

## THE DEVELOPMENT OF THE MARINER'S CHART

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### SUMMARY

The key to the problem of projecting rhumb-lines as straight lines — the chief requirement of a navigational chart — was suggested by the Flemish cartographer and cosmographer Gerard Mercator. There is no evidence, however, that Mercator understood the mathematical principle of the projection which now bears his name. This principle was discovered independently by Thomas Hariot (whose investigations were not published) and Edward Wright after Mercator's death. The principal aims in this paper are : first, to trace the development of the plane chart from the portolan chart; second, to discuss the contributions made in particular by Pedro Nuñez, John Dee and Mercator, in the quest for a chart suitable for navigation, especially in high latitudes, which would be free from the defects of the "plane chart", the "navigation globe" and the "polar zenithal charts" used or suggested up to the end of the sixteenth century; and, third, to emphasize the essential link between Nuñez, Dee and Mercator, which appears to have been forged at the University of Louvain at which all three men studied during the sixteenth century. By the beginning of the seventeenth century the problem of the mariner's map had been solved following the introduction of Edward Wright's Table of Meridional Parts.

### 1. THE PORTOLAN CHART

CORTESÃO, in his recent *History of Portuguese Cartography*, emphasizes that, "... the renaissance of truly scientific map-making began with the portolan charts created in the XIII century to meet the needs of seafarers..." [1]. NORDENSKIÖLD, in his *Periplus*, remarked that the portolan chart was, "... the most perfect map of the Middle Ages, the Iliad of Cartography..." [2]; and JERVIS, in his *The World in Maps*, after declaring that portolan charts cannot be included in the general condemnation of maps of the Middle Ages, pointed out that portolan charts, "... represent the spontaneous attempt of sailors and merchants, armed with a compass, the

heaviness of mediaeval night just passing, to solve for themselves the peculiar problems of cartography..." [3].

A puzzling feature of portolan charts is that in the earliest example extant [4] comparative perfection seems to have been achieved. This is difficult to explain without assuming a long process of evolution; and there is no evidence for this.

A portolan chart is a projectionless chart in which the cartographer merely depicted the coast giving correct distances between, and mutual relative positions of, headlands, ports and other coastal features. It carries no graticule of parallels of latitude and meridians although a scale of distance is given. Portolan charts appear to have been drawn on the basis of the accumulated experience of mariners from observations of compass directions and distances between coastal features [5]. Considering the period when the early portolan charts were drawn, and the primitive stage of nautical astronomy at the time, the outlines of coasts and islands are striking in their similarity to those on modern maps of comparable scale.

Portolan charts were developed for mariners engaged in voyaging within the enclosed waters of the Mediterranean, but from the early fourteenth century portolan charts of the Atlantic coastlands of western Europe and Africa were available. By that time the centre of gravity of maritime activity had shifted westwards out of the Mediterranean region and the Portuguese had rapidly become the pre-eminent maritime nation. The Canaries had been rediscovered by Portuguese seamen in 1336, and these islands formed a base from which further exploration southwards along the African coast was made. But for navigating in the open Atlantic, as opposed to the African coastal voyages, new techniques were needed, and it was the influence and judgement of Prince Henry [6], *the Infante*, as the Portuguese have always called him, which brought forward the advent of nautical astronomy by which the latitudes of ships' positions at sea, as well as places ashore, could be found from relatively simple astronomical observations and principles. The new techniques for finding latitude, from an altitude observation of the Sun or a star at meridian passage or of the North Star --- the *Stella Maris* --- at twilight, were developed essentially by the cosmographers whom Henry gathered around him [7].

When it became general for seamen to practise rudimentary nautical astronomy, navigation was facilitated by graduating the mariner's chart with a scale of latitude. The first known chart on which this was done is a Portuguese chart now preserved in the Bayerische Staatsbibliothek in Munich. It is unsigned and undated but is believed to have been drawn c. 1500.

## 2. THE PLANE CHART

From the time when charts were constructed more on the basis of latitude than on bearings and distances (the basis of the portolan charts) the question of a scale of longitude, as well as of latitude, arose. The early charts, also of Portuguese origin, on which longitude scales are given, are based on a plane cylindrical projection, producing what became known as the "plane chart" --- the "*carta plana quadrada*" as the Portuguese called it.

