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The Navigation of Columbus on His First Voyage to America

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ABSTRACT

This paper summarizes results from a computer simulation of Columbus' navigation during his first voyage to America. It is based on course and distance data in his *Journal* and on information derived from other sources of 15th century cartography and navigation. Certain debated issues — the length of Columbus' mile unit, his "double accounting" of distances, his "land league", etc. — are discussed.

INTRODUCTION

Columbus' *Journal* of his first voyage to America is known only through an abstract made by Las Casas in the early 16th century.[1] Even so, this abstract contains an almost complete daily account of Columbus' ship movements during the whole voyage. Modeling the voyage with this data permits us to test hypotheses about the voyage, and to refine our knowledge of the navigation of southern Europeans in the 15th century.

Simulations have been done before, e.g. by Nunn (1924), McElroy (1941), Fuson and Treftz (1976), and Marden (1986) and Judge (1986), principally to locate Columbus' first landfall in the New World. Daily courses are converted to latitude and longitude positions and plotted on a Mercator chart to form a "Mercator course". Spherical trigonometry and considerations of magnetic declination, currents and leeway are involved.

Columbus had no concept of a "Mercator course". He simply laid off the ship's daily or half-day progress on a map as a line segment of appropriate length and bearing from the last reckoned position to form a "plane chart course" of the voyage. His is modeled by a course on a flat earth with meridians running vertically and lines of latitude running horizontally through every point. The Appendix gives details of his method.

The plane chart course of the *Journal* data shown in Figure 1 is Columbus' voyage as he saw it. The figure is the key to much of what follows. All relevant measurements used here are taken from it.[2]

HOW LONG IS COLUMBUS' MILE?

The simulation requires an estimate for the length of Columbus' mile or league. The *Journal* only tells us there were four miles to his league. Many writers believe Columbus used the Roman mile of about 4,850 English feet.[3] But a smaller mile of about 4,100 English feet is needed to keep the fleet from overshooting the Bahamas, and to return it to the Azores.[4] The question is, was there a short mile of this length in use by mariners in Columbus' time?

Evidence of the Charts

Measurements show that the western Mediterranean on many 14th and 15th century Italian and Catalan nautical charts is scaled to a mile of about 4,100 English feet. The first to study this subject in any detail were the geographer Hermann Wagner (1895), with his student Ernst Steger (1896), and the explorer Adolf Nordenskiold.[5] Wagner (1900, p. 280), whose analyses seem the most credible, concluded that the short mile was known to Columbus' contemporaries as the *millarium geometricum* of 1,000 *passus geometricus* of 5 *pes geometricus*, and that the Roman mile was 1,000 *passus vulgares* or 1,200 *passus geometricus*. Consequently, the geometric mile was 5/6ths the Roman mile, or about 4,045 English feet.

Evidence from Contemporary Commerce

Differences among contemporary commercial units of length indicate there may have been two Roman mile units in Columbus' day, one of about 4,823 English feet and another, the neo-Roman mile, of about 4,888 English feet. Machabey's (1962) extensive study of these commercial units provides a basis for defining the probable length of the geometric mile. Machabey defines ten groups of units, all built up from the Roman foot (= 29.4 cm.) of 16 Roman digits. For example, the neo-Roman foot of about 29.8 cm. is taken as 81/80ths (= 324/320) of the Roman foot, the ratio apparently deriving from the recalibration of a perch of 18 feet of 18 Roman digits to the foot (= 324 digits) to one of 20 feet of 16 (neo-Roman) digits to the foot (= 320 digits).[6]

The Machabey class of widest use is based on the foot of Bourgogne of 18 Roman digits (about 33 cm.) — close to the classical *pes Drusianus* of 33.3 cm. Two and one-half of these feet defined the *aune* of Provins, the standard measure of the Champagne fairs. One-third of the *aune* is the *palm* (*pan*, *empan*) of the Bourgogne foot (i.e. 3/4ths foot). The use of this *palm* at the fairs insured its use throughout the region from Venice to Catalonia — eight *palms* to the *canna* of the cloth trade. Columbus made explicit use of the *palm* (e.g. the entry for October 21), but not a "foot" unit.

The *palm* of the Bourgogne foot (= 24.75 cm., i.e. 3/4ths of 18 Roman digits or of 33 cm.) is undoubtedly the *pas geometricus* of the foot of the neo-Roman mile (= 24.83 cm., i.e. 5/6ths of 16 neo-Roman digits or of 29.8 cm.). A mile of 5,000 of these *palms* is about 4,060 English feet. This is the value taken here to represent the geometric mile of the portolan charts. Four of these miles, the "geometric league", is the length of Columbus' league used to scale the simulation.

WHO KNEW WHERE THE FLEET WAS?

The Pilots of the Fleet

Each ship in the fleet had an assigned pilot: Peralonso Niño of Moguer on the flagship, Christobal Garcia Sarmiento on *Pinta*, and Sancho Ruiz de Gama on *Niña*. When these "official" pilots were off duty others did their jobs. Bartolome Roldan, an able seaman on *Niña*, was probably apprenticed to Sancho Ruiz. The Captain or Master might also fill in for the pilot or perform independent checks of his work to insure against getting lost. Columbus was certainly keeping track of the fleet's progress independent of Peralonso. The *Journal* implies that Vincente Anes Pinzon, Captain of *Niña*, also was running a log of daily positions. Martin Alonso Pinzon, Captain of *Pinta* and Columbus had ship-to-ship discussions about the fleet's position. It is also probable that Francisco Martin Pinzon and Juan de La Cosa, respective Masters of *Pinta* and the flagship, could also pilot a ship.

Comparison of Position Estimates

A question of interest is how the pilots' navigational skills compare with Columbus', and with one another's. Since later writers disparage pilots' skills while putting Columbus on a pedestal, one wonders about the truth of the matter.

