Mateo Jorge, a Pilot of the Casa de la Contratación 16th Century Sevilla: a Study in the Transmission of Science and Technology as Expressed in the Graphics of a Rutter of Practical Navigation

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Introduction

A common English language idiom "a picture is often worth 1,000 words" conveys the notion that a well-crafted graphic complements the text in conveying ideas. In the 16th century the printed word from movable typeset was a relatively new technology, a little over 100 years old. The Spanish published scientific ideas in print during the period of the discoveries of the New World. Many ideas of cosmography and navigation were published by principles of the Casa de la Contratación in Sevilla (the Casa). The Casa served as the Spanish house of business contracts for the convoys with the New World. The Casa was also the repository of cosmography and practical navigational knowledge and the institution that trained the pilots of the convoys.[1] Many documents of the repository relating to specific sailing routes and specific navigational findings were carefully guarded manuscripts and were never printed nor widely shared.

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[1] Pilot/piloting and navigator/navigation are used synonymously in this article even though they have different meanings in practical navigation.

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One constant among manuscripts and printed material, closely held or in circulation, was the use of graphics to transmit concepts and applied knowledge. Instruments of navigation were built from detailed technical graphics. Symbols became accepted, were codified and used as shorthand. Colors and line styles were used to differentiate or accent. Pointing arrows (call outs), labels and text "sidebars" were used to amplify and explain. These graphics were quite technical in nature as well as artistic. Centuries later some of these graphics would have been called nomograms or alignment charts, mapping the mathematical relationship between variables of navigational interest.

In this article, we hope to establish solid evidence to support a theory of influences that suggests classic printed works on cosmography of the Casa informed pilots, i.e. that pilots studied these treatises and applied theoretical knowledge to practical navigational techniques. We will develop our evidence by explaining and comparing graphics from the manuscript of a pilot of the Casa to similar graphics appearing in classic works of the Casa. We specifically suggest a reconsideration of the role in the Casa and among the pilots of the classic work of Martin Cortés, the *Breve compendio de la sphera y de la arte de navigar*.

Mateo Jorge and the Mateo Manuscript-the Provenance

Mateo Jorge was a pilot major of the Casa in 16th century Sevilla[2]. There are three documents that support this: Mateo Jorge produced a manuscript derrottero (ca. 1582-1612), a rutter or sailing log[3]; a written judgment was made in 1606 against Mateo Jorge, a pilot of the Casa[4]; Mateo Jorge and his father Luis Jorge are mentioned as pilots by Andres Garcia de Céspedes the pilot major of the Casa in his *Regimiento de Navegacion*[5]. In addition to our own examination of the Mateo manuscript and supporting original source documents, Dr. Luisa Martín-Meras, the Director of Cartography of the Museo Naval, Madrid, provided suggestions as to the provenance of Mateo Jorge and the Mateo MS.

The Mateo MS, now housed in the Naval Museum in Madrid, was kept at the earliest from 1582 until at least 1612. The date of 1582 is based on the appearance of tables of declination of the sun in accordance with the Gregorian calendar in the Mateo MS. The date of 1612 appears in a sketch of a landfall[6]. The Mateo MS contains practical navigational directions and knowledge about specific routes typical of log books of pilots from the Casa in the 16th century, but also reflects a strong theoretical foundation which Mateo Jorge received through direct instruction and, most importantly, from reading treatises on the art of navigation.

The manuscript itself, although written in various hands, appears to be the work of Mateo Jorge. The hands all correspond to late 16th century and early 17th century cursive (secretarial hand); the dominate hand appears to be similar to two sample hands found in Agustín Millares Carlo's *Tratado de paleografía española*, Vol.III (3rd ed., 1983), Plates 421 and 419 dated 1566 and 1571 respectively while another[7] resembles that in Plate 423, dated 1602. The Mateo MS, although containing different dates, reflects the hands of this time period, albeit individualized by Mateo Jorge and by scribes that may have intervened in this work. In the fly leaves a person who calls himself Miguel de Bartriste writes in a poor, early 17th century script that he is owed money for a variety of services, especially in connection with damages sustained during one of the voyages at San Lucas where apparently one of the timbers of the ship had to be replaced. There is a sketch of the hull of a boat in fly leaf 3; on fly-leaf 4 the writer mentions nights, days and hours that he put into his work including at the capstan. In the rest of the fly leaves he continues to itemize his services and demands to be paid. What is not clear is whether this fly-leaf text relates to the judgment against Mateo Jorge.

In the 1606 judicial decree in which the sentence given by Dr. Garcia Carreño in 1604 was upheld, Mateo Jorge is required to pay his fine of 60,000 maravedis. Mateo Jorge is accused not only of having risked the loss of his fleet but also of incurring extra expenses in costs and salaries. The court may have decided to increase his fine from 40,000 maravedis to the

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[2] The head of all the pilots of the Casa was called the Pilot Major, a term also used for the pilot of a group of ships in convoy to the New World; Mateo Jorge was the latter.

[3] Museo. Naval (MN), Madrid, MS 2550, 1582-1612.

[4] Archivo General de Indias (AGI), Contratación 151, B. N10.

[5] Colección Clásicas Tavera (CCT), Obras Clásicos de Náutica y Navegación, Serie II, vol.17, CD-ROM. Cespedes, Andres Garcia de, *Regimiento de Navegacion*, Madrid, 1606, f. 139r, f. 161r.

[6] MN, MS 2550, f. 78v.

[7] MN, MS 2550, ff. 2r-16r.

final figure of 60.000 repeated in left margin notes of the decree. The text of the decree is written in 17th century "escritura de jura".

Only a little is known about the person of Mateo Jorge. In Andrés García de Céspedes's *Regimiento de Navegación y de la hidrografía*, two men with the last name Jorge are mentioned, one is Luys Jorge, who is originally from Lisbon and is recognized by Céspedes as one of the best pilots of the route from the Cape of Good Hope to Cape Guardafu (horn of Africa) and from the Canary Islands to the Cape of Good Hope[8]. Céspedes recognizes a Mateo Jorge as an experienced pilot[9]. This Mateo Jorge made corrections to the route to the Isla de Mujeres, and to other places along the Yucatan coast. Whether the two other emendations mentioned after these belong to Mateo Jorge as well is not clear. They deal with the coast of Caracas and islands of the Indies. These emendations may be attributed to Mateo Jorge because these places, Tierra Firme, islas de Barlovento, Santo Domingo, and Canal de Bahamas are also mentioned in the Mateo MS. Luys or Luis Jorge was in all likelihood Mateo's father and himself a highly regarded pilot major (who probably taught his son well). Father and son legacies are not uncommon in the history of the Casa (Alonso and Geronimo de Chaves, Stephen and William Burrough). Luis may have been a rival of Céspedes, cosmographer major to the king, whose treatise dominated 17th century navigation in Spain[10].

