1993

How Far West Am I?: The Almanac as An Explorer's Yardstick

Arlen J. Large
The Wall Street Journal

Large, Arlen J., "How Far West Am I?: The Almanac as An Explorer's Yardstick" (1993). *Great Plains Quarterly*. 752.
https://digitalcommons.unl.edu/greatplainsquarterly/752

HOW FAR WEST AM I?
THE ALMANAC AS AN EXPLORER'S YARDSTICK

ARLEN J. LARGE

On 14 September 1494, three ships from Spain lay anchored at the southeastern tip of Hispaniola. Their admiral, Christopher Columbus, looked up at a full moon expecting something to happen, and it did.

Darkness nibbled at one edge of the lunar disc, the start of an eclipse predicted in an almanac carried by the Admiral. The book had been prepared twenty years before by a Nuremberg mathematician called Regiomontanus. The almanac gave the date and time of that eclipse as clocked from Europe. Watching sand in an hourglass, Columbus decided his local time for the event lagged five and a half hours behind Portugal's Cape St. Vincent, the nearest tip of Europe. From that Columbus tried to judge how far west he was at this stop on his second voyage to America.

More than three hundred years later Meriwether Lewis made the same kind of calculation at his winter fort in modern North Dakota. His almanac forecast the time in Greenwich, England, that a lunar eclipse would end on 14 January 1805. When the American explorer saw the moon escape from the same eclipse, he noted his North Dakota time and figured his longitude was 99°27' west of Greenwich.

Both Columbus and Lewis investigated distant places at a time when astronomy was considered the main scientific way of fixing their positions. Historians of American exploration know well the names of other travelers who were guided by the sky: Alexander Mackenzie, John Evans, David Thompson, Zebulon Pike, Stephen Long, John Charles Fremont, and John Wesley Powell.

Like Columbus and Lewis, these explorers needed almanacs predicting the times of various celestial events to help locate their place on earth. Their travel accounts, however, rarely explained how almanacs contributed to their

Arlen J. Large is a former reporter for The Wall Street Journal, *1956-86, and a past president of the Lewis and Clark Trail Heritage Foundation.*

[GPQ 13 (Spring 1993): 117-131]

own measurement of daily progress and to the maps they brought home. For example, many of the mysterious columns of astronomical digits filling the Lewis and Clark journals have meaning only when linked to the almanacs they carried. To understand how explorers navigated America historians therefore might find it helpful to review the general concepts of antique almanac usage. And that, in turn, requires an acquaintance with some European almanac savants—Giovanni Domenico Cassini, Tobias Mayer, Nevil Maskelyne—whose names aren't often linked with the Great Plains and Rocky Mountains.

The kind of almanac used by navigators is properly known as an *ephemeris*, which forecasts the celestial positions of the sun, moon, and planets. For a long while astronomy navigation coexisted with the spookier practices of astrology; the Regiomontanus almanac, for one, bragged that it could divine the future and predict the weather. The Paris Observatory started compiling the first real astronomical almanac in 1679, but it was the Royal Greenwich Observatory's *Nautical Almanac and Astronomical Ephemeris* that became the prime position-fixing handbook for the explorers and mappers of North America's interior.

In calculating how far they had come from home, these investigators relied—as we still rely—on conventions inherited from the ancients: a global grid of north-south and east-west coordinate lines developed by Claudius Ptolomy in the second century C.E. for the Mediterranean world.[1] The arcing lines of Ptolomy's latitudes and longitudes chopped the arcing lines of his grid into 360 units or degrees, an inconvenient legacy of old Babylon.

Ptolomy decided degrees of longitude should be counted eastward from a base meridian running through the Canary Islands off the coast of Morocco—to him the edge of the western world. Many mapmakers continued to count 360 degrees all the way around the globe from the Canaries well into the eighteenth century, which is why North American longitudes on old maps often numbered in the high 200s. Rival prime meridians proliferated, including Toledo, the Azores, Copenhagen, Paris, and others. The first English prime meridian ran through the dome of St. Paul's Cathedral in London before being switched to suburban Greenwich. Not until 1884 did an international convention formally ratify Greenwich as the world's prime meridian, from which 180 degrees of longitude diverge east and west.[2]

The idea of locating a place on Ptolomy's coordinate grid by astronomy also had ancient roots. Geographers quite early realized they could measure north-south travel by tracking the elevation of the North Star at night or of the sun at noon after adjusting for seasonal variations. That gives latitude in degrees from the equator; the earliest almanacs provided navigators year-round tables of the sun's seasonal height needed for this calculation. For the harder task of measuring east-west movement, Hipparchus of Nicaea theorized as early as 150 B.C.E. that a distant celestial occurrence like a lunar eclipse could be used to establish longitude.

The basic principle underlying the use of astronomy to get longitude is that time equals distance: in one hour of time, the earth rotates through 15° of longitude. That's the rate at which the moment of local noon moves westward as the earth turns beneath the sun. Thus each hour of difference between the local noons of two observers equals 15° of longitudinal separation. The function of a celestial event that can be seen simultaneously in places distant from each other is to signal the observer at each place *the exact instant* at which to mark the local time shown on each respective clock. In practice an almanac substitutes for the home-base observer, giving the traveling observer a reference against which to compare local time. The non-astronomical method of carrying a chronometer set on the time of a known longitude serves the same function.

That's the theory, anyway. As will be seen, precise position-fixing often was elusive in practice during the age of exploration. A traveler could be misled by the built-in error of his own almanac if it placed the moon just a smidgeon away from its real location. Instruments still weren't terribly accurate, and paperwork mistakes could snare busy seamen, soldiers, and traders who may have had little practice in celestial mathematics.

Both Columbus in 1494 and Lewis in 1805 tried to exploit the theory with lunar eclipses, and their answers were both off the mark. Columbus faced greater disadvantages, for his hourglass was too crude for comparing his local time with the eclipse time shown in Regiomontanus's almanac. Also, his result depended on accurate almanac predictions of the moon's orbital motion, and Regiomontanus made his forecasts without benefit of the later writings of Nicholas Copernicus, Johannes Kepler, and Isaac Newton on how orbits really work.

If Columbus's local time of the eclipse was five and a half hours behind his chosen base meridian of Cape St. Vincent, he would have been at about the same longitude as New Orleans—1500 miles too far west. Everybody has wondered how the great navigator could have been so wrong. Samuel Eliot Morison, the Admiral's best-known chronicler, has suggested Columbus gladly embraced the mistake because it reinforced his conviction that he was on the doorstep of Asia.[3] Ernst Zinner, Regiomontanus's biographer, has offered a more specific explanation: in calculating sun hours from the western tip of Europe, Columbus overlooked the fact that Regiomontanus had given the time of the eclipse for the meridian of Nuremberg in central Germany—not from Cape St. Vincent in Portugal[4]. If you measure five and a half hours west from Nuremberg at a rate of 15° per hour, in Columbus's latitude you land in the middle of the island of Hispaniola, only 200 miles west of Columbus's anchorage. That's not so bad, considering the handicaps.