The characteristic feature of the plane chart, as indicated by the Portuguese name, is the simple network of squares forming the graticule. On a plane chart, parallels of latitude at equal intervals on the Earth are projected as equidistant parallel straight lines; and equiangular spaced meridians on the Earth are projected as equidistantly spaced straight lines which cross the charted parallels of latitude at right angles. The scale of distance along the projected equator is the same as that along every meridian, so that the graticule is a network of squares.

In books dealing with map projections [8] the graticule of a plane chart is usually described as a "simple cylindrical" or "plate carrée" conventional (non-perspective) projection. The equator is projected as a straight line of length  $2\pi R$ , where  $R$  is the radius of the "reduced Earth" from which the projection is constructed. All meridians are projected as straight lines which intersect the projected equator at right angles, and they are projected true to scale; that is, as lines of length  $\pi R$ . All parallels of latitude are projected as straight parallel lines of length equal to that of the projected equator. The scale along the equator and along every projected meridian is true, but east-west distortions increase proportionately to the secant of the latitude.

To the sailor the plane chart conformed to the technique known as "latitude sailing" in which the ship was directed northwards or southwards (as the case required) until she reached the parallel of the latitude of the destination. Having reached this parallel the ship was directed due east or west to make the desired landfall. When sailing due east or west a ship traces out a track which is parallel to the equator; and this, also, is in exact accord with the plane chart. Moreover, all meridians on the globular Earth cut parallels of latitude at  $90^\circ$ ; and, again, this conforms to the plane chart. But it was puzzling to non-mathematical sailors that if two ships started on the same parallel of latitude and sailed due north (or south) at the same speed, their distance apart — as they were told by mathematicians — would change; whereas the plane chart makes it appear that the distance apart would remain constant.

Although sailors have always known that the Earth is spherical — simple observations make this fact obvious — the recognition that the Earth is a sphere is one thing, but the understanding of the *properties* of a spherical surface is quite another matter. The inaccuracies resulting from the use of a plane chart stem from the difficulty of handling the convergence of the meridians. The resulting errors are not serious when navigating in low latitudes; and, at the equator, where the meridians are parallel to each other and the convergency is zero, little or no error arises from the use of a plane chart. But when navigating in high latitudes the use of a plane chart produces serious error.

### 3. THE RHUMB-LINE

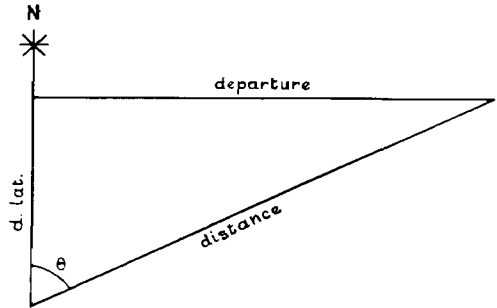
A rhumb-line is any of the radial lines on a compass card terminating at one of the 32 points of the compass. It is easy to see that, when a ship sails on a constant course, the extension of the rhumb-line coinciding with

the lubber line on the compass bowl, through the ship's fore-and-aft line ahead, makes an equal angle — the "course-angle" or "meridian-angle" — with every meridian she crosses. It is for this reason that a line on the Earth which cuts all meridians at a constant angle is also called a rhumb-line.

When sailing obliquely across meridians on a given rhumb-line, the problem of solving the position of arrival after having sailed a given distance from a given position, and the converse problem of finding the rhumb-line direction and distance between two given positions, were problems of considerable difficulty to early seamen.