The first record of the pilots' estimates of western progress is on September 19: *Niña's* pilot, 440 leagues; *Pinta's*, 420; the flagship's, 400. Taking Hierro as the point of measurement, the distance to the computer plotted position (presumably Columbus' own estimate) is 420 leagues. At this point of the journey everyone was pretty well in agreement.

On September 25 the Admiral and Martin Alonso Pinzon discussed their current position relative to a map. But no comparative data is given. A relevant position check on October 1 is considered later on.

The most interesting records of the pilots' position estimates occur during the last two weeks before the fleet made landfall in the Azores. The dates: February 6-7, February 10, and February 15. The position estimates are given in terms of the nearest possible east-west (latitude) and north-south (longitude) landfalls, e.g. Madeira east, Flores north. This made it easy to plot them on a copy of Figure 1. Then their locations relative to the simulator-calculated fleet position for the day in question were read from the map and plotted in Figure 2.

In the days just before landfall Anes and Ruiz were estimating they were 55 to 65 leagues ahead of the simulation, but positioned in about the same latitude (the boxed points in Figure 2); Roldan and Peralonso were also estimating about the same latitude, but were running some 130 leagues ahead of the simulation. Columbus' stated east-west position estimate of February 7 is only 10 leagues ahead of the simulation (the first boxed point of his group of estimates) — reasonably consistent with his *Journal* data.[7] However, he thinks he is some 42 leagues north of the simulation. Perhaps he suspects the accuracy of his "chart pricking". On February 3, when the simulation puts him due west of Madeira, he notes that the height of Polaris suggests they are in the latitude of Cape St. Vincent, some 90 leagues further north. Perhaps the 42 league northerly displacement from the calculated latitude is a compromise based on that observation.[8]

The relative positions of the other groups of pilots do not change much for the period February 6-10. But on February 10 "the Admiral found himself much off his course," that is, off his plotted course as simulated in Figure 1. He set his east-west position back some 90 leagues from the simulation (his map plot) and 150 from the closest of the other pilots. He still believed the fleet to be some 18 leagues further north of the other pilots' estimates, but not as far north as he thought on February 7. Was visibility deteriorating in advance of the great storm about to hit the fleet, making him lose confidence in his earlier observation of Polaris?

Finally, they made landfall on February 15. Having set his estimated actual position so far back and a little north of his plotted position of February 10, Columbus logically concluded that he must be in the Azores (solid circle in Figure 2). Anes and Ruiz placed the fleet at Madeira since their plotted position on the 15th was under 30 leagues from that island. Roldan and Peralonso, plotting a position on the 15th far ahead and off the coast of Casablanca, reasoned that because of the cold, stormy weather they must be further north, near Lisbon.

Columbus' Use of Seamarks

Measurements of Figure 1 indicate that on February 10 the fleet's true position was about 140 leagues west of Santa Maria in the Azores. Columbus, setting himself 150 leagues behind the pilots, located the fleet 130 leagues west of Santa Maria (i.e. south and a little west of Flores), or 10 leagues east (ahead) of the fleet's true position; the simulator (i.e. Columbus' probable map plot) was 90 leagues further east; Anes and Ruiz were 145 (= 90 + 55) leagues east; and Roldan and Peralonso were probably still running 220 (= 90 + 130) leagues east. Columbus thought they were further north of their calculated latitude considering the height of Polaris and the colder weather. But why did he set himself some 90 leagues west of his plotted position? Though the reason is not indicated, a hint is given in the last sentence of the entry for February 10: "He also says here that he had made 263 leagues from the island of Hierro on the outbound voyage when he saw the first weed etc." Had Las Casas copied the full text of the original we might have the reason sought.

All during the voyage Columbus used and recorded seamarks — birds, vegetation, fish, etc. — as indicators of location, despite their mobility. In particular, he recorded sightings of seaweed as they crossed the Sargasso Sea. Marking Figure 1 for the days on which weed was seen shows that: From January 23 through 27 no sighting of weed is reported though the fleet's route parallels and crosses its course of the previous October 2 and 3 when weed was sighted. On September 29 and 30 they had also seen much weed. But from October 4 through 7 they reported no sightings. (At the time they were on the western limb of the Sargasso Sea.) Apparently Columbus reasoned on February 10 that they crossed their outbound route just ahead of their position on October 2 and 3, during which time they sailed some 86 leagues, enough to account for the 90 leagues in question.

This case illustrates well why Columbus was an outstanding navigator. His calculated positions are not significantly different from those of Anes and Ruiz. Though his map plot (the simulation) is some 60 leagues behind their's, and closer to the fleet's true position, the difference is under 3% of the 2,500 leagues or so they had travelled. What made his navigation superior was his willingness to use evidence other than his map plots to reckon his probable position at sea. Even so, he seems to have continued maintaining his original plane chart course just as the other pilots did. After all, if a seamark observed later on indicated an alternative interpretation, the basic course observations would be essential for an intelligent reappraisal.

WHY DID ALL THE PILOTS OVERESTIMATE THEIR EASTERLY PROGRESS?

The "Land League"

Knowing how Columbus may have detected his overestimate of progress on February 10 from the appearance of seaweed does not answer why the error was made in the first place. It so happens that Morison (1942, I, p. 248, 261) and others have observed that the fleet's progress along the coast of Cuba is much overestimated. To account for this, Morison suggests that the Admiral used a "land league" of about 1.6 nautical miles for distance measurement when sailing near land. It is numerically equivalent to two Roman miles or about 1.5 Arab miles.[9] However, if one reduces the simulator's east-west progress along Cuba and Española to the true distance in geometric leagues from Rio de Mares to Cabo del Enamorado, one can account for about 80 of the 90 leagues Columbus set back the fleet's position on February 10.