What distinguishes the Mateo MS manuscript are the artistically hand-crafted graphics, several painted in brilliant colors and some animated so as to spin. Due to secrecy, or simply to the discarding of navigational worksheets after their immediate use, there is often a lack of original documents to answer questions on the details and specifics of practical navigation. The importance of the Mateo MS graphics lies in the insights they provide into the state of the practice of this applied science at the end of the 16th century.

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[8] CCT, Cespedes, *Regimiento*, f. 139r.

[9] CCT, Cespedes, *Regimiento*, f. 161r.

[10] Haring, Clarence Henry, Ph.D. *Trade and Navigation between Spain and the Indies*. Gloucester, Mass., 1964, pag. 313.

Research Questions

Our research deals with how graphics were instrumental in transmitting scientific and navigational information among the pilots of the Casa. Leaving aside the great cosmographic debates of the 16th century, we asked ourselves: "What did the practical navigator know? How did he come to know it? What did he really do with what he knew in a practical sense when out at sea?" To begin to answer these questions we focused on Mateo Jorge and his manuscript rutter or sailing log. The Mateo MS graphics were compared to graphics appearing in earlier or contemporary works found in the *Obras Clasicas de Nautica y Navegacion* (the *Obras*) of the Fundacion Historica Tavera (CD-ROM). The navigational and mathematical basis of the graphics in the Mateo MS was analyzed against relevant information found in the *Obras*; the text for order of contents, style of script, evidence of multiple hands, key words and margin mark-up; and the maps for source.

WHAT DID THE PRACTICAL NAVIGATOR (MATEO JORGE) KNOW?

Our source of information about what Mateo Jorge knew comes from the manuscript rutter or sailing log attributed to him. The manuscript text is structured and contains sailing directions between specified locations as expressed in rhumbs and leagues, land fall sightings to expect, latitudes of specified locations and descriptions of locations. There are also 48 manuscript graphics including the Ptolemaic cosmography[11], the celestial sphere[12],

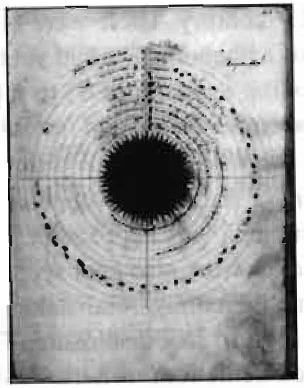

Figure 1 Ptolemaic Cosmography

Figure 2 Celestial Sphere

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[11] MN, MS 2550, f. 45r.

[12] MN, MS 2550, f. 46r.

instruments, tables, lists and geometrical and mathematical algorithms. In analyzing the graphics, we made significant inferences about what Mateo Jorge knew about the mathematics of practical navigation.

Four Fundamentals-Time, Direction, Distance, Location

Four fundamentals to the mathematics of practical navigation on the high seas in any century are time, direction, distance and location. The mathematics of navigation should be a matter of measuring and calculating the relationship between these fundamentals: we know where we are; we know where we want to go; we head in the correct direction to get to the destination in a predictable amount of time measured from the place of departure. In the late 16th century, the navigators of the Casa like Mateo Jorge integrated these four fundamentals into a system of practical navigation to be able to regularly transit to and from the New World.

To understand the knowledge Mateo Jorge possessed as a 16th century navigator, we of the 21st century must suspend our belief in what we know about these four fundamental concepts, specifically the accuracy and precision with which we understand time, direction, distance and location. Precision in measurement of time to minutes and seconds did not drive day-in day-out life as in the 21st century. There were no gyro-compasses to point to true north; magnetism as a phenomenon had yet to be identified. There was no satellite global positioning system (GPS) to tell us to the precision of a meter where we are in real-time. Charts and maps to orient us were not available at a click or two on the World-Wide-Web/internet.

During the "Cold War" of the late 20th century, access to the most precise satellite GPS navigating data was kept secret. Undoubtedly, specific 16th century navigating techniques were also kept secret, not printed or expunged from circulated documents; the commercial stakes involved in navigating to the New World were too high to risk disclosure. There may be another reason for our lack of documentation; rutters, logs, sailing directions are "results". Worksheets for calculating time, direction, distance and location are not always kept, even in 21st century practical navigation. Worksheets are an intermediate step often discarded after use. Fortunately, the Mateo MS graphics provide clues. Although just one document, the evidence in the Mateo MS suggests some answers to our research questions when examined with regards to the mathematics of time, direction, distance and location.

Time

There are several pieces of evidence that suggest how Mateo Jorge perceived of time. There are: a table of the week and hours of the day and the *dominion of the planets*[13]; three graphical constructions of the *geometric algorithm* for determining hourly time with the sundial[14]; a table for four years of the *declination of the sun* that suggests the solar calendar in use[15]; and, precise technical drawings for *instruments* that measure time and the temporal occurrence of terrestrial and celestial events based on observations of celestial bodies.

Dominion of the Planets, Natural-Artificial Time

The table of the dominion of the planets[16] associates the order of each of the seven Ptolemaic non-stellar celestial bodies with the order of the days of the week and each of the hours of the respective day with their planet. This is astrology, considered then an ancient science as valid as astronomy. Human behavior at a given hour in the day of the week is under the influence, the dominion, of the given planet. The table of the dominion of the planets in the Mateo MS suggests that the pilots of the 16th century Casa like Mateo Jorge combined astrology with astronomy to create their scientific frame of reference.

Figure 3 Dominion of Planets

In astronomy and navigation, the solar day is defined by successive meridian passages of the sun, 24 hours, and the sidereal day by successive meridian passages of the star Aries, about 4 minu-

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[13] MN, MS 2550, f. 46v.

[14] MN, MS 2550, f. 66r.

[15] MN, MS 2550, f. 56r.

[16] MN, MS 2550, f. 46v.

tes less than the solar day. The text to the right of the Mateo MS table of the dominion of the planets explains how to calculate "natural" time and "artificial" time. In artificial time the 24 hours of the solar day are each of equal duration regardless of daylight and darkness. The sailor at sea in the 16th century would often describe the hour of the day by the position of the sun in the sky as expressed in rhumbs, i.e., points of the compass. So, for example, 6 in the morning would be "east", noon would be "south" (in the more northern latitudes), 6 at night would be "west". In this "natural time" determined by the position of the sun, there are always 12 hours of the solar day (sunrise to sunset) and 12 hours of the solar night (sunset to sunrise). The length of those natural hours of the solar day and of the solar night are adjusted; in the Mateo MS example 16 artificial hours of the day (sunrise to sunset) would be 12 natural hours each of 80 minutes, 8 artificial hours of the night (sunset to sunrise) would be 12 natural hours each of 40 minutes. The text also describes measuring the angular position and movement of the sun to determine the hour of the day. The example is a 12 degree angular movement of the sun across the sky as one hour, implying 15 sixty minute hours between sunrise and sunset.