When a ship sails along an oblique rhumb-line the *distance* sailed, and the *northing* (difference of latitude, d. lat.) and *easting* (departure), may be regarded as forming the sides of a plane right-angled triangle: the angle opposite to the side representing the departure being the course angle ( $\theta$ ); the hypotenuse, the distance; and the third side, the d. lat. This plane triangle is an artifice which shows the relationships known as the "canons of plane sailing", viz :

$$\begin{aligned} \text{departure} &= \text{distance} \times \sin \theta \\ \text{d. lat.} &= \text{distance} \times \cos \theta \\ \frac{\text{dep.}}{\text{d. lat.}} &= \tan \theta \end{aligned}$$



It used to be (and still is to some extent) a common belief that the artifice now called the "plane sailing triangle" represents a triangle on the Earth's surface. This belief was strengthened by erroneous and confused definitions such as, "Plane sailing is the art of navigating a ship upon principles deduced from the notion of the Earth's being an extended plane" [9], which appeared in many early navigation manuals. Because the Earth is spherical no triangular area on its surface can be a plane triangle; but the somewhat spurious argument was advanced that the smaller is a triangle on the Earth's surface the more nearly is it plane. This led to the erroneous belief that the canons of plane sailing hold good only for short distances. But it is readily proved [10] that the rules hold good for *all* distances.

It would be wrong to suppose that early mariners were ignorant of the defects of the plane chart and of plane sailing; but they were hampered in not understanding how to overcome these defects.

A major problem faced by early Atlantic voyagers arose from their inability to find longitude or to estimate reliably distances sailed eastwards or westwards. This meant that charted positions of places on the western side of the Atlantic compared with those of places on the eastern side were, not surprisingly, often wildly in error in their longitudes. This difficulty gradually was overcome and charted positions ultimately assumed reasonable accuracy. But even so, the general problem of sailing across the Atlantic continued to be aggravated by the inherent defects of the plane

chart. For example, it can easily be verified, as HEWSON [11] has pointed out, that the distance by plane chart between the Lizard and the Azores is 2800 miles compared with the correct rhumb-line distance of 1875 miles!

The errors arising from the use of the plane chart increase with latitude. The Portuguese, therefore, during the early phase of the Age of Discoveries, were not affected unduly by using the plane chart within about 35° of the equator. But northern Europeans who voyaged in the northern part of the Atlantic in their quest for a route to the Spice Islands of the Pacific, were hampered considerably in their east-west navigations.

#### 4. THE NAVIGATOR'S GLOBE

A navigational globe is an exact replica of the Earth, and the chief advantage of such a device for solving sailing problems is that it suffers no distortion except, of course, of scale. Provided that it is accurately made, sufficiently large to give accurate answers, and robust enough to stand up to the rough treatment to which it inevitably would be subjected on board a lively ship at sea, a globe was an admirable instrument for nautical use. John Davis, the renowned Elizabethan explorer-navigator, writing in the late sixteenth century [12], remarked that, "... The use of the Globe is of so great ease, certainty and pleasure, as that the commendation thereof cannot be sufficiently expressed...".

Robert Hues, whose *Treatise on Globes* [13] was first published in 1594, was an Oxford scholar who devoted himself to the study of geography and astronomy. He had sailed on an Atlantic voyage with Thomas Cavendish and his experience at sea qualified him to write with authority on the use of globes for navigation.

The fifth part of the *Treatise*, under the title "Of the Rombes that are described on the Terrestrial Globe and their Use", is the work of Thomas Hariot (1560-1624), the eminent Elizabethan mathematician and nautical adviser to Sir Walter Raleigh. In this part Hariot showed how rhumb-line sailing problems could be solved by means of a globe. He wrote:

Turne about the Globe until some Rumbes or other do cross the Meridian, at the latitude of the place whence you set forth. Then again turne about either toward the East or West, as the matter shall require, untill that an equall number of degrees in the Equator to the difference of longitude of the two places do pass the Meridian. Then afterward looke whether or not the aforesaid Rumbes doe crosse the Meridian at the latitude of the place where you are, for if it does so you may then conclude that it is the Rumbes you have gone by; but if otherwise, you must take another, and try it in like manner till you light upon one that will do it... The Rumbes being found, wee are next to seeke the distance betwixt the two places. Nonius [Núñez] teacheth a way to doe this in any Rumbes, by taking with your compasses the space of 10 leagues, or halfe a degree. Others take 20 leagues or a whole degree. But I approve of neither of these, nor yet regret either. Only I give this advertisement by the way, that according the greater or lesse distance from the Equator, a greater or lesse measure may be taken. For neare the Equator where the Rumbes are little different from great circles, you may take a greater measure to goe by. But when you are farre from the Equator you must then take as small a distance as you can, because that here the Rumbes are very crooked... [14].