Working with the 1805 eclipse, Lewis had the advantages of an expensive chronometer to record his local time plus the British Nautical Almanac's improved lunar positions based on Newton's laws of motion. His Fort Mandan longitude computation of 99° 27' west of Greenwich was eighty-five miles too far east of the modern figure of 101°16'.[5] Longitudes obtained this way are inherently imprecise. The earth casts a fuzzy-edged shadow on the moon, and Lewis had to make a subjective decision about timing the shadow's final departure. Besides that, it would appear Lewis left out an additional step in his calculations needed to put his local time on the same footing as the Greenwich time shown in his almanac. That additional adjustment alone would have brought him closer, but still thirty miles too far *west* of his true position.[6] In drawing his map of the area, co-commander William Clark decided to borrow a better longitude derived from the work of a previous explorer, David Thompson.

For much of human history the difficulty of finding longitude wasn't a terribly disabling problem. Mediterranean sailors going east or west needed only to keep the shore in sight. Norsemen pushed their boats westward from Scandinavia to Iceland to Greenland in manageable stages by keeping Polaris steady off their right shoulders. By around 1000 C.E. they required only a final westward hop of about three hundred miles across Davis Strait to bump into "Helluland," today's Baffin Island. From there they turned south to their short-lived L'Anse aux Meadows settlement in Newfoundland. Basically the route only required latitude navigation and, once learned, it was repeatable.[7]

The need to find longitude became more pressing when advances in sailing technology permitted long voyages across blue water, as dramatized by the difficulty Columbus had in determining his position. The longitude puzzle may actually have cost the life of Robert Cavelier de LaSalle. From his base in Canada this French entrepreneur led a small party southward down the Mississippi River, reaching its mouth at the Gulf of Mexico on 9 April 1682. With an astrolabe—the ancestor of a modern sextant—LaSalle measured the altitude of Polaris and computed a latitude of 27° north of the equator.[8] That was too far south by 130 miles, but something. He had at hand no better way of figuring his longitude than did Columbus 188 years before, and for LaSalle there was no timely lunar eclipse.

FIG. 1. *Giovanni Domenico Cassini, the Paris Observatory developer of longitude-finding with eclipses of the moons of Jupiter.* Courtesy of the Library of Congress.

Not knowing that longitude severely handicapped LaSalle when he tried two years later to return to the Mississippi's mouth by sea. LaSalle's convoy of would-be settlers pushed into the Gulf of Mexico in December 1684. En route the ships' navigators readily computed latitudes and even took a stab at longitudes, possibly by measuring the local compass variation. It had long been known that the magnetic north pole is offset from the geographic pole and that a traveler's magnetic compass would show a changing angle of offset as it was moved east or west. Among others, England's Edmond Halley—later of comet fame—offered the shaky hope that contour maps linking these angles could be used to track longitude.[9] The method generally was inaccurate, but if that's what LaSalle's ships were using, a reading on 20 December rather correctly put them on the longitude of the Mississippi's multiple mouths.[10] Had LaSalle known that was the meridian reached on his 1682 visit by land, he could have ordered his ships north right there and nailed his target. Instead, he kept sailing west until he hit the coast of Texas. There the original mission fell apart, and LaSalle later was murdered by some of his own men.

Ironically, it was just at this moment that European astronomers were devising the first real breakthrough in the longitude problem, one that would be of practical benefit to several explorers of the American land. Halley's compass variation charts never became practical, partly because the magnetic pole itself kept wandering. Eclipses of the moon weren't helpful because on average there are only two of them each year—some years there are none at all—not good enough for an explorer needing to know his longitude right now.[11]

But the solar system has other moons, and four of them were first seen circling the planet Jupiter by the Paduan astronomer Galileo Galilei in 1610. Jupiter is an easy-to-find headlight in the night sky, but its moons couldn't be seen without the small homemade telescope that Galileo turned upon it. Galileo quickly realized that an eclipse of a moon behind the planet could be clocked simultaneously by observers at two places on earth, thus giving their relative longitude. In 1616 he offered his plan to the King of Spain and again in 1636 to the seafarers of Holland.[12] Because a navigator would have to hold a long telescope steady on Jupiter, the method wouldn't work on a rolling ship at sea, so the Spanish and Dutch navies weren't interested.

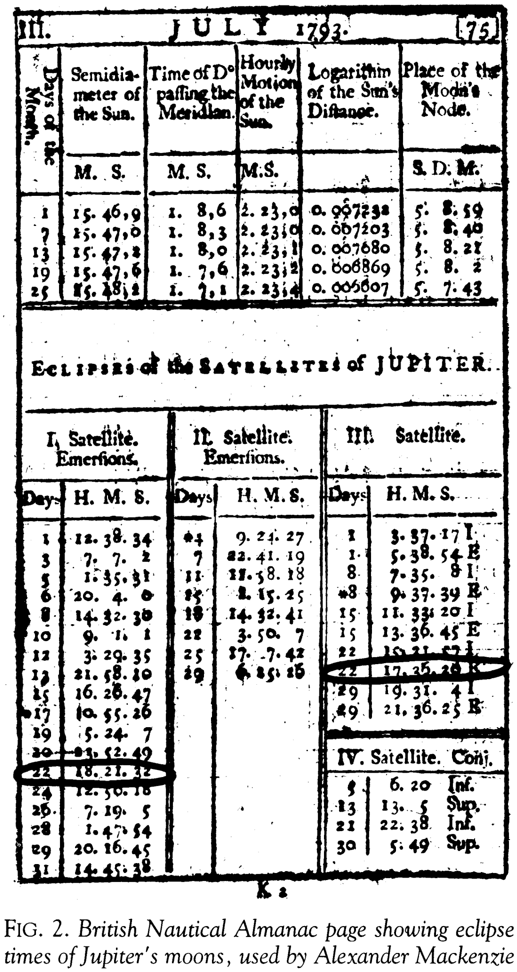
After Galileo's death in 1642, however, his idea was grabbed eagerly for use on dry land by the brilliant team of scientists that Louis XIV assembled at the Paris Observatory. Louis's prize catch was Giovanni Domenico Cassini (Fig. 1), an Italian astronomer who spent sixteen years refining Galileo's tables of the Jovian satellites now known as Io, Europa, Ganymede, and Callisto. In 1690 the Observatory's national almanac, *Connoissance des Temps*, began publishing regular predictions of the every-other-day eclipses of Io as timed from the meridian of Paris.[13]

The importance of Jupiter in cracking the longitude problem tends to be unappreciated today because the idea sounds so quaint. From Paris Cassini dispatched surveying teams to aim telescopes at Jupiter from Siam, Egypt, Madagascar, Goa, and the Caribbean islands of Guadeloupe and Martinique. Cassini thus established the first good global network of benchmark longitudes from which other longitudes could be estimated. The moment a distant surveyor saw Io disappear behind Jupiter or its trailing shadow cast by the sun, he knew exactly what time it was in Paris by referring to the French almanac. Comparing Paris time with his local time of Io's disappearance gave longitude at the familiar rate of 15° for each hour of difference.

Eclipse tables for all four Galilean satellites were adapted for the meridian of Greenwich when Britain's Royal Observatory began issuing its Nautical Almanac there in 1766. The almanac declared that eclipses of Jupiter's moons "are well known to afford the readiest, and for general Practice the best Method of settling the Longitudes of Places at Land; and it is by their Means principally that Geography has been so much reformed within a Century past . . .".[14]

Experts advised using a refracting telescope big enough to magnify Jupiter forty times for accurate timing of the moons as they disappeared behind the planet (immersion) or popped into view (emersion). A London-bought telescope lugged by Alexander Mackenzie to Canada's Pacific coast in 1793 was awkward baggage for his ten-man party, but the effort paid off. On the night of 22 July Mackenzie set it up near the now-famous rock at the saltwater Dean Channel where he inscribed the news of his reaching the coast. An hour after sunset, he trained the telescope at the spot where his Nautical Almanac said Ganymede, the third satellite, would emerge from the planet's shadow at 17 hours, 36 minutes, and 20 seconds (see Fig. 2). That was now-obsolete Greenwich astronomical time, in which the day was reckoned from noon to noon instead of midnight to midnight. Equivalent civil time in Greenwich would have been after dawn at 5:36 a.m. on July 23. It didn't matter that a Greenwich observer couldn't actually see Jupiter in daylight; the calculated almanac time was what counted.

