro Reinel in one of whose surviving charts, one of the Atlantic of *c.* 1504, it is first found. Though by no means a perfect answer, charts with the oblique meridian served into the seventeenth century in place of a globe or of a chart constructed on mathematically correct principles, first described by the English scholar Edward Wright in 1599 and now known as the Mercator chart.

Meanwhile the tempo of navigational invention and improvement was quickening. Under the inspiration of the Spanish monarchs, Ferdinand and Isabella, Spanish scholars and navigators began to impose the charm of order upon navigational knowledge and to teach mariners the art of navigation systematically. Moreover, under the Emperor, Spaniards taught the seamen of the Mediterranean and of northern Europe the art of navigation through the printed manuals which, from 1519, they began to publish.

In the Casa de Contratación, established in Seville in 1503, on the lines of the older Casa da Índia in Lisbon, Ferdinand in 1508 set up a hydrographic office and a school of navigation where the latest discoveries were incorporated in a great master chart, the *padrón real.* This became the standard for all others, and was supervised by a *Piloto-Major.* Within a few years the manufacture of instruments, their testing and the examination of pilots to assess their competence as navigators was a matter of strictly formulated routine. The Casa was behind the preparations for Magellan's great expedition around the world, begun in 1519. For this an instrument of variation was especially devised for measuring magnetic variation of the compass at sea — the invention of this instrument was of fundamental importance to hydrography and oceanic voyaging. In the 1530s, partly as a result of its success, a great struggle was waged by science against tradition, in the Casa de Contratación which Sebastian Cabot, the Piloto-Major since 1518, won, for he insisted upon correcting magnetic bearings into true bearings, by applying corrections for variation before charts were constructed. It would seem that, besides using true bearings, he insisted upon latitude observations being used also for delineating charts. Thus the true plane sea chart was at length painfully evolved for and as a consequence of latitude sailing. But Cabot, whose great engraved planisphere of 1545 yet survives in Paris, advocated and used the method of construction first devised by the Portuguese hydrographer Diogo Ribeiro in his great world planispheres of 1525, 1527 and 1529. Ribeiro, working in the Casa de Contratación, had drawn the Mediterranean in his planispheres on the basis of estimated distances, true bearings and observed latitudes of places. It was in the 1530s also that Pedro Nunes, *Cosmógrafo-mor* of Portugal, first elucidated for Portuguese navigators the hydrographical problems of distance and of convergence of the meridians on the plane chart and also the spiral nature of rhumb lines on the globe. These two theses he published for the benefit of all men in 1537 and thus enabled the young scholar Gerhard Mercator, working in the Netherlands which was then, like Spain, a part of the Empire of Charles V, to publish in 1541 the first terrestrial globe to incorporate rhumb lines. This globe was thus of general navigational use and it remained in use for some fifty years, being popular with the English into the 1590s.

Admiral Guillén has truly written — «The principle and traditional maritime countries of Europe learned their navigation from Spanish works». The first Spanish navigation manual published was written by the scholar and lawyer Fernandez de Enciso and came out in Seville in 1519; it was republished in 1530 and again in 1546. It included the first *derrota* or Spanish sailing directions for overseas ever printed. These, translated into English by John Frampton and published in London in 1578 as *A briefe description... of the Weast India*, became the first printed English sailing directions for overseas. Enciso expressed perfectly his faith in the new navigation — for this is what it was — of latitude sailing; so perfectly, indeed, that I must quote him in part: «Here end», he wrote, «the treatise of the sphere... and the Regiments of the Sun and the North Star by means of which mariners can position and direct themselves at sea. Also... cosmography for sailing directions and latitudes, by which pilots can know whence and whither they are going far better than ever before in order to discover lands yet to be found...». Here is the voice of one crying out in delight when the world was but half discovered and the wonder of the new science of latitude navigation had not grown jaded by long use.

Sixteen years later a great Portuguese scholar, Francisco Faleiro, writing in Castilian, published at Seville (in 1535) *Tratado del Esphera*. It was a work notable for many reasons, but particularly because it set the framework for subsequent manuals of navigation. For instance, it defined navigational terms, it described what the navigator should do to keep track of his ship and the procedure by which he should do it, and it reduced to diagrammatic form rules to raise or lay 1° of latitude and the effect of magnetic variation upon the ship's steering compass. Next came Pedro de Medina's great *Arte de Navegar* of 1545 which, translated into English and published in London in 1581 and again in 1595, became a standard English text book. With its brilliant diagrams, clear tables and lucid text Medina's *Arte* was a masterpiece of exposition as it was of printing; nevertheless its pattern was set by Faleiro.