But Hariot suggested a better method of finding the distance, for the use of which method he provided a table in which is given the number of degrees, minutes and seconds, on each of the seven rhumbs, between two adjacent cardinal points, answering to a degree of a meridian. This table [15] is illustrated below :

	Rumbes	Deg.	Min.	Sec.	
In the	First	1	1	10	Answer to a degree in the Equator or Meridian
	Second	1	4	56	
	Third	1	12	9	
	Fourth	1	24	51	
	Fifth	1	47	59	
	Sixth	2	36	47	
	Seventh	5	37	33	

The following example served to show how the table was to be used:

If a ship have sailed from C. Verde in Africke, lying on the 14 gr. 30 m. of Northerne-Latitude, to C. Saint Augustine in Brazill, having in Southerne Latitude 8 gr. 30 m. by the Rumbes of South West and by South, and it be demanded what is the distance betwixt these two places.

For finding of this we dispose our tearmes of proportion after this manner, 1 gr. of latitude in this Rumbes (which is the Third from the Meridian) hath 1 gr. 12 m. 9 sec., that is to say 72  $\frac{9}{60}$  miles; therefore, 23 gr. (which is the difference of latitude) require 1659 miles and almost an halfe, or something more than 553 English leagues... [16].

It is evident that the terrestrial globe used for navigation in the way described by Hariot needed to be engraved not only with parallels of latitude and meridians but also with rhumb-lines. First to do this; and, indeed, first to explain the nature of rhumb-lines, was the eminent Portuguese mathematician Pedro Nuñez (1492-1577).

## 5. PEDRO NUÑEZ

Nuñez, Chief Cosmographer to the King of Portugal and Professor of Mathematics at Coimbra, is credited for having been first to analyse the errors arising from the use of a plane chart. It appears [17] that Portuguese mariners complained to Nuñez of the practical difficulties in using a plane chart, whereupon the Cosmographer studied the matter and published his investigations in two small treatises, *Tratado em defensam da carta de marear*, and *Tratado sobre certas duvidas da nauegacão* which were published in his *Tratado da Sphera* in 1537. In these treatises Nuñez drew attention to the convergence of the meridians and pointed out that meridians were projected erroneously as straight lines on the mariner's chart. He demonstrated that "linhos dos rumbos", or rhumb-lines, although being taken as least, or "straight-line", distances on the chart were not least distances between places on the globular Earth. Moreover, he showed that rhumb-lines on the Earth are equi-angular spirals which continually approach the Earth's poles.

In his treatise *Tratado em defensam da carta de marear*, Nuñez gave a diagram consisting of a circle representing the equator with four diameters to represent eight equi-spaced meridians. From each of the points on the circle intersected by a meridian four curves are constructed, each cutting the meridians they cross at a constant angle. These curves are spiral lines which continually approach the pole which is projected at the centre of the equatorial circle.

Nuñez drew rhumb-lines on a terrestrial globe by means of a flexible instrument of brass, constructing each rhumb-line, little by little, until it approached the pole [18]. The instrument used by Nuñez gave, in sum, an approximate rhumb-line composed of a relatively large number of small great circle arcs. This called for criticism by later (and lesser) workers. Robert Hues, for example, wrote :

For, seeing that the portion of a great circle, being intercepted betwixt diverse Meridians, though never so little distant from each other, maketh unequal angles with the same, a Rhumbe cannot consist of them... But this inequality of Angles is not perceived (saith Nonius [Nuñez] by the sense, unlesse it bee in Meridians farre remote from one another. Be it so, notwithstanding, the error of this position is discoverable by art and demonstration. Neither doth it become so great a Mathematician to examine rules of art by judgement of the sense...

Hues' proof that rhumb-lines do not pass through the poles is interesting :

For seeing that the same Rhumbe is inclined to all Meridians — and all Meridians doe pass through the Poles — it would then follow that if a Rhumbe should pass through the Poles, the same line in the same point would cross infinite other lines; which is impossible, because that a part of any Angle cannot be equal to the whole...