In the absence of one standard method for knowing time in the 16th century, the evidence in the Mateo MS suggests the pilot of the 16th century Casa kept at least two, natural and artificial. We also know the duration of time the helmsman spent on the wheel was measured by turning a 30 minute "hour glass" of sand. Time was also measured against a prime meridian passing through Lisbon, Salamanca, Sevilla, Cadiz, the Azores, Cape Verde or any of several other points. What we in the 21st century call "standard" time is an agreement among significant world institutions to accept each block of 15 degrees of longitude as a time zone with a uniform hour throughout and a prime meridian passing through Greenwich, England[17]. This agreement did not happen until 1884 and then among only 25 countries. Greenwich was not widely accepted until early in the 20th century as the prime meridian; in the 21st century there are still exceptions to standard time. For a pilot of the 16th century like Mateo Jorge to keep time by more than one method for more than one use should not be surprising nor seem unreasonable.

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[17] Blaise, Clark. *Time Lord*. New York, 2000, pag. 12.

Sundial Algorithm

There are three graphics of a geometric algorithm for construction of both a horizontal and vertical sundial in the Mateo MS[18]. The graphics and labeling suggest the algorithm is the one found in the Martin Cortés[19] and the Richard Eden translation of the Cortés. The algorithm solves for the artificial hours (i.e., 24 equal hours) of the solar day. The algorithm is mathematically elegant, reducing what is a complex three-dimensional algorithm to a two-dimensional construction that solves for both vertical and horizontal sundials. The mathematical elegance derives from dividing the hemisphere into 90 degrees vice 180 degrees for purposes of construction. Using the conventions of mathematics, the precision of the geometric sundial algorithm in the Mateo MS is to one hour of time and 5 degrees of latitude. The construction or thickness of the stylus would determine the accuracy of the measurement.

The three graphics in the Mateo MS are constructed for latitudes of 10, 20, 40 and 45 degrees. These latitudes are consistent with the localities logged in the Mateo MS rutters, given 16th century latitudes. Ten degrees of latitude is just below Cartagena. Twenty degrees of latitude is just above Dominica and just below Habana. Given the precision in latitude of 5 degrees in the algorithm, this covers the Indies area. Forty degrees of latitude is halfway up the Portuguese coast. Forty-five degrees is just north of Bayonne, covering the transit from Sevilla to San Sebastian and Bayonne. The evidence is that with these sundial algorithms, knowing latitude to within 5 degrees, Mateo Jorge could know time to within one hour for the specific places in his rutters.

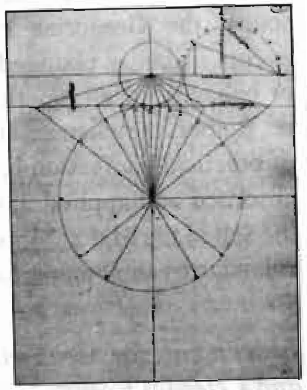

Figure 4 Sundial Algorithm

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[18] MN, MS 2550, ff. 65r, 65v, 66r.

[19] Colecion Clasicas Tavera (CCT), Obras Clasicos de Nautica y Navigacion, Serie II, vol.17, CD-ROM, Cortes y Albacar, Martin, *Breve compendio de la sphere y de la arte de navegar* ... . Sevilla, 1551, f. xlix v.

Tables of the Declination of the Sun (Gregorian calendar)

There are four years of tables of the declination of the sun in the Mateo MS[20]. The tables are based on the Gregorian calendar; zero declination is March 21st vice March 10th as in the Julian calendar. Several countries including Spain and Portugal adopted the Gregorian calendar early in 1582; England and her colonies in 1756; Russia, Persia and several other countries did not until 1926. A number of scientific events fundamental to navigation occurred in the mid to late 16th century and into the 17th century: Copernicus heliocentric view of the universe, Kepler's elliptical construction of the solar system, Galileo's telescope, the Gregorian calendar. None of these events instantly changed the cosmographic view or behavior of all practical navigators everywhere. Rather, the changes in precision and accuracy of practical navigation based on these events took decades to centuries to be absorbed and applied more generally. However, the tables of declination of the sun in the Mateo MS suggest almost immediate adoption of the Gregorian calendar by the Spanish and Portuguese pilots of the Casa.

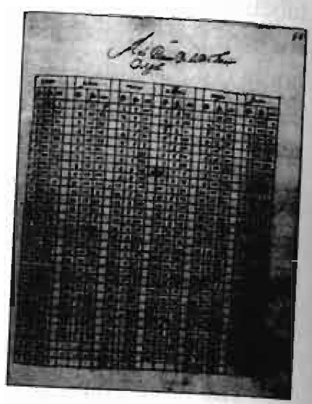

Figure 5 Gregorian Tables

Instruments for Measuring Time, and Time of Terrestrial and Celestial Events

In addition to the sundial algorithm, there are technical graphics in the Mateo MS for three other instruments used to measure time or the time of terrestrial and celestial occurrences, two nocturnals[21], a perpetual almanac[22] and a tide calculator[23]. The nocturnal determines the hour at night by viewing the orientation of the guard star, Kochab, marking the lip of the "little dipper" (Canus Minor), with respect to the north pole star, Polaris, as they make their nightly rotation around the pole. The difference of about four minutes between the sidereal day and the solar day requires calendar date as an entering argument in the nocturnal algorithm with 25 April aligned with north. The index of the inner roundel labeled with hours is placed on the calendar date on the outer roundel. The arm is aligned with the orientation of the guard in the sky and the time of the night is read off of the inner roundel. There are two graphics of the nocturnal in the Mateo MS, the nocturnal graphic on the top of the folio with 25 April aligned with north and the nocturnal graphic on the bottom of the folio with 20 March aligned with south.

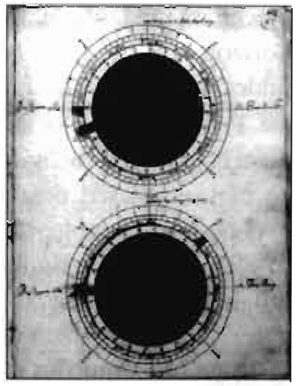

Figure 6 Nocturnal

There are two graphics in the Mateo MS for the perpetual almanac, both are incomplete. The one graphic[24] is the spinner triangle, plumb line and inner roundel. The more complete graphic[25] is missing the spinner triangle used to sight the angle of the sun above the horizon as well as the plumb line. This graphic contains a separate drawing of concentric circles aligned with the perpetual almanac in what suggests a side-on view. The concentric circle drawing simplifies the determination of entering arguments in tables of declination of the sun. The perpetual almanac determines the time of sunrise and sunset and the declination of the sun for a given calendar day. The index is

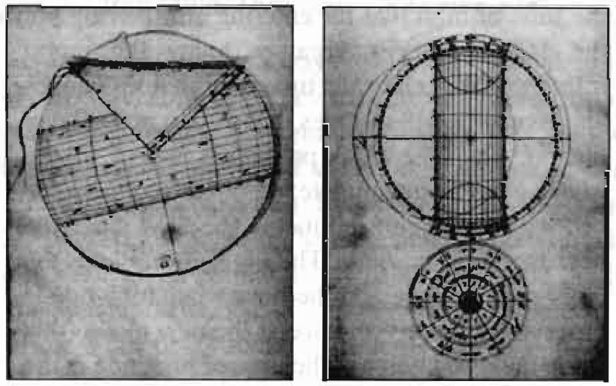

Figure 7 Perpetual Calendar

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[20] MN, MS 2550, f. 56r.