Earlier that day Mackenzie had used sextant sightings of the sun's altitude to synchronize his watch with local noon. He used that watch to time Ganymede when it actually appeared, and 45 minutes later he similarly timed an emersion of Io, the first satellite. The Scottish explorer subtracted each of these observed times



III. JULY 1793. [75]

Days of the Month.	Semidiameter of the Sun. M. S.	Time of D° paſſing the Meridian. M. S.	Hourly Motion of the Sun. M.S.	Logarithm of the Sun's Diſtance.	Place of the Moon's Node. S. D. M.
1	15. 46,9	1. 8,6	2. 23,0	0. 007232	5. 8. 59
7	15. 47,0	1. 8,3	2. 23,0	0. 007203	5. 8. 40
13	15. 47,2	1. 8,0	2. 23,1	0. 007680	5. 8. 21
19	15. 47,6	1. 7,6	2. 23,2	0. 006869	5. 8. 2
25	15. 48,2	1. 7,1	2. 23,4	0. 006607	5. 7. 43

ECLIPSES of the SATELLITES of JUPITER.

I. Satellite. Emerſions. Days	H. M. S.	II. Satellite. Emerſions. Days	H. M. S.	III. Satellite. Days	H. M. S.
1	12. 38. 34	4	9. 24. 27	1	3. 37. 17 I
3	7. 7. 2	7	22. 41. 19	1	5. 38. 54 E
5	1. 35. 31	11	11. 58. 18	8	7. 35. 8 I
6	20. 4. 0	15	1. 15. 25	8	9. 37. 39 E
8	14. 32. 30	18	14. 32. 41	15	11. 33. 20 I
10	9. 1. 1	22	3. 50. 7	15	13. 36. 45 E
12	3. 29. 35	25	17. 7. 42	22	15. 31. 57 I
13	21. 58. 10	29	6. 25. 16	22	17. 36. 20 E
15	16. 26. 47			29	19. 31. 4 I
17	10. 55. 26			29	21. 36. 25 E
19	5. 24. 7				
20	23. 52. 49				
22	18. 21. 32				
24	12. 50. 18				
26	7. 19. 5				
28	1. 47. 54				
29	20. 16. 45				
31	14. 45. 38				

IV. Satellite.		Conj.
5	6. 20	Inf.
13	13. 5	Sup.
21	22. 38	Inf.
30	5. 49	Sup.

K 2

FIG. 2. *British Nautical Almanac page showing eclipse times of Jupiter's moons, used by Alexander Mackenzie in computing his 22 July 1793, Pacific coast longitude.* Courtesy of the Library of Congress.

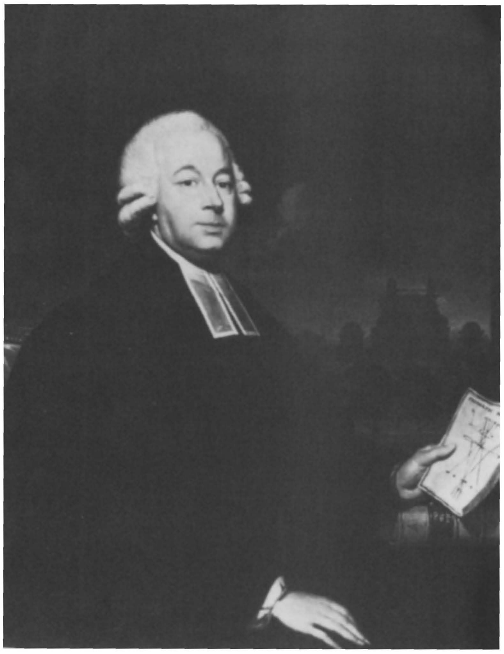


FIG. 3. *Nevil Maskelyne, Royal Greenwich Observatory editor of the* Nautical Almanac and Astronomical Ephemeris *from 1766 to 1811*. The Van der Puyl portrait at the Royal Society, courtesy of the Library of Congress.

from the predicted almanac times of the emersions, and averaged the differences. This average lagged 8 hours, 32 minutes, and 2 seconds behind Greenwich time, from which he computed a longitude of 128°02' W.

That was thirty-five miles too far west of the longitude given on modern maps, but Mackenzie was relieved to get anything. "I had now determined my situation," he said in his published journal, "which is the most fortunate circumstance of my long, painful, and perilous journey, as a few cloudy days would have prevented me from ascertaining the final longitude of it."[15]

For much of the next century Jupiter's moons offered other explorers of America an on-the-spot way to figure longitude without a lot of tough mathematics, provided they carried tables of eclipse predictions. Not having them was only one of the misfortunes that befell Lieutenant Zebulon Pike in 1806 when he was sent by General James Wilkinson on a spying mission to the Rocky Mountains. The general had instructed Pike

> to employ your telescope in observing the eclipses of Jupiter's satellites, having previously regulated and adjusted your watch by your quadrant, taking care to note with great nicety the periods of immersions and emersions of the eclipsed satellites.

The actual longitudes would have to be computed after Pike's return, however, because Wilkinson couldn't provide him with tables listing Greenwich times of the Jovian eclipses.

The navigation plan was ruined when Spanish troops captured Pike in the Rockies and confiscated most of his papers, including the local times of the satellite eclipses he had observed and recorded. When he got back to Washington, Pike at last had access to an almanac's Greenwich times, but now there were no observed western eclipse times to compare them with, and thus no longitudes. That made the map of his trip "very imperfect," he conceded.[16]

With both telescope and almanac at hand, Lieutenant John Charles Fremont readily obtained longitudes from fourteen Jupiter observations during his 1843-44 tour of the west. Like other explorers, weary after a hard day's travel, Fremont experienced the tedium of waiting into the night for an almanac-predicted event in the heavens. Reporting from Idaho, he said, "I sat up for an observation of the first satellite of Jupiter, the emersion of which took place about midnight; but fell asleep at the telescope." When he woke up Io was already there, too late to time.[17] In Oregon Charles Preuss, the German draftsman of Fremont's highly regarded maps, grumbled into his diary about a campfire vigil for an eclipse of Io: "To tell the truth, I wish the dear Lord had not attached any satellites at all to Jupiter. One can lose one's mind over it. These immersions occur so often that one forgets how to sleep."[18]

Other explorers didn't want to bother with a fragile telescope, fearing it would be too easily broken on a long trip. For them the main alternative for getting longitude was a method known as "lunar distances," which required only a sturdy sextant for measuring angles in the sky. The concept had been experimented with by European theorists for a couple of centuries. It only came into practical use for travelers a decade before the American Revolution, thanks mainly to Nevil Maskelyne (Fig. 3), the fifth Astronomer Royal at the Greenwich Observatory.