It is of importance to note that immediately before taking up his appointment as Royal Cosmographer in 1529, Nuñez had studied at the University of Louvain. The year after this Gerard Mercator entered the same university to study under Gemma Frisius. There can be little or no doubt that Mercator was aware of Nuñez's treatises on navigation, and it is not unreasonable to suppose that the Flemish cartographer developed the ideas of the Portuguese scholar.

## 6. PARADOXAL SAILING

The errors of the plane chart rendered it all but useless for navigating in high latitudes, and the defects of the globe made it unsuitable as a practical instrument for use on board ship. In an effort to overcome the deficiencies of the plane chart and globe, particularly for the northern voyages of discovery in which English navigators were engaged, Doctor John Dee (1527-1608) suggested the use of a chart based on a polar zenithal projection.

The name of John Dee, argued Professor E.G.R. TAYLOR [19], is one which every navigator has good cause to respect. Dee's contributions to nautical science and his influence on the progress of maritime expansion during Elizabethan times, which were remarkable and highly significant, are discussed in detail by Professor TAYLOR in her *Tudor Geography* [20]. Commander D.W. WATERS also stresses the importance of Dee and

credits him for "first grasping the possibilities of arithmetical navigation, for doing the pioneer work on it, and for teaching its potentialities to navigators" [21].

After studying at Cambridge John Dee entered the University of Louvain where he learnt that, "mathematics is a practical as well as a theoretical art". What must have influenced Dee greatly during his sojourn at Louvain -- "the fountain-head of learning", as he described it -- was his close contact with five of the more eminent of his geographical contemporaries. These, Gemma Frisius, Pedro Nuñez, Gerard Mercator, Abraham Ortelius and Orontius Finnaeus, were his friends as well as his teachers and critics.

At this point it is important to note the link between Nuñez and Dee. The relationship between them was close to the extent that in 1558 Dr. John Dee appointed Nuñez his literary executor, and it is interesting to inquire into Dee's development of the ideas on rhumb-lines which his friend Nuñez had published in Latin -- for scholars everywhere to read.

On his return to England, Dee was appointed by the Muscovy Company, at its inception in 1550, to advise on matters navigational. In this capacity he invented his polar map, which he called his "paradoxall compass", in about 1556, and this map represented a practical development of the ideas on rhumb-lines introduced by Nuñez.

On a polar zenithal projection the convergency of the meridians is obvious, and a rhumb-line, carefully plotted on such a projection, appears as a spiral. The fact that a rhumb-line, which is a "straight" line of constant course, is projected as a spiral on a polar zenithal chart is an apparent paradox; and this seems to have been the reason why Dee called his chart a "paradoxall compass".

No written explanation by Dee, of the manner of using his "paradoxall compass" has survived, but a manuscript set of tables [22] written by Dee in 1558 gives, in effect, the difference of longitude resulting from a change of one degree of latitude on each of the seven rhumbs. This table provides the clue to the practical use of the polar chart.

William Barlow, in his *The Navigators Supply* [23] of 1597 described two forms of "Spiralle Carde". One of these, a polar case of the stereographic projection [24], results in "enlarging the Landes described towards the Equator"; and the other, a polar case of the orthographic projection [25], results in "enlarging the Landes described towards the Pole".

But neither Dee's nor Barlow's polar charts provided a practical solution to the sailing problem so far as the seaman was concerned, because of the comparative difficulty of plotting a rhumb-line on a zenithal projection -- this being a prerequisite of measuring a course-angle.

## 7. MERCATOR AND HIS WORLD MAP OF 1569

Gerard Mercator (1512-1594) studied under Gemma Frisius at Louvain; and, as noted above, was a friend of John Dee and, doubtless, was



acquainted with the work of Pedro Nuñez. He first came into prominence as an engraver; and, indeed, assisted in the engraving of the terrestrial globe designed by Gemma in 1537. Mercator was ultimately to supersede his master and, in 1541, he made his first globe, on which the spiral lines of Pedro Nuñez were engraved.

Dr. Ernst CRONE [26] has indicated that a model globe of the Earth on which meridians, parallels of latitude and rhumb-lines are engraved, renders it possible to find the latitudes of points at which any given rhumb-line cuts successive meridians. Perhaps Mercator's realization of this led him to his solution to the problem of the navigational chart.