The postulated "land league" seems doubtful. The inconsistency of changing one's units of measure in the middle of a running calculation, and not labeling them differently in addition, is to invite problems. That pilots would knowingly operate as postulated seems illogical to some, including Verhoog (1954, p. 1105) and this writer.

Effect of Currents on the Fleet Near Cuba

There is an alternate explanation. The Pilot Charts for October through December show currents of 0.5 knots to 0.7-0.8 knots WNW along the northeast coast of Cuba. In 24 hours a 0.5 knot current can carry a ship 18 geometric miles. The Admiral complains of currents at several places near Cuba. On the night of November 20 he could not reach Puerto del Principe "because currents set him to the northwest."

Figure 3 (left) shows how the simulator plotted the fleet's progress south from Isabela and along Cuba. The fleet passed Puerto del Principe on November 13 and backtracked to anchor there on the 14th. On the 19th they set sail again, NNE, on a roundtrip of about 38 hours, not quite making Puerto del Principe because of the currents. So they went NE out to sea. It took them until the 24th to make land again, this time at the same point they passed on the 14th when they backtracked to Puerto del Principe.

The two plotted locations of Puerto del Principe and the more easterly landfall are separated by some 7 and 12 leagues, respectively. The differences are not identical because in the first instance the fleet was subject to the currents for 28 hours, in the second for 38 hours. A drift distance of seven geometric leagues in 28 hours, and 12 leagues in 38, imply currents of 0.67 and 0.84 knots, respectively — just in the range indicated on modern pilot charts.

Figure 3 (right) shows the course along Cuba replotted after subjecting the fleet to a conservative 0.5 knot northwesterly current. Now Puerto del Principe and the other landfall are brought into correct position.[10]

Table 1
True vs. Calculated Positions Corrected for Current

	BEARINGS			MODEL VS. TRUE DISTANCES				
FROM - TO	TRUE	MODEL	ERR	TRUE	GEO MI	%ERR	ROM MI	%ERR
Rio de Mares - Isabela	43	51	8	144	137	-4.9	164	13.7
Rio de Mares - C Lindo	115	120	5	119	125	5.0	150	25.5
P Principe - C Lindo	112	124	12	67	80	19.4	96	42.6
P Principe - R de Mares	298	293	-5	51	46	-9.8	55	7.7
P Principe - Isabela	23	32	9	139	122	-12.2	146	4.8
C Lindo - Isabela	358	359	1	153	148	-3.3	178	15.6
Average Error:			5 degrees E			-1.0%		18.3%

Implications of the Model Corrected for Currents

The plot of Figure 3 (right) has interesting implications. Three points of this traverse are generally considered to be positively identified: Rio de Mares (Gibara), Puerto del Principe (Bahia de Tanamo), and Cabo Lindo (Puente Fraile). Suppose the northern point of Isabela is actually Bird Rock, at the northwest point of Crooked Island, the fleet's still debated landfall of October 19. Table 1 compares the Mercator chart distance-bearing readings of these points with measurements from Figure 3 (right) which are converted to nautical miles. The assumption that the distances are in geometric miles fits the geography quite well with a - 1% average error. The Roman mile is a poor fit.

The bearings in Figure 3 (right) tend to be rotated east some five degrees, suggesting a westerly variation of the compass in the region just north of eastern Cuba in 1492-93. Columbus' statement about being subject to NW currents which actually bear about WNW also suggest a westerly variation. These observations are at variance with interpretations of Van Bemmelen's (1899) isogonic chart for 1500. That chart only estimates magnetic declination to 60 degrees west longitude, near which, at latitude 25 degrees, the westerly variation decreases slightly along Columbus track. McElroy (1941) and Morison (1942, I, p. 292) extrapolate the isogonic lines out to 70 degrees west longitude. If one extends the McElroy-Morison isogonic lines even further west, then an easterly variation is indicated for the region just north of eastern Cuba, with a value of 1 degree E at Watlings Island according to McElroy (1941, p. 225). Van Bemmelen's (1893) isogonic charts for the 16th century all show the Greater Antilles and Bahamas with a westerly variation. The effect of this local westerly variation, other things being equal, is to bring the fleet to a somewhat more southerly point in the Bahamas than McElroy's and Marden's calculations indicate. Clearly, Van Bemmelen's isogonic chart of 1500 should be revised if at all possible.

COLUMBUS' "DOUBLE ACCOUNTING" OF DISTANCES

On September 10, and elsewhere, Las Casas says that Columbus reported less progress than he reckoned "so that the men would not be frightened if the voyage were long." There are 23 such cases noted in the *Journal*. An interesting question is what kind of rule, if any, did Columbus use to refigure progress for the crew?

Columbus' 5/6ths Rule

Figure 4 shows Columbus' estimates of progress plotted against the figures he told the men. These data correlate well (correlation coefficient = 0.80) suggesting that the Admiral's personal estimates and those he reported to the crew are truely in the ratio of 5:6 — the slope of the line which runs through the datapoints. Many of the discrepancies seem to be due to roundoff or small arithmetic blunders. Although Columbus had a very slight statistical bias to quote an amount smaller than 5/6ths his personal estimate whenever it was large, the only datapoints one might suspect may have been deliberately underestimated are those of October 4 and 10.