Sebastian Cabot had been Pilot-Major of the Casa de Contratación for thirty years when, after the death of Henry VIII, he was invited by the English Privy Council — probably through the English merchants long settled in Seville to whom he was well known and to the Governor of whom, William Ostrich, he was related — to come over to England and teach the English the art of navigation. At that time few, if any, Englishmen knew the art or had instruments, charts and books of navigation, none of which was obtainable in England. Early in 1548 Cabot, deeply versed and experienced in all the knowledge and skills known by some educated Englishmen to be necessary for great navigations, arrived in England, never to return to Spain. Here he organised a navigation training ship, the bark *Aucher*, and soon had fifty or sixty English mariners trained as navigators. By 1553 the English had been initiated also by two Portuguese pilots, António Pinteado and Francisco Rodrigues, into the secrets of the wind system which controlled the success or failure of voyages to the coast of Guinea. Two years later Richard Eden, by including in his *Decades of the Newe Worlde*, a translation of Aviedo's *Of the ordinary navygation from Spayne to the West Indies*, gave a good idea to English seamen of the trans-Atlantic routes used by the Spaniards.

It is an ill wind that blows nobody any good. While in many ways the rule of Mary Tudor — Bloody Mary — over the English from 1553 to 1559 was cruel, unhappy and economically disastrous, the fact that she was married to the young King Philip II of Spain can be seen to have been fruitful in the long run beyond the dreams of avarice. Stephen Borough, Chief Pilot of the English Muscovy Company, virtually founded by Sebastian Cabot a few years earlier to exploit commercially the navigational skill which he had inculcated into English mariners, was invited in 1558 to visit the Casa de Contratación in Seville. There he had been shown the system of training which for the last half-century had been turning out navigators competent to conduct ships over all the oceans of the world; he had been shown their instruments and manuals, amongst these, no doubt, Pedro de Medina's *Regimiento de Navegacion* of two years earlier, with its brilliant illustrations of how to take astrolabe solar and cross-staff stellar observations for latitude determination. However that may be, he came back filled with admiration for the organisation and its achievements and, by 1561, at his behest, Richard Eden had translated into English Martin Cortes' great navigational manual of 1551 (or the edition of 1556), *Breve Compendio de la Sphera y de la arte de navegar*, as *The Arte of Navigation*. This work, incorporating, like those of Enciso, Fernandez and Medina, material from the Portuguese pionner works can truly be said to have been the work which navigated the English seamen to their meteoric rise to fame as, to use the phrases of a Venetian Ambassador of the 1580s, «great sea dogs». It was, in my view, probably the most formative, the most influential book after the Bible in the English language. More than any other it shaped the destiny of the English nation and of the English-speaking peoples which have sprung from their loins. How dependent the English navigator of the sixteenth century was upon Iberian navigational know-how is probably best epitomised by Sir Francis Drake, the greatest English navigator of his age. On his epic voyage around the world, 1577-80, he seized a Portuguese pilot, Nuno da Silva for the passage to Brazil and down the east coast of America; in the Pacific he seized the charts and rutters of two Spanish pilots bound for Manila (whom he released before he crossed the Pacific as they refused to navigate him). He had set off equipped with a chart of the world made in Portugal and with three books relating to navigation of which one was probably Medina's *Arte of Navigation* or Nicholas de Nicholai's French edition of 1554, another probably Richard Eden's translation of Cortes, *The Arte of Navigation*, of which a second edition had come out in 1572. If the third was Bourne's *Regiment of the Sea* of 1574, the first English-written book on the art of navigation, virtually all its material was of Lusitanian origin. However that may be, Martin Cortes's *Arte of Navigation* was still being published in 1630, over fifty years later, as a standard English manual of navigation. As late as 1610 Edward Wright lifted, in translation, the whole of Zamorano's chapter on the plane chart from his navigational manual of 1581, *Compendio del arte de Navegar*, for the second edition of his classic *Certaine Errors in Navigation*.

«I saye that I am the first», Martin Cortes had written in his dedication to the Emperor Charles V, «that have brought the arte of navigation into a brief compendiousness... descrybyng the practise and speculation of the same, gevyng also true rules to Maryners... teachyng them the making and use of instruments, to knowe and take the altitude of the Sunne... and motions of the Moone... the makyng of Dyalles... that... shall shewe the true houres... And... have declared the secrete properties of the lode stone, with... the variation of the compasse...». What more need be said to underline the English seaman's indebtedness to Portugal and Spain.