Because of the convergence of the meridians the segments of the rhumb-line on the globe between successive pairs of meridians get shorter as the latitude increases. As a compensation for this the scale of distance must, therefore, be expanded as the latitude increases. This expresses, in a crude form, the principle of the Mercator projection.

At the present time the Mercator projection is described as a conventional cylindrical orthomorphic projection, every line on which is exaggerated proportionally to the secant of its latitude. The term 'orthomorphic', as it applies to map projections, means that angles at every point on the map are not distorted. This, and the need for a chart on which rhumb-lines are projected as straight lines, are the essential properties of the type of chart for which the seaman sought in vain for so long.

Unfortunately we have no direct evidence of how Mercator constructed his world map of 1569; but it is not unlikely that his procedure was similar to that indicated by CRONE. Careful measurements of the spacing of the parallels of latitude on this map reveal errors of a magnitude which demonstrates that he could not have used trigonometrical tables (although they were available) as the basis of construction.

The publication of the world map, under the title *Nova et aucta orbis terrae descriptio ad usum navigantium emendate accommodata* [27], marked the zenith of Mercator's cartographic career. The extensive text which accompanied the map was in Latin; it included conjectural coastlines based on literary sources; and it was not drawn according to the conventions adopted for a sea-chart. Nevertheless, it was designed, as the title indicates, expressly for navigational purposes [28].

The principal aim of Mercator in producing his masterpiece is given in the preface to his readers which clearly demonstrates that he had navigators in mind :

...sphaerae superficiem ita in planum extendere, ut situs locorum tan secundum directionem distantiamque veram quam secundum longitudinem latitudinemque debitam undequaque inter se correspondeant, ac regionem figurae in sphaera apparentes... [29].

It might be thought that immediately after the publication of Mercator's new chart "ad usum navigantium" that sailors would have seized upon the new projection to assist them in their navigation. But this was not the case. It is of interest to note that William Barlow referred to the Mercator map in his *The Navigators Supply* of 1597 [30]. After mentioning the imperfections of the common "carde" used by sailors he remarked :

...and yet I cannot here conceale one great secrete concerning these Cardes, namely, that there is a certaine draught of them very Artificiall and regular: which being well vnderstode, redresseth the errours of the other: and (as farre as I canne discernē) will so satisfie the Navigators expectation, as no Carde hitherto inuented was euer comparable vnto it, neither (as I thinke) any that shal hereafter, wil in al respects surpassē it...

Barlow's prophesy came to pass and even today no chart is more suitable for the seafarers' needs than one constructed on the Mercator projection. But even thirty years after its publication in 1567, Barlow wrote that "a cloude (as it were) and thicke myste of ignorance doth keep it hitherto concealed".

For the better understanding and making of sea-charts along the lines Mercator proposed, Barlow gave a demonstration which, he said, he had, "obtained of a friende of mine of like profession" [31], showing the proportional increase in the spacing of parallels as latitude increases. But Barlow's demonstration was not convincing.

The law for the accurate spacing of projected parallels of latitude on a Mercator map is due, essentially, to Edward Wright (1558-1615), the eminent Elizabethan scholar and Fellow of Caius College, Cambridge. To Wright is due the invention, in about 1593, of the "meridional parts table" by which the simple rectangular graticule of a Mercator chart can readily be constructed.

The first table of meridional parts appeared in Thomas Blundevil's *Exercises of 1594* [32]. The table is entitled: "A Table to draw thereby the Parallels in the Mariners Card, together with the use thereof in truer sort than they haue been drawn heretofore, and the use thereof". The table gives for each degree of latitude from 1° to 80°: "Equall parts of the Meridian on the Mariners Card, of which euer degree of the Equinoctiall conteineth 60 miles".

The first substantial explanation of the mathematical principle of the Mercator chart came with the publication of Wright's own *Certaine Errors in Navigation*, first published in 1599 [33].