[21] MN, MS 2550, f. 67r.

[22] MN, MS 2550, ff. 51v, 62v.

[23] MN, MS 2550, f. 51r.

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[24] MN, MS 2550, f. 51v.

[25] MN, MS 2550, f. 62v.

placed on the latitude, the triangle aligned with the angle of the sun above the horizon and the hour of sunrise or sunset is read from the inner cylinder under the applicable sign of the zodiac (month).

Predicting the local hour of sunrise and sunset in artificial (equal hour) time is essential to "a day's work" in practical navigation, the daily sequence of tasks based on the predictable recurrence of celestial and terrestrial events. For example, the angular heights of stellar objects like the pole star or elements of the Southern Cross are used to determine latitude. The constellation of the zodiac in which the sun rises confirms the calendar month and date. The best horizon at sea for measuring the height of stellar objects, with instruments requiring a horizon as reference, is observed roughly one-half hour before sunrise or after sunset. The very practical reason for predicting the time of sunrise or sunset in the 16th century, as in the 21st century, is to awaken the navigator. A navigator, like the pilot Mateo Jorge, needs time to prepare the instruments, the tables, the charts and the sight reduction (calculation) forms, to decide what celestial objects will be observed and where they will be in the sky and to reduce his sightings (make his calculations) in a timely manner. He provides sailing directions after sunrise to the day watch and leaves night sailing orders after sunset for the night watch.

The worst thing a navigator can do is run his ship aground. Prediction of the time of high tide for entering and leaving port is therefore essential. By the 16th century navigators knew the moon influenced the tides. The time of high tide changes approximately 48 minutes day-to-day in a 30 day lunar cycle. The tidal prediction wheel in the Mateo MS[26] is incomplete; the inner roundel scribed with the age of the moon, the days since the new moon, is missing. The algorithm places the inner roundel index on the hour when high tide is observed at the given place at the new moon (this value must be known). The time of high tide at the given place is then read from the given day in the lunar cycle. Tidal wheels were scribed to the precision of a quarter of an hour, not 48 minutes, for simplicity of use. An adjustment of one day was made every lunar cycle to avoid accumulation of error.

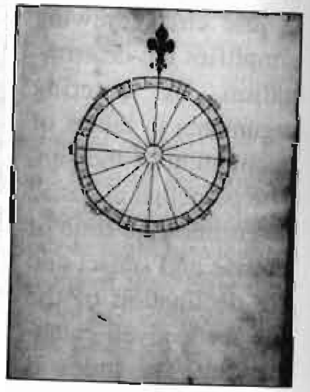

Figure 8 Tide Calculator

Direction

The 16th century pilot of the Casa was completely dependent upon the wind for motive power. The direction of the wind, called rhumbs, limited the directions in which the pilot could sail the ship. Mathematically a rhumb is a line of direction that crosses lines of latitude (or longitude) at equal angles on a planar chart and would be depicted as a spiral on a globe. The convention for naming rhumbs in the 16th century is represented by the points of the compass circle or "rose". The compass rose was divided into at least the 8 principle rhumbs (North, South, East, West, NE, SE, SW, and NW), to 16 points (add NNE, ENE, ESE, SSE, SSW, WSW, WNW, NNW) or to 32 points (add N by E, E by S, S by W, W by N, NE by N, SE by E, SW by S, NW by W, NE by E, SE by S, SW by W, NW by N, E by N, S by E, W by S, N by W). The Mateo MS has several drawings of the compass rose with 32 points[27].

Precision and Accuracy in the Horizontal Direction – Running Fix

The compass in the 21st century is almost always calibrated to 360 degrees of precision with a very fine stylus for accuracy to within a degree. If the 8, 16, 32 traditional rhumbs appear on the 21st century compass, they are for decoration. The 21st century navigator plots and steers, with turbine power on-demand, a course at least to the precision of a degree. In other words, the pilot commands "steer 279 degrees" With GPS, the precision can be within a degree and the direction to steer given automatically to an automatic pilot. The 16th century pilot, dependent upon the wind for motive power, would sail to the precision of one of the 8, 16 or 32 rhumbs. In degrees, that is to the precision of 45 degrees, 22.5 degrees or 11.25 degrees respectively.

In the Mateo MS, there is evidence of land falls made to the precision of the 8, 16, or 32 points of the compass rose[28]. There is another graphic of a

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[26] MN, MS 2550, f. 51r.

[27] MN, MS 2550, f. 47r.

[28] MN, MS 2550, f. 61v.

geometric algorithm with precision to angular degrees in the horizontal direction[29]. The navigational context of the algorithm is not specifically stated but suggests a "running fix" perhaps with regards to land fall. In practical navigation one type of running fix takes advantage of the moving ship to triangulate observations of one fixed object at two different points along the straight run of the ship. A sighting of an object is made. The bearing, which is angular distance in degrees from a reference, is determined by "shooting" or sighting the object through an aperture across a circle scribed in degrees (a horizontal ring or sea astrolabe). The ship "runs" or travels a measured distance on a steady course. The same object is sighted again and the bearing taken. Mathematically there are now two angles and an enclosed side of a triangle. The triangle can be solved trigonometrically or geometrically with a pair of dividers as in the Mateo MS. The result is an algorithm that uses direction to the precision of degrees to solve for distances. In the Mateo MS algorithm, those distances are in units of 60 and 30 which suggest minutes of latitude or longitude used in conjunction with a chart, perhaps while running a coast with known landmarks.

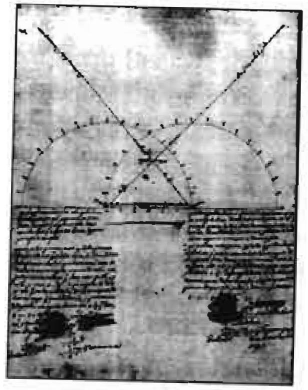

Figure 9 Running Fix

Magnetic Compass-Variation by the Equal Altitude Method

"Can Dead Men Vote Twice" (CDMVT). This is the mnemonic that at least one generation of Midshipmen at the United States Naval Academy, the author included, learned to account for errors in the compass. To wit: read the Compass heading; add (or subtract) Declination, the documented and predictable (magnetic) disturbances from compass surroundings on the ship to obtain Magnetic compass bearing; then add (or subtract) Variation of the magnetic compass from geographic north to obtain True direction. In the 16th century the compass did not always point to known directions like the pole star or the sun at meridian passage. The ancients and the practical navigators of the 15th and 16th centuries probably accounted for variation but in undocumented ways while the theorists argued.