The Portuguese Maritime League

The Portuguese maritime league of four neo-Roman miles and the geometric league of four geometric miles are in the ratio of 5:6. That is, (4)(4,888) = 19,552 English feet, and (6/5)(4)(4,060) = 19,488 English feet, respectively, a trivial difference of 64 feet.[11] Machabey (1962, p. 48) documents the existence in the early 16th century of a "league of Bourgogne" of 18,000 feet of Bourgogne of 33 cm. which is identical to the Portuguese maritime league.[12] Further, according to al-Farghani, the terrestrial degree is 56 and 2/3rds Arab miles, and the *parasang* is three Arab miles, making the *parasang* equivalent to the Portuguese maritime league.[13]

All these equivalents suggest that Iberians were familiar with an itinerary unit equivalent to the Portuguese maritime league. So one might presume Columbus was converting his own leagues in geometric miles into Portuguese maritime leagues for the crew were it not for the fact that Las Casas indicates that the Admiral meant to hide the truth. But the *Journal* suggests Las Casas may have been mistaken. On October 1 Columbus' pilot reported he reckoned they were 578 leagues west of Hierro. Here Las Casas also indicates that Columbus announced 584 leagues of progress to the crew, thus confirming Peralonso's estimate. But Las Casas also notes that the figure "he kept to himself" was 707 leagues. Note that 5/6ths of 707 is 589 Portuguese maritime leagues, close enough to 584 to blame the difference on an arithmetic blunder, or on a copyist's misreading of "9" for "4".

If Peralonso's 584 are geometric leagues then they made only 178 (= 578 - 400) leagues during the same 12 days the Admiral was estimating progress of 287 (= 707 - 420) leagues — an excessive relative error of some 38%. At the start of that period, September 19, Peralonso was only running 20 leagues behind the Admiral. How to explain these conflicting results?

Suppose the pilots reckoned their estimates in Portuguese maritime leagues, while Columbus reckoned his in geometric miles (and leagues). Whenever the Admiral wanted to make comparisons he would have to convert his figures to their units, or their's to his. Or if he wanted to communicate his estimates to them in their terms, he would be obliged to convert his units to their's. In this event the pilots' estimates of September 19 must have been converted by Columbus to units of geometric leagues for comparison purposes, since they correspond to the simulation results which are scaled in geometric leagues. Conversely, Peralonso's estimate of October 1 must be in Portuguese maritime leagues, considering that the Admiral's conversion of 707 leagues is close to Peralonso's estimate. These observations and the close correlation indicated in Figure 4 suggest that all the short estimates Columbus told the crew of daily progress are also in units of Portuguese maritime leagues.

One concludes, therefore, that Las Casas was mistaken. The Admiral seems never to have intended to keep the truth from the crew, but rather to relate progress in units they could most readily understand. Quoting his estimates in geometric leagues, which are numerically greater than the equivalent Portuguese maritime leagues, would both mislead and might unduly worry the crew on a long voyage. Eighty kilometers always seems further away than 50 miles though these distances are equal. Considering the close quarters aboard those ships and the large numbers of people who knew something of the pilot's craft if is hard to see how the Admiral could have sustained a conspiracy even had he intended to.

An Unexplained Difficulty

It is necessary to point out that the data for October 1 presents difficulties which may possibly weaken the foregoing argument. The simulation progress through October 1, measured on Figure 1 using dividers, is just about 648 geometric (542 Portuguese maritime) leagues, not the 707 (respectively, 584) estimated by Columbus. Since the sum of all the league distances up to this point is only 668.7, the "707" figure is probably a bad map reading. It is fairly easy to misread the scales of portolan charts by multiples of 50 leagues (the major scale division) since one must measure by counting unlabelled divisions. The simulation's estimate indicates that Peralonso's has either fallen back 70 (= 648 - 578) geometric leagues, or has jumped ahead 36 (= 578 - 542) Portuguese maritime leagues.

If Peralonso were using a geometric league then he lost 50 (= 70 - 20) leagues in 12 days, whereas he lost 20 leagues in the previous 10 days since they passed Hierro. If he were using the Portuguese maritime league then he gained 53 (= 17 + 36) leagues in the 12 days. Can we suspect that his estimate of September 19 was a bad map reading, some 50 leagues too short? Clearly there is a problem here, the solution to which is not evident. At present it takes too many questionable assumptions to resolve it.

CONCLUSIONS

The plane chart simulation of Columbus' first voyage to the New World is a useful contemporary view of the voyage that suggests alternate, mutually consistent, interpretations of some debated issues concerning the voyage. The value of such models is that one may explore the credibility of hypotheses to explain events (e.g. that the absence of seaweed on the homebound voyage caused Columbus to set his course back 90 leagues) and have some assurance that one is being consistent with other factors built into the model.

In addition, the model shows that Columbus' navigation is consistent with what is known of 15th century Italian practice.

It would probably be useful to fine-tune the simulation by reappraising the assumptions and data used in the light of what has been learned from this first version. Though difficult, and requiring the appraisal of several routes, the model revision should include a detailed analysis of the voyage leg from Guanahani to Cuba and the leg along the coast of Española, taking currents and leeway into account.

APPENDIX
THE ITALIAN METHOD OF OCEAN NAVIGATION

By Columbus' time Italian and Catalan seamen had had some 300 years of experience perfecting a graphical method for tracking their position at sea through the use of the magnetic compass, dividers, the sand glass, and the chart. There seems to be no single source which describes all the practical details of the method. The summary description that follows is derived from numerous primary and secondary sources, among the more important of which are Egerton MS.73 (British Library) and Cotrugli (1464), and printed compilations like Kamel (1926), Nordenskiold (1897), Kretschmer (1909), DaCosta (1939), and Cortesão and Albuquerque (1960), with hints of shipboard activity derived from the crusader (e.g. Roger of Howden), pilgrim (e.g. Friar Felix, von Harff), and seaman (e.g. Albizzi, in Mallet (1967)) literature. Perhaps the single most important source is Columbus' *Journal*.