Maritime Britain wanted above all a way to find longitude at sea, which Jupiter couldn't provide. Since its founding in 1675 the Greenwich Observatory had been compiling a catalog of accurate positions of stars to serve as a reference background for the moving moon. In 1755 the British were able to borrow a superior table of lunar motions carefully worked out by a German astronomer, Tobias Mayer.[19]

Maskelyne used all this material to assemble tables predicting where the moon would be at three-hour intervals, Greenwich time, every day of the year. The locations were shown as angular distances between the moon and a nearby star or the sun. The angles were constantly changing as the moon moved eastward by roughly its own diameter each hour against the starry background. When a distant navigator determined that the moon and one of the reference stars were at exactly the angular distance shown in the almanac, he knew the time in Greenwich.

The Greenwich Observatory's annual *Nautical Almanac and Astronomical Ephemeris* first appeared in 1766 with Maskelyne's lunar distance tables as its centerpiece. The former clergyman was to continue editing the almanac until his death in 1811. Even he conceded that a single moon-star distance measurement could incur an error of nearly a degree of longitude, due partly to the residual "imperfection" of the almanac's lunar tables. For greater accuracy he advised the traveler to measure the moon's distance from two stars, "if he can be so lucky."[20]

A traceable thread of Maskelyne's influence on North American exploration can be seen in the career of an early "computer" he trained to figure the tedious tables of moon-star angles in the almanac. The computer, named William Wales, left his Greenwich job in 1772 to sail on Captain James Cook's second exploratory voyage to the Pacific.[21] During that trip Wales trained a teenage midshipman named George Vancouver in the mathematical intricacies of obtaining longitude by lunar distance.[22] Twenty years later Vancouver commanded his own naval survey of America's Pacific Northwest coast, using Greenwich-time chronometers and Maskelyne's lunar distances to fix longitudes for the mouth of the Columbia River and other notable points.[23] Vancouver's longitudes became the accepted western anchors for maps drawn by William Clark and later explorers of the interior.

P. Elmsly, a bookseller in the Strand, was the authorized London outlet for the Nautical Almanac. From there copies easily found their way to America, where they were considered fair game for pirating by anybody with a printing press. In 1802 John Garnett, a publisher in New Brunswick, New Jersey, began printing what he described as "a cheap American Edition of the Nautical Almanac beginning with 1803 to be continued regularly, and no pains will be spared to make it equally correct with the original." Needing in 1804 a new "London" edition for copying, the publisher obtained one from the American Philosophical Society in Philadelphia. Said a grateful Garnett: "I am much obliged to you for sending the N.A. of 1807, which shall now be printed without delay."[24]

From whatever source, the British lunar distance tables were circulating even before the turn of the century in America for use by land explorers. In the 1790s both James Mackay and John Evans used lunar distances in mapping stretches of the Missouri River for their Spanish-licensed trading company, which had more than an academic interest in finding longitude. In those days the longitude of the entrance of

TABLE 1.

ASTRONOMICAL OBSERVATIONS FOR NAVIGATION RECORDED DURING THE LEWIS AND CLARK EXPEDITION

From 17 December 1803, at Camp Dubois, Illinois,
to 25 August 1806, at Cheyenne River, South Dakota

	Number of Observations[1]
For Latitude (40%)	
Sun's altitude at noon	104
Sun's altitude, a.m. or p.m.	8
Altitude of Polaris	1
For Longitude (49%)	
To obtain Greenwich time	
Lunar distance from sun	32
Lunar distance from Nautical Almanac stars	28
Lunar eclipse	1
To obtain local time	
Sun's equal altitudes in a.m. and p.m., to determine the moment of local noon.	
Completed observations, with at least one p.m. reading[2]	66
Incomplete due to clouds	11
For Variation of Magnetic Compass from True North (11%)	
Sun's azimuth and altitude, a.m. or p.m.	25
Azimuth of Polaris	5
Total Recorded Observations	281

[1] An "observation" consists of one or more measurements taken for a single objective. For example, six successive readings of the angle between the moon and Spica are counted as a single observation, as is one measurement of the azimuth of Polaris from true north.

[2] Also used to produce 2 latitude estimates.

Source: *Journals of the Lewis and Clark Expedition*, edited by Gary Moulton (Lincoln: University of Nebraska Press, 1983–) and Reuben Gold Thwaites, *Original Journals of the Lewis and Clark Expedition* (New York: Dodd, Mead, 1904–05).

the Platte River into the Missouri was a demarcation line for carving up markets in the Indian trade.[25]

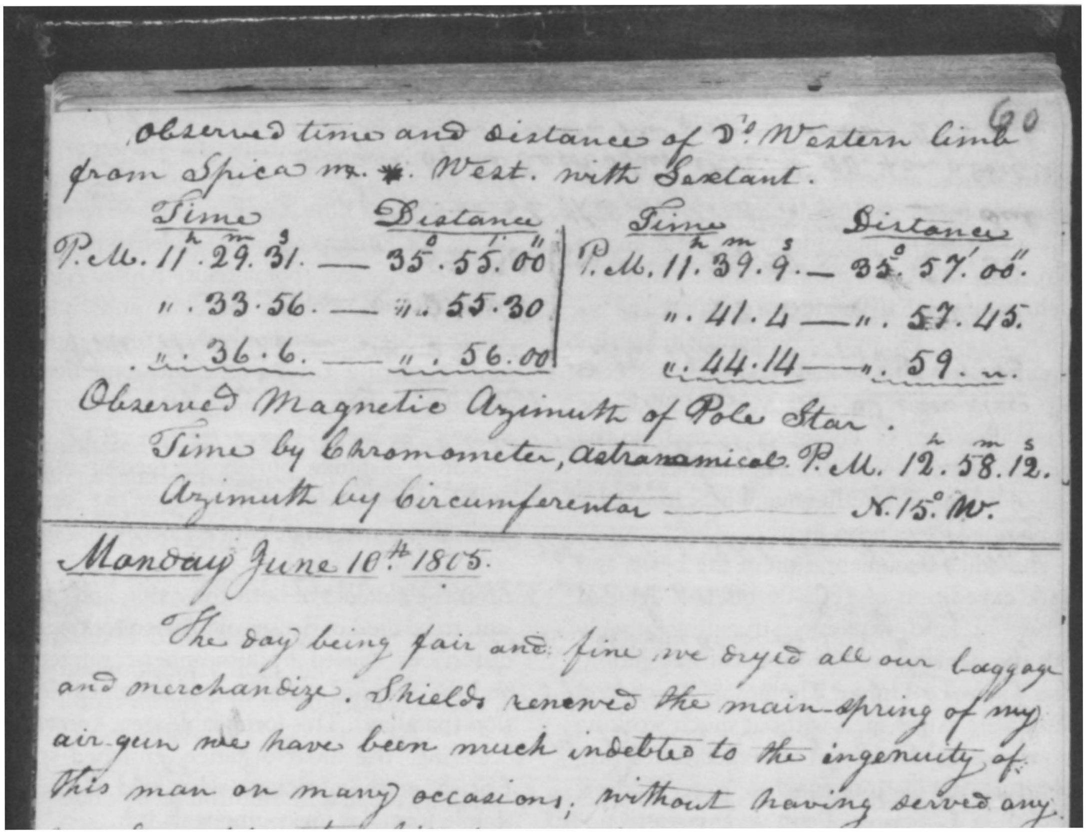
In December 1797, David Thompson, surveyor for the North West Company of fur traders, arrived at the Mandan villages in North Dakota from his base in Manitoba. He brought only a sextant for matching moon-star angles with those in Maskelyne's almanac. The thoroughly professional Thompson computed a longitude of 101°14' west of Greenwich for this important tribal trade mart and drew a sketch map of the area.[26] In 1803 Meriwether Lewis picked up a copy of Thompson's map from the British Embassy in Washington, and the Mandan longitude became another major benchmark for his planned expedition west.[27]