I do not subscribe to the view that it was ever easy, least of all for the pioneers, to invent ways and means to find the latitude and the time at sea in order, in Martin Cortes's words, «to bryng them into the way that wander». For with him, I ask as he did, when navigation in the oceans was as novel and difficult as to-day it is in space, «What can be more difficult than to guyde a shyppe engoulfed, where only water and heaven may be seene?»

What Martin Cortes was saying, in effect, was what Edward Wright, in the year 1610, said: «...in our time the whole art of Navigation is groune to much greater perfection, than... ever it had in any former ages».

To concluse, by the time that Edward Wright wrote this, the art of navigation had long been practised by many English seamen. Virtually all that they knew of it and practised at that time was based upon the Iberian invention in the middle of the fifteenth century, of the science of nautical astronomy and upon the instrumental inventions made and the technical skills developed in the resultant art of navigation by Portuguese and Spaniesh scholars and seamen in the ensuing century. It was the fruits of the navigational genius of these men which the English reaped in the first Elizabethan age.

## *DISCUSSÃO*

A. Cortesão. — I am the first to regret that time is rather scarce and therefore our schedule so tight that most of the excellent papers presented at this Meeting cannot be read and discussed in full, as they deserve. Both myself and Professor Albuquerque, our Secretary General, have realized this from the beginning; but, first, it would not have been practical to extend our Meeting over more than four days, and, second, it would have been difficult to foresee that so many and such important and substantial papers would be presented for discussion. As it happened, we would have needed four weeks or more instead of four days, and that is why I have always worried about keeping our schedule of work within bounds. I owe all of you this apology for appearing almost always rather strict. Fortunately all the papers will be published, together with their discussions, in the Proceedings of this Meeting. I suppose this will make a bulky volume which may come to have an important place on the shelves of all interested in the history of nautical science and cartography. Cmdr. Waters' paper is just one of the many in cause. It is not only beautifully written and delightful to read, but one full session would scarcely be enough for its proper discussion.

As Cmdr. Waters said, «by 1460, the year in which Prince Henry died, a new science, the science of nautical astronomy, had been initiated and begun to be applied as an aid to the seaman anxious to know where he was in the featureless ocean». In Vol. II of my

*History of Portuguese Cartography*, which I hope will be published towards the end of 1969, I seek to show that the initial or experimental phase in the process of development of this new science began not later than the first years of the second quarter of the xv century, just when Prince Henry started his great maritime venture. All new sciences have an experimental phase, based on the accumulated knowledge gathered by many generations during the previous centuries or millenia. Cmdr. Waters has referred to the «latitude scale added to a portolan-type chart of the Atlantic». This was done first by Portuguese cartographers just as a consequence of astronomical navigation. It signalled the third of the five great periods of the history of cartography, inseparable from the history of nautical science: the first was the measurement of a degree of the great circle by Eratosthenes, the second was the coming into being of the Mediterranean portolan chart, the fourth was the discovery of Mercator's projection, and the fifth was the invention of the maritime chronometer.

As Cmdr. Waters has said in the concluding words of his remarkable paper — and nobody could say it with more authority and more beautifully — «it was the fruit of the navigational genius of Portugese and Spanish scholars and seamen which the English reaped in the first Elizabethan reign». I should add: the English and the peoples of the whole world.

WASHBURN. — As an ex-colonial of Commander Waters's country, I share, his pride in English priority in solving the problem of longitude, but if I may be as contentious as my revolutionary ancestors may I say that «solving the problem of longitude» must be considered (1) relative to the purpose to be served and (2) relative to the degree of accuracy achieved. The «problem of longitude» was, in this relative sense, solved to *greater* purpose but with a lesser *degree* of accuracy by the Portuguese, by Columbus, by Magellan, etc. by various means, such as dead reckoning. As to the question of the degree of accuracy of the determination of longitude, Commander Waters points out that even with Harrison's chronometer, the accuracy was subject to an error of possibly thirty miles. But why isolate *this* moment on the continuum to say that the problem was solved? Today, by means of satellites in space and other aids, we can more accurately determine our position on the face of the earth than we could on the 18th century. Moreover, Cook, in his first voyage, *without* the chronometer, achieved virtually the same degree of accuracy in determining his position as he did in later voyages *with* the chronometer. I would assert, therefore, that it is inaccurate to speak of the «problem of longitude» being solved at any particular moment without reference to the purpose served and to the degree of accuracy achieved.

ERNEST CRONE. — I thank Commander Waters for his most interesting paper on the Iberian bases of the English art of navigation in the 16th century.

The same could be said in relation to the Netherlands. The books of which he showed the titlepages and the titlepages of the translations are in the Dutch language too. There is a translation of Medina (1545) in Dutch (1580) and a number of later editions of Zamorano and of Bourne's book, which is based on Portuguese sources.