Secondary sources cite a number of 16th century arguments as to the source of variation and instruments and methods to measure variation. These sources, for example, recount that Felipe Guillen (ca. 1525, Sevilla) as documented in Francisco Faleiro (*Tracto del Esphera* 1535) and Pedro Nuñez devised instruments that cast shadows on the compass card before and after local apparent noon so as to measure variation[30]. Or, that Pedro de Medina (1545) claimed variation did not exist[31], was a product of mistakes[32] or was due to circular motion of the pole star[33]. Martin Cortés (1551) is cited as the first to document variation in the compass due to terrestrial attraction, a difference between geographic (true) north and north as determined by the (magnetic) compass[34]. Whatever the differences may have been among 16th century cosmographers, we will focus on the practical knowledge that a pilot like Mateo Jorge had and how he accounted for compass variation.

In the 21st century we consider variation in the magnetic signature of the earth to be the reason for the difference between the true North Pole and the magnetic North Pole. To complicate matters, the earth's magnetic signature (and therefore magnetic compass variation) also changes over calendar time, fortunately in a mathematically predictable way. While now we use digital computer models to calculate magnetic variation, in 1585 William Burrough documented a method (probably long-used by the practical pilot) for calculating variation of the (magnetic) compass, the equal altitude method[35]. Using this method, the arithmetic average of the magnetic bearing to the sun is calculated when the sun is at the same altitude before and after noon meridian passage (the highest altitude of the sun in the daily sky). The difference between that average and the meridian passage (000 or 180 degrees) is local variation of the magnetic compass.

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[29] MN, MS 2550, f. 49v.

[30] Waters, D.W. *The Art of Navigation in England in Elizabethan and Early Stuart Times*. New Haven, Connecticut, 1958, pag. 70.

[31] Waters, *The Art of Navigation*, pag. 71.

[32] Hewson, Commander J.B. *A History of the Practice of Navigation*. Glasgow, Great Britain, 1951, pag. 120.

[33] Taylor, E.G.R. *The Haven Finding Art*. London, U.K., 1956, pag. 189.

[34] Waters, *The Art of Navigation*, pag. 71.

[35] Waters, *The Art of Navigation*, pag. 158.

The effect of compass variation (magnetic) and perhaps a Nuñez-like shadow instrument is present in the Mateo MS in a number of graphics[36]. The Mateo MS also has an annotated graphic describing a version of the equal altitude method for computing variation[37] that requires altitude readings of the sun on the astrolabe before meridian passage at around one point of the compass N by E (11 1/4 degrees) and after meridian passage at around one point of the compass N by W (11 1/4 degrees). In the text accompanying the graphic, precision of direction is expressed in fractions of points of the compass. Mateo Jorge describes the algorithm for both equatorial and southern latitudes where the observer of the sun is actually "below" the declination of the sun and more northern latitudes where the declination of the sun is below the observer. This description reflects the places where Mateo Jorge traveled in the New World and around Africa. Mateo Jorge's accounting for compass variation is also consistent with the writings of Martin Cortés. The significance of this consistency becomes clear later in this article when we discuss the suggested origins of graphics in the Mateo MS.

Figure 10 Equal Altitude Method

Loxodromes-Box of Toledo

In the Mateo MS, what may seem in the 21st century to be an exercise in spiro graph doodling is in all likelihood loxodromes in various stages of construction[38] for use in conjunction with nautical charts. Loxodromes are a grid of rhumbs drawn as cross-connected lines from each of the 8, 16 or 32 points of the compass. When a line is plotted on a chart to get from here to there, the pilot of the Casa would choose the nearest parallel loxodrome to determine sailing direction and hence a required rhumb or wind. Parallel rulers had not yet been invented. Loxodrome constructions in the Mateo MS suggest Mateo Jorge sailed with the use of nautical charts. The horizontal-vertical grid lines underneath the loxodromes act as a Box of Toledo; grid lines suggest a means to mark off either latitude-longitude or the number of leagues of travel in the east-west, north-south direction. Distance measured or made good across the Box of Toledo in the direction of a loxodrome would be calculated by the use of proportional triangles or the Pythagorean theorem.

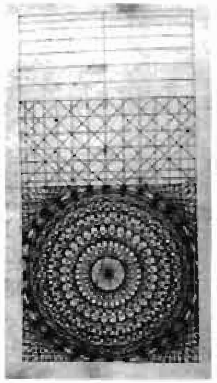

Figure 11 Loxodromes

Distance

The conventional wisdom is that the pilots of the Casa used dead reckoning and latitude sailing as the predominant system of navigation in the 16th century. In dead reckoning, the pilot knows where he is, sails in a specific direction at a known speed for a known duration of time and therefore can calculate his destination. Wind, currents, and precision and accuracy in knowing time, direction, distance and location can cause errors along the way. In latitude sailing, the pilot knows the latitude of the destination and sails northerly or southerly to attain that latitude and then sails on that latitude in the east or west direction until landfall at the desired place. Sailing direction for the 16th century pilot of the Casa was constrained by the wind. Consequently, latitude sailing required rules to get the pilot back on the desired latitude when he discovered by means of celestial observation that he had drifted off. Mathematical rules to "raise" or "lay" a degree of latitude incorporated plane geometry and measures of distance still to cover.

Leagues per Degree of Longitude

Leagues were the measure for distance at sea in the 16th century. There was dispute early in the century between the Spanish and Portuguese over the measurement of a league and the number of degrees of longitude in a degree at the equator and the various latitudes[39]. The rationale for the debate had serious practical and economic consequences for Spain and Portugal. The outcome would determine who owned what lands when the Papal Line of

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[36] MN, MS 2550, f. 47r, f. 47v.

[37] MN, MS 2550, f. 50v.

[38] MN, MS 2550, f. 55v.

[39] Lamb, Ursula. *Cosmographers and Pilots of the Spanish Maritime Empire*. Great Yarmouth, Norfolk, Great Britain, 1995, pag. V52.

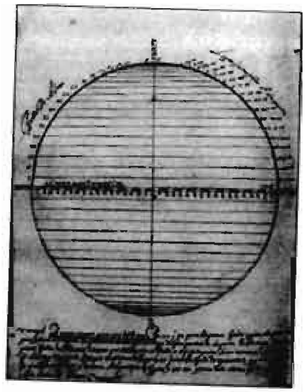

Figure 12 Leagues per Degree

Demarcation (Treaty of Tordesillas) was extended to the other side of the globe, the location of a major object of commerce, the Moluccas (Spice Islands). The Spanish favored a league to be three miles long and 16 2/3 leagues to a degree of longitude at the equator. The Portuguese favored four miles of 5,000 feet in a league and 17 ½ leagues to a degree of longitude at the equator. By the end of the 16th century claims over the Moluccas were settled. The evidence in the Mateo MS suggests use of 17 ½ leagues to a degree of longitude at the equator[40].