The helmsman conned the ship under the supervision of the officer of the watch. He maintained the prescribed course by keeping the appropriate magnetic compass point aligned with the lubber line. Sail settings were adjusted to assist in maintaining the course. An observer might be assigned to verify the helmsman's constancy (two were required on important 16th century Spanish vessels). Columbus rebuked the helmsmen several times on September 9 for straying from the course.[14]

A ship's boy, positioned under the quarterdeck to keep the sand dry, maintained the ship's time during the watch by turning the half-hour sand glasses as the sand ran out and by hammering a gong or bell to announce the time. A second boy in the forecastle might operate a second sand glass as a check on the first.[15]

Periodically the pilot checked the ship's speed, especially upon a change in sailing conditions. Speed was estimated this way: At the start of the voyage a fixed distance (conjecturally 50 *palms*, about 40 English feet)[16] was marked along the rails. When a speed estimate was needed, the pilot (probably with an assistant) used a rhythmical ditty[17] to count the seconds it took for some flotsam or a wood chip to float the distance between the rail marks. Using a conversion table (possibly carved in the ship's rail), or mental arithmetic, the pilot converted the time count to miles per hour. Fifty *palms* in 36 seconds is 1 mph, etc.[18]

The pilot recorded the relative change in the ship's position on his maneuvering board (*toleta del marteloio* = gridiron of the hammering), a vellum sheet with a large circle of radiating rhumbs and a mile scale or embedded square grid. Using dividers, he marked off the estimated distance travelled on the course bearing from the previously marked position.[19]

Every 12 or 24 hours (say at sunrise and sunset) the pilot measured the distance and bearing between the end points of the traverse marked on his maneuvering board to obtain the "course made good". The resultant bearing and distance was transferred to a nautical chart (called "pricking the chart" in later centuries). The course made good was also recorded in a journal or log book along with other pertinent data on the ship's progress, events and observations.[20] The marks on the maneuvering board were then erased in preparation for recording the next traverse.

At dawn and dusk (noon and midnight in later centuries) the pilots pooled their opinions about their actual position. The limitations of the maneuvering board method were understood, at least intuitively (viz effects of estimating errors, leeway, storms, etc.). Actual observations of natural phenomena (water conditions, sea life, star and sun positions, etc.) were compared to expectations for the apparent progress of the voyage. Columbus' *Journal* is particularly rich in examples of this sort.

The use of instruments for estimating latitude was lately growing in importance, especially for voyages down the coast of Africa. Without instruments the pole star or solar height of key coastal points might be memorized in personal units (e.g. "the height of a bent arm above the horizon"),[21] or in multiples of distances between well-known neighboring stars. Columbus records making such a non-instrumental latitude estimate on February 3, 1493. This method is quite old (Marcus, 1953). It indicated what a course due east or due west would lead to, but little else. See Kelley (1983, p. 107) for remarks on Columbus' use of the quadrant.

Observations of seamarks and latitude very much influenced daily changes of course. It is important to note, however, that these observations do not seem to have been incorporated into the pilot's formal navigation process involving the maneuvering board (*toleta*) and chart. That is, having concluded that he is, say, 50 leagues NW of his plotted position on his map, the pilot would not start tracking progress from that new position, but would continue from where he left off until land was sighted and identified. The *Journal* record of Columbus' route off Cuba (Figure 3 (left)) and his calculated positions (i.e. those of the simulation in Figure 1) versus his February 3 latitude estimate both suggest this conclusion. The pilot could easily use dividers to keep track of his assumed position relative to his dead reckoning (plane chart course) by laying off a previously noted distance and bearing from his current dead reckoning position.

The Italians taught all the western sea powers to use their method. With the 16th century it underwent various modifications as attempts were made to correct for the sphericity of the earth and for the magnetic declination of the compass.

NOTES

1. There are several Spanish transcriptions and English translations of the *Journal*, most recently by Dunn and Kelley (1987). Also see Morison (1963), and Jane (1960).

2. The technical data and procedures from which Figure 1 derives are described in Kelley (1983).

3. E. G. Markham (1893, p. 18, n2), Thatcher (1903, I, p. 516, n1), Nunn (1924, p. 18), DaCosta (1939, p. 180, n253), Jane (1960, p. 203, n3), Morison (1942, I, p. 247; 1963, p. 44).

4. d'Albertis' (1893) estimates Columbus' mile was 4,049. 3 English feet (1,234.24 m). McElroy (1941) calculates a Mercator course, modified to account for Van Bemmelen's (1899) estimates of magnetic declination in the Atlantic circa 1500, using a 4,393 English foot mile for the outbound leg, and 4,104 for the homebound leg. Had McElroy accounted for the prevailing westerly currents of about 0.4 knots his outbound mile would be 4,025 English feet, comparable to d'Albertis' estimate. Though Marden (1986, p. 577) theorizes Columbus used a league of 2.82 nautical miles (implies a 4,286 English foot mile), his calculations indicate it is too large by 9%. He must have computed the course with about a 3,900 English foot mile.

5. Nordenskiold (1897, p. 24) regarded the mile of the portolan chart as about one-fifth of a Spanish or Catalan league of 19,800 Toledo feet (of 19,426 Roman feet or of 18,844 English feet), or 3,769 English feet. This short mile seems much too short.

6. Kelley (1983, p. 103-4) summarizes Machabey's results. Dilke (1971, p. 82) also identifies these Roman foot units. He notes there was a normal Roman foot of 29.57 cm. (implies a 4,850.7 English foot mile), and an earlier foot of 29.73 cm. (essentially Machabey's neo-Roman foot). And from the third century AD there was a shorter foot of 29.42 cm.

7. True distances, converted to geometric miles, were substituted for missing data (documented in Kelley (1983)). Since *Journal* distances along Española tend to be overestimates, true distance substitutes would tend to shorten the track and explain why Columbus' stated position is 10 leagues ahead of the simulation.

8. On January 30 the fleet suddenly changed from a northeasterly trending course to S by E for 13. 5 leagues before reversing ground to a N by E course. If S by E is an error for N by E as McElroy thought, then subsequent simulation positions should be placed some 27 leagues further north and closer to the Admiral's supposed latitude positions of Feb. 7 and 10.