I add a few words on the way to finding the latitude at sea. The observation of the altitude of the Sun could only be done at noon. In case at that moment the Sun was obscured by a cloud, the observation was not possible and the navigator had to wait for the next day, hoping for success.

Finding the latitude by observation before or after noon was a question of spherical trigonometry which no navigator of the 17th and greater part of the 18th century of any country understood.

The finding of the latitude by a double observation of the Sun and the time elapsed between the observations we thank to a Dutch mathematician Cornelis Douwes who invented a system of computing the latitude, which every navigator was able to use, without mathematical knowledge. His method was made use of by the navigators of all seafaring nations in the world from 1750 to 1850. It is remarkable that manuscript tables which Douwes had made for his pupils for test at sea, came into the hands of English naval officers who at once understood the extreme usefulness of the system. They had them printed (Harrison's Solar Tables) and they appeared some time before the tables of Douwes appeared in Holland.

PIMENTEL BARATA. — Faço notar que o quadro do Museu de Greenwich «Portuguese Carracks», a mais bela e primeira representação pictórica marítima da Europa, no século XVI, é feita sobre assunto português: o transporte da Infanta D. Beatriz para Saboia. Recordo que este quadro esteve 400 anos em Portugal, até que em 1911 foi vendido para a Alemanha, daqui para a Holanda, e finalmente comprado por Sir James Caird para o Museu Marítimo de Greenwich.

A segunda observação refere-se à divisão da régua pelo método de «meia-lua» muito usado nos estaleiros da Europa até o século XIX, para determinar as ordenadas das curvas do navio. Era um dos métodos de graduar o graminho e provàvelmente remonta ao tempo dos gregos.

URSULA LAMB. — Spanish literature reflects a change of sentiment concerning oceanic navigation including the exploration of the unknown. The stereotype of loss and peril at sea gives way to the feeling of safety under the rule of the stars. Pedro de Medina says in his *Libro de la Verdad*: «y después que escribí el Libro del *Arte de Navegar* por donde los mareantes se rígen en sus navegaciones sín peligros de ignorancia... me pareció debía escribir otro libro para que los navegantes por el tempestuoso mar deste mundo ... llegemos al puerto seguro...».

TEIXEIRA DA MOTA. — Na clara síntese que o Comandante David Waters acaba de nos oferecer, apraz-me especialmente pôr em relevo a sua total aceitação da ideia de que no Atlântico, antes de uma «navegação de latitudes», houve uma «navegação de alturas». Esta ideia, ao que julgo primeiramente apresentada por António Barbosa, logo foi desenvolvida por E. G. R. Taylor, com o apoio de novos argumentos, nomeadamente a demonstração de que Cristóvão Colombo conheceu entre os portugueses tal método. Embora a ideia de que a «navegação por alturas» existiu antes da «navegação por latitudes» tivesse de entrada sido objecto de algumas reservas, parece estar agora tendo como merece, uma mais larga aceitação.

DAVID WATERS. — In my view, the development of latitude sailing by the Portuguese and Spanish pioneer seamen and scholars of the fifteenth century was an intelectual feat of the first order and comparable to the solution of the longitude problem as I have attempted to emphasize. There was no immediately obvious solution to the problem of how to help a navigator in the ocean to have a more accurate position on his chart than he could obtain by dead reckoning, based on estimated courses and distances sailed only. The causes of his errors were not known. In the Mediterranean currents have little effect on the way made good by a ship, in the ocean they have a very great effect but until the means to determine a ship's longitude (as well as her latitude) in the late eighteenth century had been developed it was impossible to determine the velocity of ocean currents and therefore to be sure that it was ocean currents which affected the mariner's reckoning. Similarly, until the means to measure magnetic variation at sea had been developed, as it was in the sixteenth century, it was impossible to determine how much a seaman's position was in error as a result of magnetic var iation.

Latitude navigation was not initiated over night. It was evolved out of altitude navigation as the late Prof. E. G. R. Taylor so ably elucidated some ten years ago. So, to sum up, altitude navigation originally using the Pole star and later the Sun was introduced probably in the first half of the fifteenth century after Prince Henry started sending out expeditions to reach down the West coast of Africa. As I have shown, this involved preparing rules of nautical astronomy and tables for calculation for the use of seamen and it was from this altitude navigation that probably in the 1470's latitude navigation for use of seamen was evolved. In this connection I must emphasize that the modern geographical gazetteer really stems from the table of latitudes prepared at the close of the fifteenth century for the use of seamen. In fact, the more we look into the history of Renaissance astronomy and geography the more do we find their development inspired by the art and science of navigation developed by the Iberian scholars and seamen.

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