Distance to Cover – Pythagoras, Proportional Triangles

There were at least two mathematical rules used in latitude sailing, the Pythagorean theorem (the lengths of a triangle are solved by $a^2 + b^2 = c^2$) and proportional triangles. Proportional triangles were used in conjunction with loxodromes to determine direction and distance to cover when raising or laying a degree. There is evidence in the Mateo MS for the use of both proportional triangles[41] and the theory[42] to solve the problem of distance yet to cover. The Mateo MS algorithm for distance to cover is calibrated in "sizes", where a size can be any unit of measure: league, degree, etc.

Figure 13 Theorem of Pythagoras

Figure 14 Proportional Triangles

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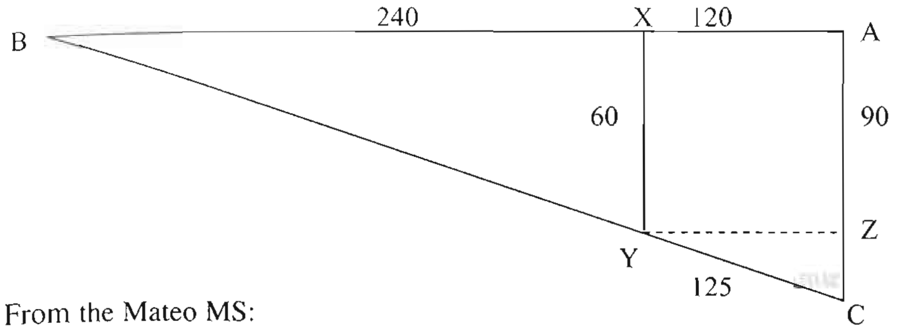
[40] MN, MS 2550, f. 69v.

[41] MN, MS 2550, f. 50r.

[42] MN, MS 2550, f. 43r.



From the Mateo MS:

90 – 60 = 30 then 120x60 = 7200 / 30 = 240 spaces to go from X.

Using a little algebra,

BX = (AX x XY) / (AC-XY).

Solving with proportional triangles, triangle BXY is similar to triangle YZC. The ratios of corresponding side lengths of two similar triangles are the same,

BX/XY = YZ/ZC.

Solving for BX, gives

BX = (XYxYZ)/ZC.

Notice,

YZ = AX,

and

ZC = AC – XY.

Therefore,

BX = (AXxXY)/(AC-XY).

Or, in Mateo terms

90 – 60 = 30 then 120x60 = 7200/30 = 240 spaces to go. QED.

Location

Location in the 16th century was determined, as in the 21st century, by the intersection of latitude and longitude. The difference between knowing location in the 21st century and the 16th century comes down to precision and accuracy. How precisely and accurately longitude was determined in general and most specifically at sea in the 16th century remains debated by scholars. There is more agreement on the precision and accuracy to determine latitude by altitude of celestial bodies; the three major ways were: from the height of the sun at meridian passage (local apparent noon), the angle of the pole star above the horizon in the more northern latitudes, the orientation of the Southern Cross in the more southern latitudes.

Instruments for Measuring Altitude

The business of making instruments for use by the pilots of the early Casa was a monopoly[43]. Several precise technical graphics exist in the Mateo MS from which instruments used to measure the height of a celestial object can be built. There are graphics of cross staffs[44], quadrants[45], seafarer's astrolabes[46] and various rings. The appearance of these graphics of instruments can be interpreted in one of two ways: Mateo Jorge was privy to the information of the monopoly as a pilot major, or, by Mateo's time, the monopoly had been broken.

Zenith Angle Method for Calculating Latitude from Sun's Altitude

One ring[47] is of special interest because of the order of graduation of the angles from the horizontal. Most rings were graduated as the globe; the horizon was zero degrees and the zenith was ninety degrees. Using these rings, latitude can be calculated using the height of the sun at meridian passage and the declination of the sun. In the simplest case, with the navigator well north of the equator and the sun's declination:

Sun's meridian altitude = 62 deg measured with the instrument
Sun's declination from tables = 20 deg north, subtract from altitude
Altitude of the equinoctial = 42 deg subtract from 90 deg
Latitude of the observer = 48 deg.

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[43] Lamb, *Cosmographers and Pilots*, pag. III4.
[44] MN, MS 2550, f. 64r.
[45] MN, MS 2550, f. 49r.
[46] MN, MS 2550, f. 62r.
[47] Ibid.

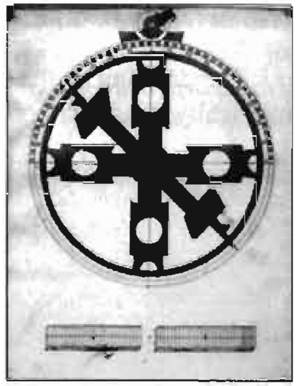
Figure 15 Zenith Angle

A computationally more efficient method (one less step) was the zenith angle method which required the ring to be scribed with zero at the pole and ninety degrees at the equator:

Sun's zenith angle at meridian = 28 deg measured with the instrument
Sun's declination from tables = 20 deg north, add to zenith angle
Latitude of the observer = 48 deg

The existence of a zenith angle method ring in the Mateo MS suggests Mateo Jorge knew and perhaps used this method of calculating altitude. This would not be surprising; Mateo Jorge was Portuguese and the Portuguese were inclined to use this method[48].

How did the practical navigator (Mateo Jorge) come to know?

To determine how a practical navigator came to know what he knew about time, direction, distance and location, we chose to analyze original source documents of the time, in particular the Mateo MS and texts found in the *Obras Clasicas de Nautica y Navegacion* (the *Obras*) of the Fundacion Historica Tavera on CD-ROM. We also made a limited review of documents of the time in the Archivos de Indias in Sevilla, specifically the pilot exams. A preliminary finding is that Mateo Jorge's knowledge came, in part, from reading or at least copying certain drawings from the classic works of Cortés (1551), Zamorano (1581) and Tornamira (1585). We come to this conclusion because of the rather striking and detailed similarities between specific graphics in the Mateo MS and specific graphics in these three classic works; at this point in our research the graphics do not seem to appear elsewhere in quite the same form. The graphics are of a geometric sundial algorithm (Cortés), a perpetual almanac for calculating celestial events (Cortés, Tornamira), a tide calculator (Zamorano) and a description of the horizon (Cortés).

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[48] Waters, *The Art of Navigation*, pag. 50.

Geometric Sundial Algorithm

The drawing of the sundial algorithm describes graphically how to geometrically construct both a horizontal and a vertical sundial. The three graphics of the geometric sundial algorithm in the Mateo MS[49] are for latitudes of 10, 20, 40 and 45 degrees, latitudes in agreement with the travels of Mateo Jorge. The graphic of the algorithm in the Cortés[50] is for 37 ½ degrees latitude, the latitude of Sevilla. Both graphics have almost identical labels: -2-D-ORIZONTAL (Cortés) -2-Del Orizontal (Mateo), where the -2-D is the convention for semi-diameter; EXE DEL MUNDO (Cortés) exe Del mundo (Mateo); LINEA DE LA CONTINGENCIA (Cortés) Linea De Lacontingencia (Mateo).