The bulky documentation of the Lewis and Clark expedition of 1803-06 offers a detailed picture of land explorers struggling bravely with the demands of astronomical navigation. (See Table 1.) Unlike Thompson, Lewis and Clark were Army men without much working knowledge of the sky. The expedition's predeparture navigation coaches were Andrew Ellicott, a Lancaster, Pennsylvania, astronomer-surveyor, and Robert Patterson, mathematics professor in Philadelphia. In March 1803, at an early point in the planning, Ellicott said Lewis needn't try to compute longitudes from his lunar distance records until the trip's end "because the transportation of the books, and tables, necessary for that purpose, would be found inconvenient on such a journey."[28] Evidently somebody later decided the inconvenience could be tolerated, as Lewis left for the west with all the manuals needed to produce longitudes in the field. These included Nautical Almanacs for 1803, 1804, and 1805, a book on calculating lunar distances, and Maskelyne's own "Tables Requisite" for using the Nautical Almanac.[29] This last contained several crutches for laymen, such as handy table converting units of time into degrees of longitude.[30] And for navigators who preferred to peek in the back of the book, Maskelyne offered twenty-four pages of known latitudes and longitudes for places around the world, including such North American points as Boston, New Orleans, San Francisco, Mexico City, and Nootka Sound.

Lewis and Clark at no point during their trip specifically mentioned consulting the Nautical Almanac, but its distinctive signature runs throughout the pages of their journals. Maskelyne listed just nine stars as nighttime reference points for lunar positions: Aldebaran, Alpha Aquilae, Antares, Fomalhaut, Alpha Arietis, Alpha Pegasi, Pollux, Regulus, and Spica.[31] Those nine stars—and only those nine—are the ones recurring throughout the expedition's records of observed angular distance from the moon.

Lunar distance purists decreed it wasn't enough for a navigator to measure the "apparent" moon-star angle alone. He also was required simultaneously to measure from the horizon the *altitudes* of both the moon and target star, to be used in dense calculations correcting distortions caused by atmospheric refraction and the skyward sight-lines of his global location (parallax). This formidable step, known as "clearing" the lunar distance, enriched some British mathematicians who sold allegedly simple formulas for coping with it.[32]

Because of various shortcut formulas, textbook descriptions of lunar-distance navigation don't explain how American explorers actually used the method in the field. When Major Stephen Long journeyed to the Rockies in 1820, he merely took apparent lunar distance angles (at just five locations on the whole round trip) and ignored the "clearing" altitudes. Lieutenant J. D. Graham, who later computed longitudes from these records, said a shortcut formula made it good enough merely to know the time and *latitudes* at which the sextant readings were taken.[33] Similarly, those entries of moon-star and moon-sun angles in the Lewis and Clark journals can't be understood if the reader also looks for "clearing" altitudes, because they aren't there. Liberation from this chore was authorized by Professor Patterson himself, who gave Lewis a set of navigational crib sheets with a shortcut formula to be used at those times, "as it may frequently happen," when altitudes couldn't be taken.[34]



60

Observed time and distance of ☽'s Western limb from Spica ♍ ✱. West. with Sextant.

Time	Distance	Time	Distance
h m s	° ' "	h m s	° ' "
P.M. 11.29.31. —	35.55.00	P.M. 11.39.9. —	35.57.00.
".33.56. —	".55.30	".41.4 —	".57.45.
".36.6. —	".56.00	".44.14 —	".59.".

Observed Magnetic Azimuth of Pole Star.
Time by Chromometer, astranamical. P.M. 12^h.58^m.12^s.
Azimuth by Circumferentar ——— N.15°W.

Monday June 10th 1805.

The day being fair and fine we dryed all our baggage and merchandize. Shields renewed the main-spring of my air-gun we have been much indebted to the ingenuity of this man on many occasions; without having served any

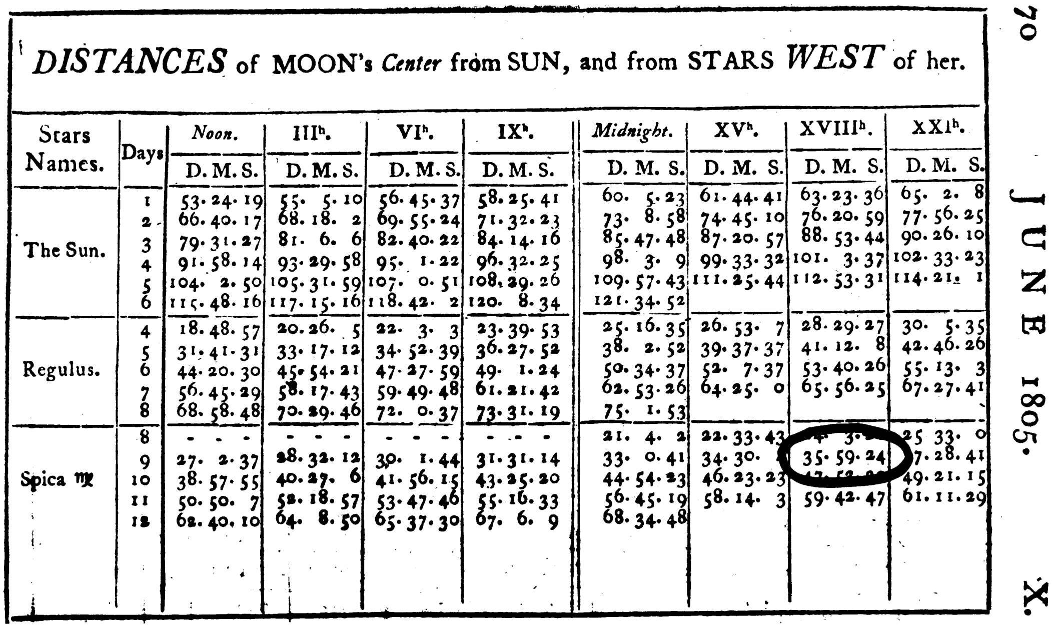
FIG. 4. *Meriwether Lewis's 9 June 1805, measurement of the moon's distance from Spica, to be matched with the Nautical Almanac's Greenwich time of the same separation.* Courtesy of the American Philosophical Society, Philadelphia.

While Lewis left with a complete kit for figuring his longitudes on the spot, President Jefferson told him to save his raw observations for delivery to the War Department, where experts "concurrently" could run computations to check his results.[35] At his jumpoff point near St. Louis, Lewis reported that he had fixed that camp's longitude with a complete lunar distance calculation from seven sets of moon angles with the sun, Aldebaran, and Spica. In the documents that have survived, however, he gave only the final answer—89°57'45" W—without recording raw data that could be checked by others.[36] This unconfirmable result, made near a town where the longitude had been known for years, was to be the only lunar distance calculation Lewis claimed to have made during the entire expedition.