9. Probably a coincidence. However, Zupko (1968, p. 98) identifies two English agrarian leagues of 10,000 and 9,375 English feet which approximate Morison's "land league".

10. A northwesterly current conforms to Columbus' observation of its direction. The magnetic declination could have accounted for the two point difference in the current's bearing from the modern Pilot Charts.

11. DaCosta (1939, p. 216) takes the Portuguese maritime league to be 5,920 m, i.e. 19,422.6 English feet.

12. I.e. (18,000) (33 cm.) = 19,488 English feet.

13. I.e. (3 Arab mi.) (6080 ft./naut. mi.) (60 mi./degree)/(56.67 Arab mi./degree) = 19,312 English feet, close to other valuations of the Portuguese maritime league. See Mehren (1964, p. 8).

14. See Kreutz (1973) and Lane (1963).

15. For the sand glass see Balmer (1978). Morison (1942, I, pp. 220-239) gives a good description of the daily cycle of operations.

16. Decades later, log lines were knotted every 42 feet, the distance the ship would travel at 1 mph in 30 seconds. See Waters (1958, p. 139).

17. Just as the formula "one one-thousand, two one-thousand, . . . " can be used to count off seconds, the repetitions of the then well-known ejaculations "*miserere*" or "*mea culpa*" could do the same job.

18. See Waters (1955). Alternatively, the "moment", an Italian unit of one-third second, may have been used to give more accurate results. See Egerton MS.73 (British Library, folio 43v), a collection of 15th century Italian charts and navigational works, inter alia, for the "moment".

19. A few maneuvering boards survive in 14th and 15th century atlases (see e.g. Kreutz (1973), DaCosta (1939), Taylor (1957, p. 116)). A small drawing of one and an essay on the trigonometry associated with it, the *raxon del marteloio*, is given in Egerton MS.73, folio 47v.

20. It is instructive to compare Columbus' *Journal* with Albizzi's (in Mallett (1967, p. 207-275)), a patron who was not also a working pilot.

21. See Taylor (1957, p. 129) for an example.

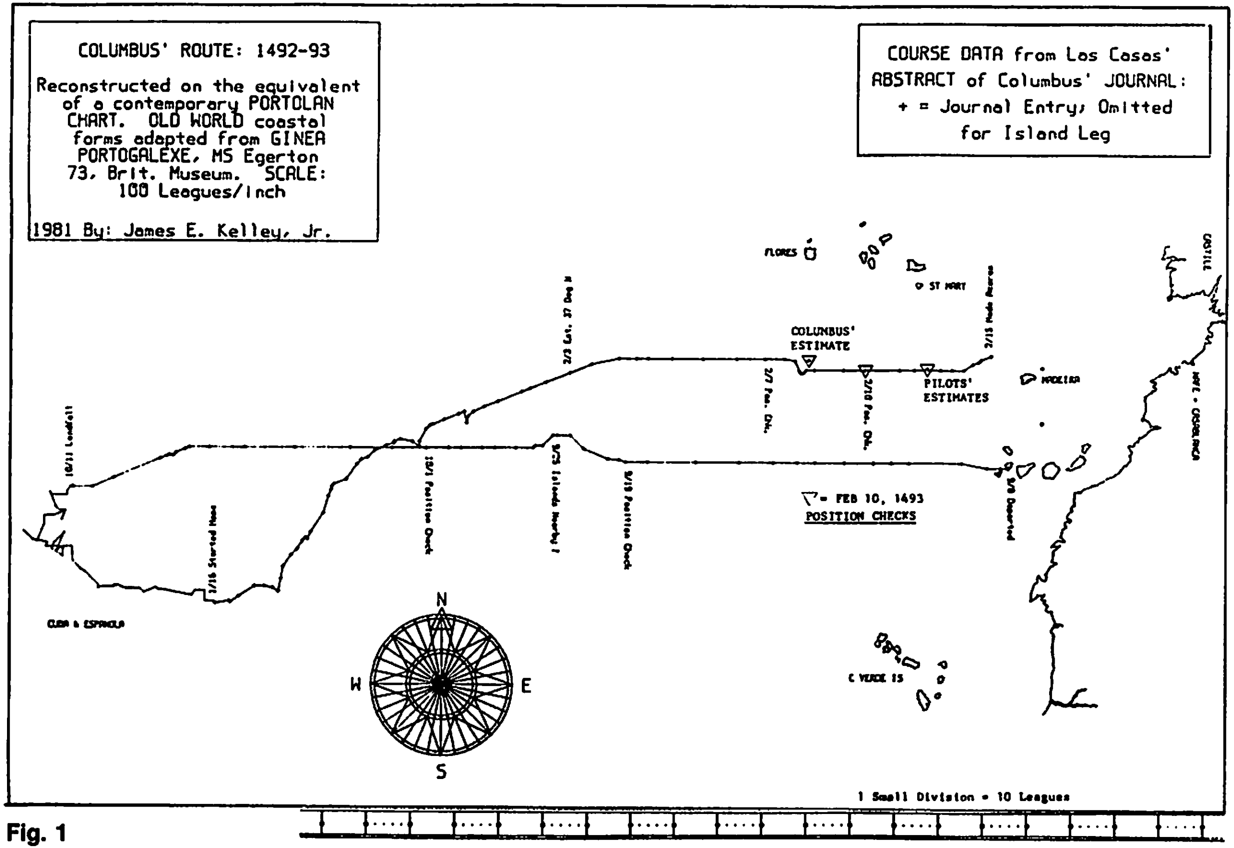

COLUMBUS' ROUTE: 1492-93
Reconstructed on the equivalent of a contemporary PORTOLAN CHART. OLD WORLD coastal forms adapted from GINEA PORTOGALEXE, MS Egerton 73, Brit. Museum. SCALE: 100 Leagues/Inch
1981 By: James E. Kelley, Jr.
COURSE DATA from Las Casas' ABSTRACT of Columbus' JOURNAL:
+ = Journal Entry; Omitted for Island Leg
FLORES
ST MART
COLUMBUS' ESTIMATE
PILOTS' ESTIMATES
FEB 10, 1493
POSITION CHECKS
10/11 Landfall
1/16 Started Home
10/1 Position Check
9/25 Islands Nearby !
9/19 Position Check
2/7 Pos. Chk.
2/10 Pos. Chk.
N
S
W
E
1 Small Division = 10 Leagues