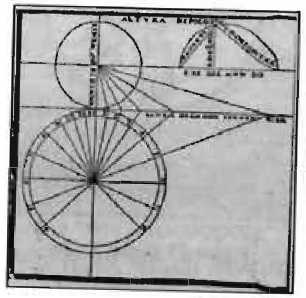

Figure 16 Cortes Sundial Algorithm

Perpetual Almanac for Calculating Celestial Events

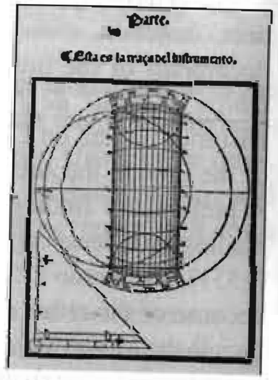

Figure 17 Cortes Perpetual Almanac

The drawing of the perpetual almanac for calculating celestial events is a technical graphic from which the instrument can be constructed. Drawings for the perpetual almanac appear in a number of the *Obras* documents on the Tavera CD-ROM. However, the graphics in the Cortés[51] and the Mateo MS[52] match as if the ones in the Mateo MS were traced from the Cortés. Each graphic has an offset circle constructed to create a sigmoid shaped pointer for the outer roundel labeled "index". Each graphic has semi-circles constructed from a diameter that intersects the inner roundel across each end of the cylindrical construction. The Cortés graphic has a triangular spinner with a fleur-de-lis and stylized tick marks on two sides with sight holes on one of those sides. The triangle is to be positioned in the center of the cylindrical construction. The earlier work-up of the Mateo MS graphic[53] has such a triangle. The later Mateo graphic[54] clearly has a hole in the center. We suggest a triangle construction similar to the Cortés triangle was at one time affixed in the Mateo MS. The animated Cortés graphic[55] is missing the spinner in the Tavera CD-ROM edition. The spinner, however, is present in the Richard Eden translation of the Martin Cortés work presumably from a copy of the Cortés that had an intact graphic. The matching graphic in the Eden[56] is an animated construction with both the triangle and the inner roundel affixed so as to spin on the outer fixed roundel.

At the bottom of the page of the Mateo MS graphic[57] of the perpetual almanac is a circular graphic. The circular graphic shares the center line of the perpetual almanac and is positioned perhaps to suggest an end-on view of the cylinder of the perpetual almanac. This circular graphic has three concentric circles each divided into twelve parts. The circular graphic has the signs of the zodiac in the outer circle, the months of the year in the middle circle and numbers in the inner circle with the number "3" in the center. The same circular graphic appears in the Tornamira[58]. The Mateo MS graphic differs from the Tornamira graphic: the signs of the zodiac are retarded one month; the numbers in the middle concentric circle differ; the Tornamira does not have a number in the center. Our preliminary research from the Tornamira shows that the circular graphic functioned as an aid for entering tables of declination of the sun, particularly of the type constructed by Martin

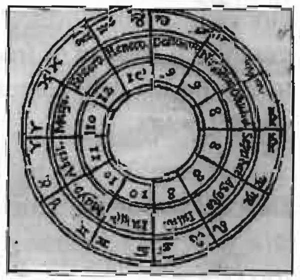

Figure 18 Tornamira Circular Alamanac

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[49] MN, MS 2550, f. 65r, f. 65v, f. 66r.

[50] CCT, Cortes, *Breve compendio,* f. xlix v.

[51] CCT, Cortes, *Breve compendio,* f. xci v, f. xcii v.

[52] MN, MS 2550, f. 52r, f. 62v.

[53] MN, MS 2550, f. 52r.

[54] MN, MS 2550, f. 62v.

[55] CCT, Cortes, *Breve compendio,* f.xcii v.

[56] Eden, Richard. *The Art of Navigation.* London, 1556, f. 83r.

[57] MN, MS 2550, f. 62v.

[58] Colecion Clasicas Tavera (CCT), Obras Clasicos de Nautica y Navigacion, Serie II, vol.17, CD-ROM, Tornamira, Francisco Vicente. *Chronographia y repertorio de los tiempos: a lo moderno, ...* Pamplona, 1585, pag. 353.

Cortés. Mateo Jorge probably used Tornamira's wheel as a model, updated the numbers in the middle concentric circle and retarded the signs of the zodiac to account for the necessary calendar regression in occurrences of celestial events.

Tide Calculator

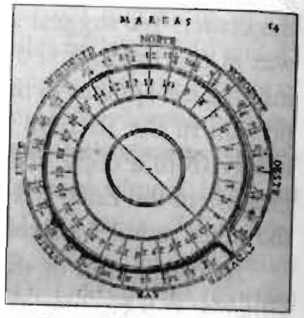

Figure 19 Zamarano Tide Calculator

The tide calculator graphic in the Mateo MS[59] and the tide calculator graphic in the Zamorano[60] are mirror images of each other. The hole in the center of the Mateo MS tide calculator suggests a missing center spinner. On the Mateo MS tide calculator graphic the usual convention is observed, Northwest is counter-clockwise from North. On the Zamorano tide calculator graphic Northwest is clockwise from North. The characteristic most comparable between the two graphics is the use of fractions for labeling quarter hours. Other tide calculators from the 16th century use a system of tick marks to denote hours and quarter hours.

Description of the Horizon

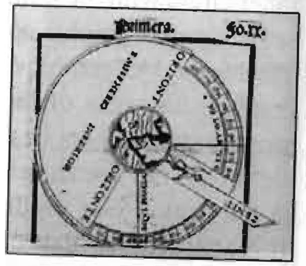

Figure 20 Cortes Horizon

The graphics in the Mateo MS[61] and the Cortés[62] that describe the horizon are identical with only two exceptions, the map of the globe and the labeling of the outer roundel. The similarities are quite striking down to the labeling and shape of the horizon spinner and pointer. The most dramatic similarity is the caricature of the man on the zenith pointer. In both the Mateo MS and the Cortés graphic, the dress of the caricature of the man is identical: V-necked blouse, knee length skirt. The pose of the man in both graphics is also identical; the right hand and finger point up; the left hand and finger extend out and down (hence, we have dubbed the caricature "disco man").

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[59] MN, MS 2550, f.5 1r.

[60] Colecion Clasicas Tavera (CCT), Obras Clasicos de Nautica y Navigacion, Serie II, vol.17, CD-ROM. Zamorano, Rodrigo. *Compendio del Arte de Navegar*. Sevilla, 1581, pag. 54.

[61] MN, MS 2550, f. 69r.

[62] CCT, Cortes, *Breve compendio*, f. xx r.

Summary of Preliminary Findings and Inferences

In addition to knowledge presumably acquired from his father, Luis, from fellow Portuguese associates, and in the Casa, Mateo Jorge must also have studied important treatises on the art and science of navigation of his times. As we have demonstrated, the several graphics in the Mateo MS analyzed in this article reveal that Mateo Jorge was influenced, in particular, by Martin Cortés's *Breve compendio de la esfera y de la arte de navegar*, written in the same time period as Pedro de Medina's 1545 *Arte de navegar* but not printed until 1551 in Seville[63].