There was at least one other attempt, however. At Fort Mandan on 23 February 1805, Lewis took a set of moon-sun angles, pegged his chronometer to local noon, and began trying to compute the corresponding time in Greenwich. He reached the point for applying shortcut formulas to the "clearing" problem and, though there was more room on the paper, quit in apparent defeat.[37] The captain evidently was trying to see if a lunar distance longitude would square with his result from the lunar eclipse the month before.

Except for this failed attempt, Lewis and Clark merely noted down the raw moon-star or moon-sun angles for longitude calculation by others upon their return home. How this should have worked in tandem with the Nautical Almanac is illustrated by Lewis's lunar distance observation on the evening of 9 June 1805, at the junction of the Missouri and Marias Rivers in modern Montana. (See Fig. 4.) The captain took six sextant sightings of the distance between the moon's western edge and the bright star Spica. The moon's eastward motion away from the star is discernable in the slight widening of their angular separation, but motion wasn't the operative factor. Rather, the six entries would be averaged into single values of time and distance for the purpose of washing out any small eyeball misjudgments at the sextant. This would freeze into the record the observation that on 9 June at the Marias, Spica was nearly 36° west of the moon—the exact average was 35°56'43"—at 11 hours, 37 minutes, and 20 seconds in the evening, the average of Lewis's chronometer times.

The Nautical Almanac (see Fig. 5) shows that on 9 June Spica would be nearly 36° west of the moon at 1800 hours, Greenwich astronomical time—the exact angle being 35°59'24". The task for a mathematician back in Washington would be to find the exact Greenwich time of Lewis's recorded moon-Spica angle. For that he would have to work a series of corrections on the raw observations of both time and distance. These would involve Lewis's own 9 June calculation relating his chronometer to local noon at the Marias, plus a "clearing" correction for Lewis's latitude, plus a final interpolation of the moon's motion to fit it within the almanac's three-hour Greenwich time intervals. If everything worked right, the computed



70 JUNE 1805. X.

DISTANCES of MOON's *Center* from SUN, and from STARS *WEST* of her.

Stars Names.	Days	*Noon.*	IIIh.	VI h.	IX h.	*Midnight.*	XV h.	XVIII h.	XXI h.
		D. M. S.	D. M. S.	D. M. S.	D. M. S.	D. M. S.	D. M. S.	D. M. S.	D. M. S.
The Sun.	1	53.24.19	55. 5.10	56.45.37	58.25.41	60. 5.23	61.44.41	63.23.36	65. 2. 8
	2	66.40.17	68.18. 2	69.55.24	71.32.23	73. 8.58	74.45.10	76.20.59	77.56.25
	3	79.31.27	81. 6. 6	82.40.22	84.14.16	85.47.48	87.20.57	88.53.44	90.26.10
	4	91.58.14	93.29.58	95. 1.22	96.32.25	98. 3. 9	99.33.32	101. 3.37	102.33.23
	5	104. 2.50	105.31.59	107. 0.51	108.29.26	109.57.43	111.25.44	112.53.31	114.21. 1
	6	115.48.16	117.15.16	118.42. 2	120. 8.34	121.34.52			
Regulus.	4	18.48.57	20.26. 5	22. 3. 3	23.39.53	25.16.35	26.53. 7	28.29.27	30. 5.35
	5	31.41.31	33.17.12	34.52.39	36.27.52	38. 2.52	39.37.37	41.12. 8	42.46.26
	6	44.20.30	45.54.21	47.27.59	49. 1.24	50.34.37	52. 7.37	53.40.26	55.13. 3
	7	56.45.29	58.17.43	59.49.48	61.21.42	62.53.26	64.25. 0	65.56.25	67.27.41
	8	68.58.48	70.29.46	72. 0.37	73.31.19	75. 1.53			
Spica ♍	8	- - -	- - -	- - -	- - -	21. 4. 2	22.33.43	[illegible]	25 33. 0
	9	27. 2.37	28.32.12	30. 1.44	31.31.14	33. 0.41	34.30. [illegible]	35.59.24	[illegible]7.28.41
	10	38.57.55	40.27. 6	41.56.15	43.25.20	44.54.23	46.23.23	[illegible]	49.21.15
	11	50.50. 7	52.18.57	53.47.46	55.16.33	56.45.19	58.14. 3	59.42.47	61.11.29
	12	62.40.10	64. 8.50	65.37.30	67. 6. 9	68.34.48			

FIG. 5. *Top half of the Nautical Almanac for June 1805, with the circled moon-Spica distance corresponding to Lewis's measurement at the Marias.* Courtesy of the Library of Congress.

time difference between the Marias and Greenwich would be 7 hours and 22 minutes, or a correct modern longitude of 110°29' W.

The English chronometer obtained by Lewis in Philadelphia wasn't reliable over extended periods. It therefore wasn't generally used in the manner intended for sea captains—keeping it set on Greenwich (or other base meridian) time for comparison with the traveler's local time.[38] Rather, the explorers employed the instrument as an ordinary watch for connecting the mean times of a short-term series of astronomical sightings.

Lewis and Clark's decision to forego lunar distance longitude calculations until their return made careful recording of their field observations all the more important, but, sadly, their bookkeeping was often sloppy. Near Beaverhead Rock in Montana, Clark measured the distance between and the moon and Antares and later gave the readings to Lewis; as recopied by Lewis, the recorded observation showed the moon going backwards![39]

If the astronomy notes approached shorthand, it may have reflected the captains' assumption that they personally could clarify doubtful entries to mathematicians working on the longitudes back in Washington. That this didn't happened was part of the whole deplorable post-expedition collapse of the management of the Lewis and Clark records. The blame must fall partly on Jefferson for giving both Lewis and Clark cushy patronage jobs in distant St. Louis instead of ordering them immediately to work full time on publication of their maps and journals. Four years after expedition's return, a cold partial record of observations was mailed to mathematician Ferdinand Rudolph Hassler in upstate New York. Without anyone to explain the shorthand, he couldn't decipher it.[40]

As a result, Clark's map of the expedition's whole route finally published in 1814 was anchored by just three good longitudinal points, all borrowed from others: the well-known position of St. Louis in the east, Thompson's approximate longitude for Fort Mandan in the middle, and Vancouver's approximate longitude for Cape Disappointment in the west. Laborious lunar distance readings had been taken at what Lewis and Clark considered key intermediate points: the Great Falls and Three Forks of the Missouri, the east and west shoulders of the Rockies, and the junction of the Snake and Columbia Rivers. These raw numbers simply moldered without anyone converting them to longitudes to be fitted to Clark's map.