Fig. 1

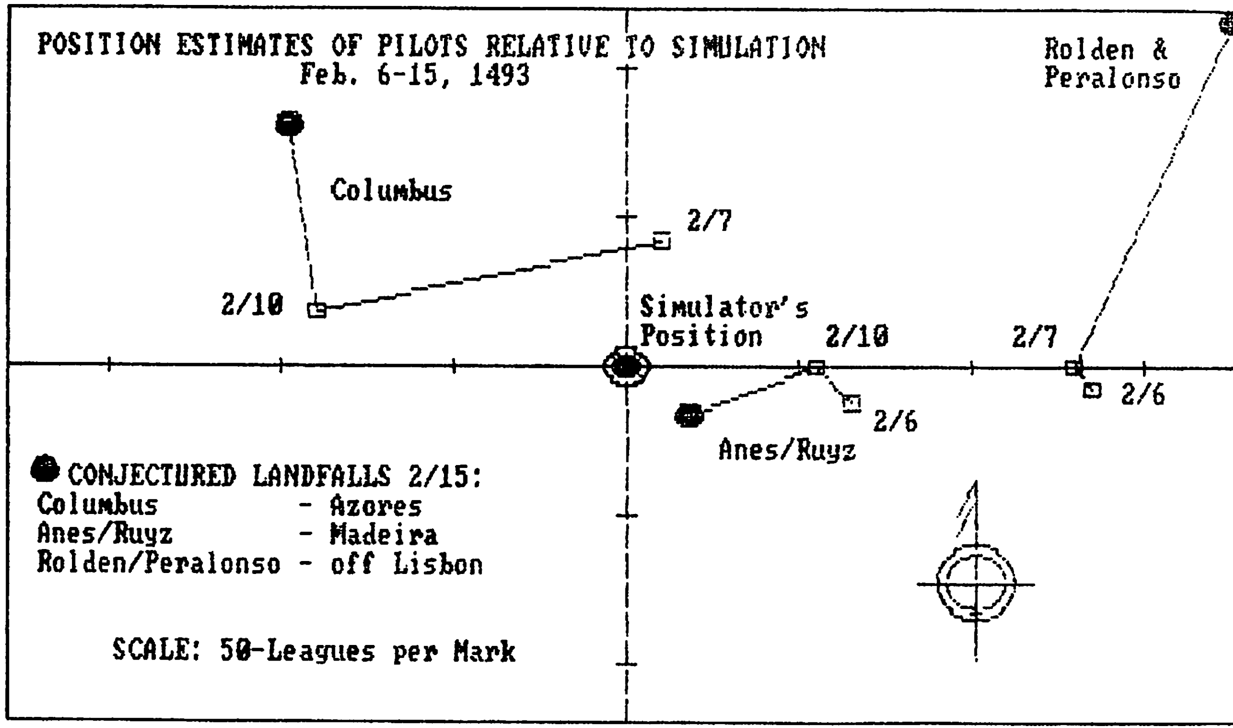

POSITION ESTIMATES OF PILOTS RELATIVE TO SIMULATION
Feb. 6-15, 1493
Rolden &
Peralonso
Columbus
2/7
2/10
Simulator's
Position
2/10
2/7
2/6
2/6
Anes/Ruyz
CONJECTURED LANDFALLS 2/15:
Columbus - Azores
Anes/Ruyz - Madeira
Rolden/Peralonso - off Lisbon
SCALE: 50-Leagues per Mark