#### NOTES AND REFERENCES

- [1] CORTESÃO, A. (1969) : *History of Portuguese Cartography*, Vol. 1, p. 215, Junta de Investigações do Ultramar, Coimbra.
- [2] NORDENSKIÖLD, A.E. (1897) : *Periplus : An essay on the early History of Charts and Sailing Directions*. P.A. Norstedt & Söner, Stockholm.
- [3] JERVIS, W.W. (1936) : *The World in Maps : A study in Map Evolution*. George Philip & Son, London.
- [4] The earliest example extant, considered to have been drawn in c. 1300, is the *Carta Pisana* preserved at the Bibliothèque Nationale in Paris. The oldest dated portolan chart is one signed by Pietro Vesconte carrying the date 1311. (Vide A. CORTESÃO (1969) *op. cit.* for detailed descriptions of early portolan charts).

- [5] See an interesting paper by E.G.R. TAYLOR (1954) : Jean Rotz and the Marine Chart. *J. Inst. Nav.* VII (2), April, pp. 136-143. Institute of Navigation, London.
- [6] Prince Henry, surnamed "the Navigator" (1394-1460), was the third son of John I of Portugal and his English wife Philippa of Lancaster, daughter of John of Gaunt, Duke of Lancaster. Henry is noted as patron and organizer of the early Portuguese overseas discoveries.
- [7] For a detailed description of these techniques, *vide* C.H. COTTER (1968) : *A History of Nautical Astronomy*, pp. 123-143. Hollis & Carter, London, American Elsevier, New York.
- [8] *Vide* C.H. COTTER (1966) : *The Astronomical and Mathematical Foundations of Geography*, p. 217. Hollis & Carter, London.
- [9] Quoted from J. ROBERTSON's *The Elements of Navigation* (London, 1772), a popular manual which ran into several editions and which was used right up to the middle of the nineteenth century.
- [10] *Vide* C.H. COTTER (1953) : *The Elements of Navigation*, pp. 95-96, Sir Isaac Pitman & Sons, London.
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- [14] *Ibid.*, p. 139.
- [15] *Ibid.*, p. 142.
- [16] *Ibid.*, p. 142.
- [17] CORTESÃO, A. (1971) : *History of Portuguese Cartography*, Vol. 2, p. 108. Junta de Investigações do Ultramar, Coimbra.
- [18] See an interesting paper by E. CRONE (1965) : Historische Opmerkingen over de Loxodroom. *De Zee (Zeevaartkundige Tijdschrift)*, Hilversum.
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- [22] DEE, J. : *Canon Gubernaticus, an Arithmetical Resolution of the Paradoxall Compass*. (Ashmolean Ms. 242). Reproduced in E.G.R. TAYLOR (1961) : *A Regiment for the sea and other writings on Navigation by William Bourne*. Hakluyt Society Publication, Series 2, Vol. CXXI, Cambridge.
- [23] BARLOW, W. (1597) : *The Navigators Supply. Conteyning many things of principall importance belonging to Nauigation*, London.

- [24] COTTER, C.H. (1966) : *The Astronomical and Mathematical Foundations of Geography*, p. 180. Hollis & Carter, London.
- [25] *Ibid.*, p. 187.
- [26] CRONE, E., *op. cit.*, (Note 18).
- [27] *New and improved representation of the terrestrial globe properly adapted for use in navigation.*
- [28] For a detailed description of the rare original Mercator world map which was (in 1933) in the possession of the Prins Hendrick Museum at Rotterdam, the reader is referred to the article by Dr. van NOUHUYS which is included in *The Hydrographic Review*, Vol. X (2), Nov. 1933, pp. 237-241, Monaco.
- [29] "... to show on a plane the sphere's surface in a way that the positions of places shall correspond with each other as far as directions and distances apart are concerned, as well as with their correct longitudes and latitudes; then, that the forms of the parts be retained, as far as possible, as they appear on the sphere...".
- [30] BARLOW, W., *op. cit.* p. K 4. (Ref. [23]).
- [31] BARLOW was a cleric and one-time Dean of Salisbury Cathedral.
- [32] BLUNDEVIL, T. (1594) : *M. Blunderville His Exercises, containing six Treatises... Verie necessarie to be read and learned of all young Gentlemen...* London.
- [33] WRIGHT, E. (1599) : *Certaine Errors in Navigation, Arising either of the ordinarie erroneous making or vsing of the sea-chart... detected and corrected.* London.