The uninterpreted readings forced Clark to guess at the longitudes crossed by the expedition between the three known anchors. He did it by simple dead reckoning, adding up the estimated distance covered on each leg of each compass heading. And that, in turn, distorted the single most important geographical discovery brought home by Lewis and Clark: the surprising *width* of the Rocky Mountain chain. Because of dead reckoning errors Clark's map somewhat exaggerated this valuable discovery, making the Rockies even wider than they are. On his 1814 map nearly 6° of longitude separate the expedition's eastern entrance at the Gates of the Mountains in Montana and its western exit from the Bitterroots in Idaho. Just under 4° separate the same points on modern maps. Even after Clark's map was published Jefferson still kept hoping—in vain—that the government would hire mathematicians to "correct the longitudes" and thus establish "the correct geography of the country, which was the main object of the expedition."[41]

During later explorations of the nineteenth century, Thompson-type professionals continued to get good longitudes while Lewis-and-Clark amateurs didn't. The War Department's multi-pronged 1854 search for a railroad route to the Pacific produced striking contrasts of performance. Captain John Pope, an Army topographical engineer, used lunar distances to establish the longitudes of seven main reference points on a far-southern rail route across Texas. At twenty-five-mile intervals between these points he noted time differences on this chronometer to estimate longitudes for twenty intermediate places. This chain of measurements fixed the Texas route "with some considerable degree of accuracy," boasted Pope.[42] Much different were the results of a northern survey near the Canadian border led by Isaac Stevens, a newly appointed governor of Washington Territory. Stevens had to confess his survey's longitudes "are not good." He offered abundant excuses: the chronometers went haywire, and nobody in his party knew how to work lunar distances. Like Clark, he had to fall back on dead reckoning estimates of distance traveled.[43]

When John Wesley Powell made his first trip through the Colorado River's Utah and Arizona canyons in 1869 he got his longitudes in a routine professional way with lunar distances.[44] But Powell was able to use a new technological wrinkle freeing him from almanac time comparisons when he started a complete survey of the Grand Canyon itself in 1871. The U.S. Coast Survey previously had nailed down the longitude of Salt Lake City as 111°53' west of Greenwich. Powell's wilderness surveyors marked the instant when the earth's rotation carried a target star across their overhead meridian. They immediately exchanged time signals over a telegraph line with observers in Salt Lake City watching for the same event. The slight time difference gave Powell's longitude from Salt Lake City, and thus by extension from Greenwich.

It took Almon Harris Thompson, Powell's topographer, more than a week in 1872 to get his instruments and telegraph table set up in the little town of Kanab, Utah, a major survey reference point fifty miles from the north rim of the Grand Canyon. New technology could wobble, however, according to Thompson's diary: "Tuesday, Sept. 24. Got good observation. Exchanged signals with Salt Lake. Line worked badly. . . . Friday, Sept. 27th. Exchanged signals. Got good observation and good exchange."[45]

Toward the end of the nineteenth century telegraphed time signals on land and cheap chronometers at sea were fast displacing old-fashioned almanac predictions about solar system moons as a way of measuring east-west travel. In 1905 the U.S. Navy began regular broadcasts of time signals by radio, and European governments quickly followed. That gave radio-equipped navigators a foolproof way of knowing Greenwich time, and it soon ended any need for the eye-straining lunar distance tables pioneered by Maskelyne. The British Nautical Almanac finally stopped publishing them in 1907.[46]

The founding of national observatories in Europe—driven by the needs of navigators—provided an astronomical basis for comparing time differences across global distance. Procedures of rough accuracy thus were available for attempts at scientific position-fixing in North America during the eighteenth and nineteenth centuries, and they helped produce increasingly refined maps of the interior as more explorers learned how to use them. Though almanacs still have a fall-back role, longitude-finding in the twentieth century grew away from astronomy with the advent of radio time signals. Today, even the hallowed comparison of time differences between two places is becoming obsolete. Anyone with the price of a compact black box can get instant digital readouts of latitudes and longitudes signaled from manmade satellites orbiting eleven thousand miles overhead. Nevil Maskelyne would be amazed.

NOTES

1. See John Parker, *Discovery: Developing Views of the Earth from Ancient Times to the Voyages of Captain Cook* (New York: Chas. Scribner's Sons, 1972), pp. 46-49, for a summary of cartographic practices of the ancient world.

2. Derek Howse, *Greenwich Time and the Discovery of the Longitude* (Oxford: Oxford University Press, 1980), pp. 127-51.

3. Samuel Eliot Morison, *Admiral of the Ocean Sea*, 2 vols. (Boston: Little, Brown & Co., 1942), 2:158-59. A more famous incident occurred on his fourth voyage when Columbus used a Regiomontanus-predicted, 29 February 1504, lunar eclipse to frighten Jamaican natives into bringing him food. Columbus used the 1504 eclipse to calculate his longitude again, and again was much too far west. Morison explained this "inexcusable" error by theorizing Columbus "was consciously fudging his figures" to confirm his proximity to China. 2:403.

4. Ernst Zinner, *Regiomontanus: His Life and Work* (Amsterdam: Elsevier Science Publishers, 1990 translation by Ezra Brown of the 1968 German ed.), p. 123. An alternative theory for Columbus's error, ascribed to mis-timing the 1494 and 1504 eclipses, has been offered by Donald W. Olson, "Columbus and an Eclipse of the Moon," *Sky & Telescope* (October 1992), pp. 437-40.

5. Gary Moulton, ed., *The Journals of the Lewis & Clark Expedition*, 8 vols. (Lincoln: University of Nebraska Press, 1983-93), 3:273-74, 280.

6. The Nautical Almanac's predicted eclipse time for Greenwich was based on *apparent* time, the kind shown on a sundial. Lewis recorded his observations according to the *mean* time carried on his chronometer (Moulton, *Journals*, 2:412-13). Mean time, as kept by all clocks, squares with sundial time on just four days a year because of the earth's noncircular orbit around the sun. At Fort Mandan Lewis calculated that his chronometer was running about an hour too slow on mean time, based on solar measurements he made thirteen days later. After adding this hour back, Lewis subtracted the corrected mean time of his eclipse-end observation from the Nautical Almanac's Greenwich apparent time of the same event. This produced his recorded time difference of 6h 37m 45s, which converts to 99°26'45" of longitude. However, he should have made an additional subtraction of 9m 56s (the "equation of time" indicated in the almanac for 15 January) to put his mean-time observation on the same basis as the Greenwich apparent-time prediction.

7. That other Norsemen later retraced Leif Ericsson's route from Greenland to America is made clear in the "Graenlendinga Saga" in Magnus Magnusson and Hermann Palsson, trans., *The Vinland Sagas: The Norse Discovery of America* (London: Penguin Books, 1965), pp. 59, 64-65.

8. Isaac J. Cox, ed., *The Journeys of Rene Robert Cavelier Sieur de LaSalle, as related by his faithful Lieutenant, Henri de Tonty [et al.]*, 2 vols. (1922; rpt. New York: AMS Press, 1973), 1:146, 166.

9. Edmond Halley's "Magnetic Variation Chart of the World" is reproduced in Eva G.R. Taylor, *The Haven-Finding Art* (New York: Abelard-Schuman Ltd., 1957), p. 252.

10. Henri Joutel, a soldier who kept the principal journal of LaSalle's 1684 voyage to the Gulf of Mexico, reported the convoy reached a longitude of 285°16' on 20 December. Cox, *Journeys of LaSalle* (note 8 above), 2:20. Joutel didn't say what base meridian this was measured from, but on Guillaume de l'Isle's 1718 map of Louisiana, which counted longitude eastward around the world from the Canaries, it would have placed the convoy almost directly south of the Mississippi's mouth.

11. Ian Ridpath, ed., *Norton's 2000.0 Star Atlas and Reference Handbook*, 18th ed. (New York: John Wiley & Sons, 1989), p. 121.

12. Stillman Drake, *Galileo at Work: His Scientific Biography* (Chicago: University of Chicago Press, 1981). pp. 193, 257-61, 374.

13. Lloyd A. Brown, *The Story of Maps* (Boston: Little, Brown & Co., 1949). See pp. 212-24 for an excellent summary of seventeenth-century scientific activity at the Paris Observatory.