As one of the approved examiners in the Casa, Medina published more practical versions of his *Arte* titled *Regimiento de navegación* in 1552 and *Suma de cosmografía* in 1561 with the objective of streamlining the instruction of pilots. These became the textbooks most commonly used in Spain, while Cortés's *Compendio* enjoyed great popularity in England[64]. In 1558, the English pilot, Stephen Burrough (and father of the aforementioned William Burrough of the equal altitude method), was invited to visit the Casa de la Contratación and given an extended tour. He returned to England with information on the Casa's excellent curriculum and also brought back a copy of Cortés's treatise which Richard Eden translated into English (1561) for the Muscovy Company[65].

Our findings are that the graphics in the Mateo MS follow very closely, some identically, those found in the Spanish printing of the Cortés *Compendio*, and that these Cortés graphics were apparently used by Mateo Jorge to guide him in his practical applications of navigational theories. Books were not available in great numbers; we can assume a pilot would meticulously copy graphics to take to sea from favored sources. We conclude, there-

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[63] Haring, *Trade and Navigation*, pag. 311.

[64] Waters, D. W. "Science and the Techniques of Navigation in the Renaissance". *Art, Science, and History in the Renaissance*. Charles S. Singleton, Ed. Baltimore: The Johns Hopkins Press, 1967, pags.214-215.

[65] Waters, *The Art of Navigation*, pags.103-104.

fore, that Mateo Jorge must have relied heavily on Cortés's work but have little evidence based on graphics that he was influenced by Medina. This also suggests that the Cortés *Compendio* was circulating among the instructors and students in the Casa and provided theoretical foundations to some important pilots such as Mateo Jorge for their navigational practices and procedures. In addition, we found one graphic in the Mateo MS that can be matched only to one in Tornamira's *Chronographía* and another graphic that, while it appears in other documents of the times, most closely matches one in Zamorano's *Compendio*. The conclusion we have drawn is that theoretical works such as these were available to practical pilots in the Casa and some, such as Mateo Jorge, applied knowledge from these works to their navigational ventures. Our position appears to run counter to that of some scholars of the Casa[66].

In this article, we have established solid evidence through both a comparison and an explanation of graphics from the Mateo MS to support this theory of influences and the importance of Cortés's work in informing practical navigation in the late 16th and early 17th century Casa de la Contratación. A recent study supports our theory and contends some pilots were instrumental in reformulating more accurate theories[67]. Hence, dialogue between pilots and cosmographers advanced both theory and practice.

Epilogue… on the Lasting Power of the Illustrated Thought

A text on the history of navigation (Garcia-Franco, 1947) demonstrates the lasting power of illustrated thought across the centuries. The text reproduces instruments drawn in the Mateo MS as examples of the instruments used in the 16th century. Garcia-Franco ascribes the graphics to an "anonymous" 16th century manuscript; we conclude they are from the Mateo MS. Examination of two graphics notes that besides the obvious similarities, the arms and plumbs of the quadrants are aligned at exactly the same graduations. The fleur design of the third quadrant is not only identical and at the same graduation, but also transparent in exactly the same place, on the sighting holes.

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[66] Lamb, *Cosmographers and Pilots*, VI 679.

[67] Roa-de-la-Carrera, Cristian. "El Nuevo Mundo como problema de conocimiento: Americo Vespucio y el discurso geografico del siglo xvi". *Hispanic Review*. 70: 2 (Autumn 2002), pp. 574-575.

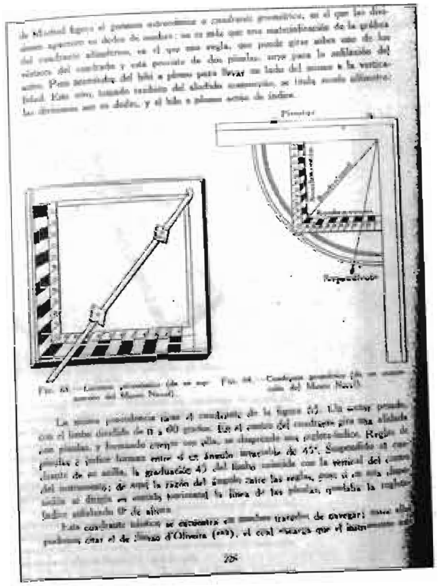

Figure 21 Garcia Instruments

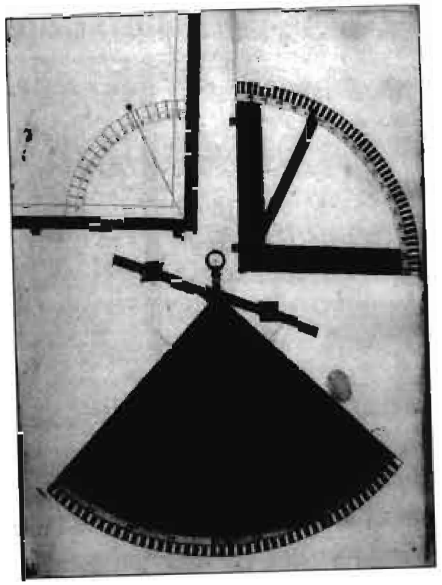

Figure 22 Mateo Quadrant

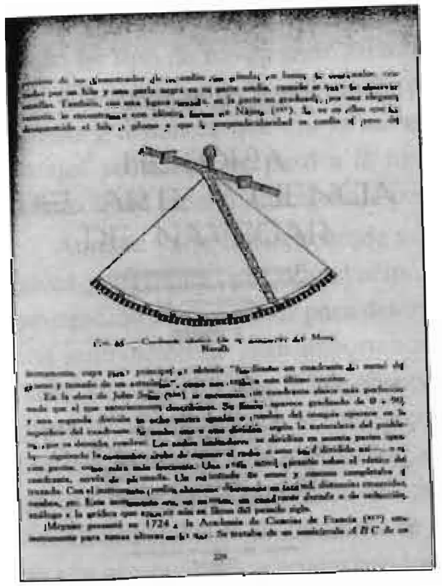

Figure 23 Garcia Quadrant

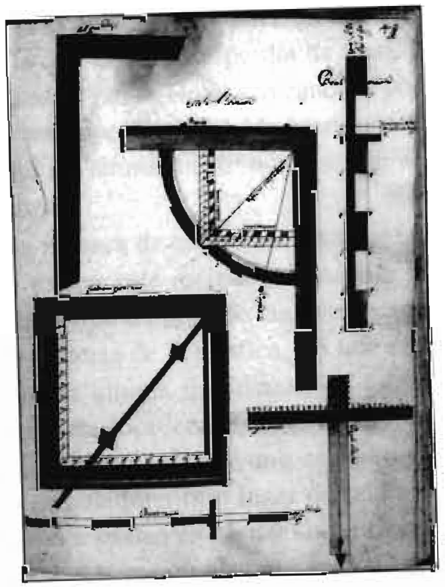

Figure 24 Mateo Instruments