Fig. 2

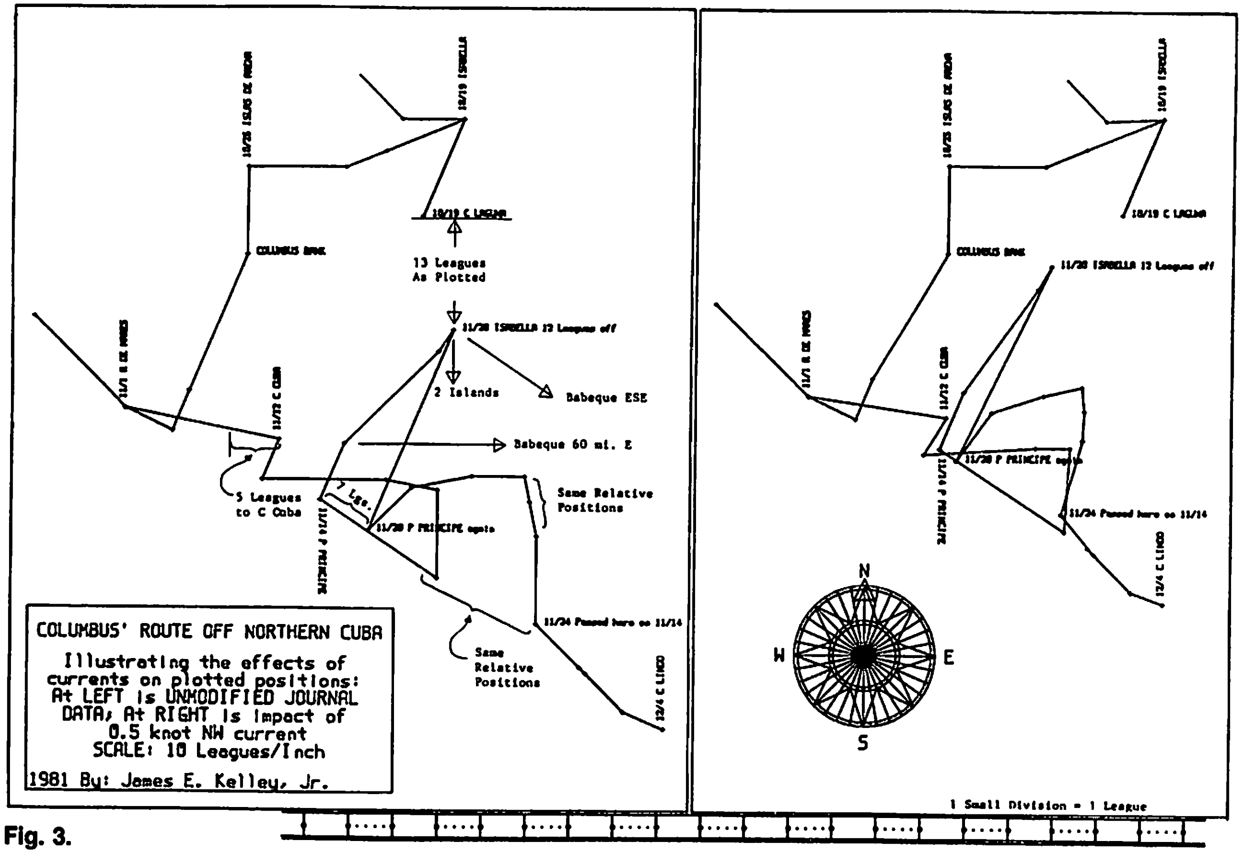
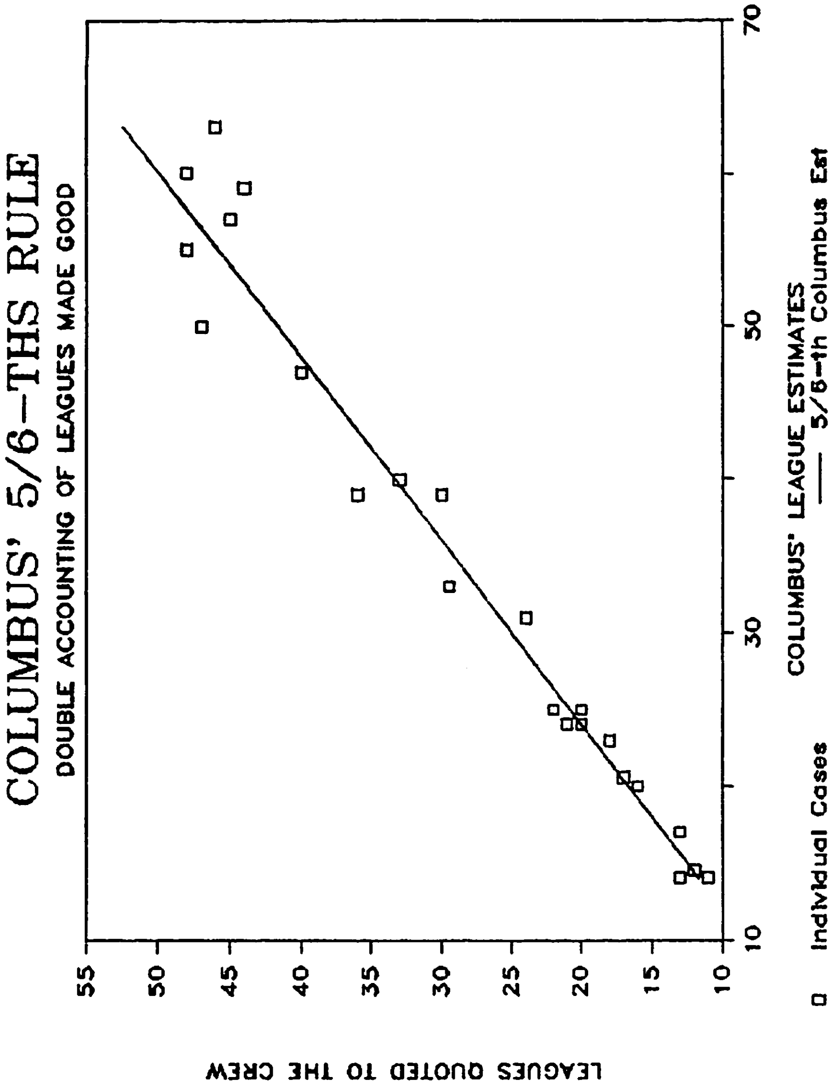

COLUMBUS' ROUTE OFF NORTHERN CUBA
Illustrating the effects of currents on plotted positions: At LEFT is UNMODIFIED JOURNAL DATA; At RIGHT is impact of 0.5 knot NW current
SCALE: 10 Leagues/Inch
1981 By: James E. Kelley, Jr.
13 Leagues As Plotted
2 Islands
Babeque ESE
Babeque 60 mi. E
5 Leagues to C Cuba
7 Lgs.
Same Relative Positions
Same Relative Positions
COLUMBUS BANK
N
S
W
E
1 Small Division = 1 League

Fig. 3.



COLUMBUS' 5/6—THS RULE
DOUBLE ACCOUNTING OF LEAGUES MADE GOOD
LEAGUES QUOTED TO THE CREW
55
50
45
40
35
30
25
20
15
10
10
30
50
70
COLUMBUS' LEAGUE ESTIMATES
Individual Cases
5/6-th Columbus Est

Fig. 4.

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