14. *The Nautical Almanac and Astronomical Ephemeris for the Year 1805* (London: Commissioners of Longitude, 1801), p. 151.

15. Alexander Mackenzie, *Voyages from Montreal* (1801; rpt. Rutland: Charles E. Tuttle Co., 1971), pp. 348-51.

16. Elliott Coues, ed., *The Expeditions of Zebulon Montgomery Pike*, 2 vols. (1895; rpt. New York: Dover Publications, 1987). See 2:564 for Wilkinson's instructions; 2:851-52 for Pike's navigational accounting.

17. Donald Jackson and Mary Lee Spence, eds., *The Expeditions of John Charles Fremont: Travels from 1838 to 1844* (Urbana: University of Illinois Press, 1970), p. 482.

18. Charles Preuss, *Exploring with Fremont*, trans. Erwin and Elisabeth Gudde. (Norman: University of Oklahoma Press, 1958), p. 92.

19. Eric G. Forbes, *The Birth of Scientific Navigation* (Greenwich: National Maritime Museum, 1974), p. 9. In recognition of Tobias Mayer's work with lunar motions the British Parliament awarded his widow £3000 in 1765.

20. *Nautical Almanac* for 1805, p. 159.

21. D.H. Sadler, *Man Is Not Lost—A record of 200 years of astronomical navigation with the Nautical Almanac, 1767-1967* (Greenwich: National Maritime Museum, 1968), p. 13.

22. W. Kay Lamb, ed., *George Vancouver—A Voyage of Discovery to the North Pacific Ocean and Round the World, 1791-1795*, 4 vols. (London: The Hakluyt Society, 1984), 1:4.

23. For a revealing study of the accuracy of position-fixing in 1792, see N. W. Emmott, "Captain Vancouver and the Lunar Distance," Royal Institute of Navigation *The Journal of Navigation* 27 (no. 4, October 1974): 490-95. Vancouver and his practiced team of professional navigators, using the world's best equipment, took multiple lunar distance measurements at Discovery Bay on Puget Sound, near modern Gardiner, Washington, getting a longitude of 122°37'41" W. That was too far east by more than 11 miles, but Emmott rated the result "extremely good" in light of the method's imprecision.

24. John Garnett to Robert Patterson, 14 January 1802, and 12 October 1804, Patterson Papers,

American Philosophical Society Library, Philadelphia. Because of persistent typesetting errors in his pirated New Jersey copies, Garnett by 1818 was asking British authorities for permission to import wholesale lots of the Nautical Almanac directly from its London publisher, according to correspondence in the Royal Greenwich Observatory archives at Cambridge University.

25. A.P. Nasatir, ed., *Before Lewis and Clark*, 2 vols. (1952; rpt. Lincoln: University of Nebraska Press, 1990), 2:417, 445.

26. Richard Glover, ed., *David Thompson's Narrative 1784-1812* (Toronto: The Champlain Society, 1962), p. 179.

27. Gary Moulton, ed., *Atlas of the Lewis & Clark Expedition* (Lincoln: University of Nebraska Press, 1983), p. 5.

28. Andrew Ellicott to Thomas Jefferson, 6 March 1803, in Donald Jackson, ed., *Letters of the Lewis and Clark Expedition*, 2nd ed., 2 vols. (Urbana: University of Illinois Press, 1978), 1:23-24.

29. Jackson, *Letters* (note 28 above), 1:96.

30. Nevil Maskelyne, *Tables Requisite to be used with the Nautical Ephemeris* (London: Commissioners of Longitude, 1802), p. 38.

31. Most of the Nautical Almanac's nine navigational stars are first-magnitude beacons chosen because they lie nearly in the moon's orbital path around the earth. Maskelyne's list was an inconsistent mix of traditional names and "scientific" Greek letter designations based on the constellations where the stars are found. Spica, Antares, and Alpha Aquilae (traditional name Altair) were the lunar distance target stars most often used by Lewis and Clark, partly because they're convenient for evening viewing during the warm travel months.

32. One of the popular lunar distance manuals was compiled by Andrew Mackay, *The Theory and Practice of Finding the Longitude at Sea or Land*, 3rd ed., 2 vols. (London: Longman, Hurst, 1810). An interesting history of lunar distance navigation is found at 1:92-95.

33. Edwin James, *Account of an Expedition from Pittsburgh to the Rocky Mountains*, 2 vols. (1823; rpt. Ann Arbor: Readex Microprint Corp., 1966). Lieutenant J.D. Graham's description of lunar distance calculations is on p. vi of his preface to the expedition's astronomical records, vol. 2.

34. From Lewis's unpublished "Astronomy Notebook" written mainly by Robert Patterson, Western Historical Manuscript Collection, State Historical Society of Missouri, Columbia, quoted with permission. Patterson's "Problem 4th" and "Problem 5th" told Lewis how to avoid taking the altitudes of lunar distance targets.

35. Jefferson's instructions to Lewis, 20 June 1803, in Jackson, *Letters* (note 28 above), 1:62.

36. Moulton, *Journals of the Lewis and Clark Expedition* (note 5 above), 2:228.

37. Ernest Staples Osgood, ed., *The Field Notes of Captain William Clark* (New Haven: Yale University Press, 1964), p. 259.

38. The marine chronometer set on Greenwich time proved accurate for getting longitudes on the late eighteenth century voyages of Captain James Cook. Not until the mid-nineteenth century, however, did cheaper, sturdier models permit wider acceptance among sea captains and land explorers alike, with lunar distances still being used to cross-check their results. In response to the growing use of chronometers, the British Nautical Almanac in 1834 started predicting celestial events according to mean, or clock, time instead of apparent, or sundial, time. Sadler, *Man is Not Lost* (note 21 above), p. 12. Thereafter "Greenwich Mean Time" became a familiar expression for navigators. The U.S. Navy began publishing its annual *American Ephemeris and Nautical Almanac* in 1852. Today the U.S. Naval Observatory and the Royal Greenwich Observatory jointly produce their annual ephemerides under a common title, *The Astronomical Almanac*.

39. Moulton, *Journals of the Lewis & Clark Expedition* (note 5 above), 5:98-99.

40. Ferdinand Rudolph Hassler to Robert Patterson, 12 August 1810, in Jackson, *Letters* (note 28 above), 2:556-59.

41. Jefferson to Jose Correa de Serra, 20 July 1816, and to William Clark, 8 September 1816, in Jackson, *Letters* (note 28 above), 2:618-19.

42. Report of Capt. John Pope, Red River-Rio Grande Route, *Reports of Explorations and Surveys to Ascertain the Most Practicable and Economical Route for a Railroad from the Mississippi River to the Pacific Ocean, 1853-1854*, 12 vols. (Washington: House of Representatives, Executive Document No. 91) 2:1-2.

43. Isaac Stevens to Jefferson Davis, 4 August 1854, in *Pacific Railroad Reports* (note 42 above), 1:450.

44. J.W. Powell, *The Exploration of the Colorado River and its Canyons* (1875; rpt. New York: Penguin Books, 1987), pp. 119, 183. Powell (p. 237) also reported trying on 7 August 1869, to get his longitude from an almanac-predicted eclipse of the sun, but the event was clouded out.

45. Herbert L. Gregory, ed., "Diary of Almon Harris Thompson," *Utah Historical Quarterly* 7 (nos. 1, 2, and 3, January, April, and July, 1939): 100.

46. Howse, *Greenwich Time* (note 2 above) p. 163-64.