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Navigation Technology in the 1500s and the Age of Exploration **Date:** ______________________

By National Park Service
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By the dawn of the 16th century, the ancient art of navigation had begun to develop rapidly in response to oceanic explorers who needed to find their positions without landmarks, to determine the locations of their discoveries, and to establish routes between the new-found lands and home. Although the relationship of certain heavenly bodies to time of day and terrestrial directions had been known since ancient times, the first two decades of the 16th century saw the rigorous application of astronomy and mathematics to navigation. The new learning met the New World.

Navigation is based largely on the spherical coordinates latitude - angular distance north or south of the equator - and longitude - angular distance east or west of a generally accepted reference location, such as the Greenwich Observatory. Finding longitude requires comparing local time, measured by a heavenly body, with the local time at a reference location, kept by a clock. Mechanical timepieces existed in the Elizabethan era, but until the late 18th century they had to be corrected frequently by sun sightings and were therefore almost useless aboard ship. Measuring latitude, on the other hand, does not require an accurate timepiece. Refinement of instruments enabled 16th-century mariners to determine latitude with reasonable accuracy. Latitude was therefore extremely important to Elizabethan navigation.

Unable to use the latitude-longitude system to the fullest, 16th-century navigators supplemented latitude with a rho-theta (distance-and-bearing) system - dead (from deduced) reckoning. Beginning at a known or assumed position, the navigator measured, as best he could, the heading and speed of the ship, the speeds of the ocean currents and the leeward (downwind) drift of the ship, and the time spent on each heading. From this information he could compute the course he had made and the distance he had covered. Dead reckoning, through educated guesswork, is often very accurate. It is still practiced on ships and aircraft, and it lies at the heart of modern doppler and inertial navigational equipment. Errors tend to accumulate in dead reckoning, so its accuracy depends in part on the length of the voyage and the ability of the navigator to use latitude and other information to limit error. But above all else, dead reckoning depends on reliable instruments.

Instruments for measuring latitude

The celestial globe was a mounted sphere depicting the heavens instead of the earth. While many were designed to grace private libraries, some were used as navigational instruments. With the introduction by Gerardus Mercator, in 1569, of practical, affordable sea charts, on which were shown parallels of latitude and meridians of longitude, the costly and delicate celestial globe gradually fell out of use.

The astrolabe was used to determine latitude by measuring the angle between the horizon and Polaris, also called the North Star, the Pole Star, or Stella Maris (Star of the Sea). Polaris was the preferred star for measuring latitude because it is less than one degree from the north celestial pole (the point in the heavens directly above the geographic north pole).

The astrolabe is an instrument of some antiquity; Persian models dating as far back as the 11th century have been found, and Englishman Geoffrey Chaucer wrote a Treatise on it in the late 1300s. By the Elizabethan era it consisted of a large brass ring fitted with an alidade or sighting rule. The user held the astrolabe by a loop at the top, turned the alidade so that he could sight the star along its length, and read the altitude off the scale engraved on the ring - difficult tasks to perform on the deck of a heaving ship. The consequences of imprecise measurement are serious (a latitude reading just one degree off produces an error in position of 60 nautical miles), so mariners often used the astrolabe in pairs, one to sight along the alidade, the other to steady the instrument and take readings. On shore, however, the astrolabe was easier to use and more accurate.

The quadrant, shaped like a quarter-circle, was another hand-held instrument of wood or brass. The user measured the altitude of Polaris by sighting through a peephole and taking a reading where a short plumb line intersected the scale on the outer edge of the arc.

The cross-staff had developed from the 10th-century Arab kamal. It consisted of a square staff 3.5-4 feet in length, bearing a scale, with four sliding cross-pieces or transversals of graduated lengths. Only one transversal was used at a time, its selection being based upon the height of the heavenly body in the sky - the higher the body, the longer the transversal. The user held on end of the staff to his eye, then slid the transversal onto the far end and moved it back and forth until its upper and lower edges seemed to touch, respectively, the observed body and the horizon. The location of the transversal on the scale was converted by a table into degrees of latitude.

Polaris is often obscured by clouds, fog, or daylight, and it is below the horizon for anyone in the Southern Hemisphere. Darkness often makes the horizon hard to find. So navigators learned to use the astrolabe, quadrant, and cross-staff with the sun. A piece of smoked glass was frequently used to keep the user from blinding himself. Under lock and key, for use by the captain and pilot only, were highly prized declination tables or astronomical charts showing calculated heights of the sun above the equator at noon for every day of the year.

The magnetic compass

The foregoing instruments provided invaluable information, but their use depended on the visibility of heavenly bodies. As a result, mariners relied on the magnetic compass, an instrument developed, probably independently, by Chinese in the 11th century and Europeans in the 12th. Day or night, fair weather or foul, Northern or Southern hemisphere, the compass always points more or less north. At first compasses seem to have been used mainly to measure wind direction, but mariners soon found them much more beneficial when used for finding headings.

A typical 16th-century compass consisted of a large magnetized needle fastened to the underside of a circular card on which the several directions were drawn. The compass rose, as it was sometimes called, usually had thirty-two points 11.25 degrees apart - north, north by east, north by northeast, and so on. (Sailors learned early in their careers to "box the compass," that is, recite all the points in order.) The needle was pivoted on a fine brass pin to enable it to swing freely. The compass card was suspended by gimbals (concentric mounting rings), which allowed the card to remain level regardless of the motion of the ship. The mechanism was kept in an open-topped box attached to a small cupboard called a bittacle (later binnacle), which was fixed to the deck in front of the helm. A lodestone, or piece of naturally magnetic iron ore, was used to re-magnetize the compass needle.

Christopher Columbus said that the compass "always seeks the truth." Unlike the modern gyroscopic compass, however, the magnetic compass does not always seek true north. The magnetic pole is not at the top of the world, but an ever-changing distance away in the Canadian Arctic. Local variations in the magnetic field of the earth produce different errors at different spots. This fact was recognized in the 15th century. The North Star gives a good approximation of true north, so compass variation was easy to measure even in the Elizabethan era. Instructions for an Atlantic voyage planned by Sir Humphrey Gilbert in 1582 list many pieces of navigational gear, including "An instrument for the variation of the compass." In his "Briefe and True Report" (1588), Thomas Hariot, chief scientist for the Lane colony (1585-1586), mentions "Mathematicall instruments," which undoubtedly included such a device. Some mariners mounted the needle on the compass card so as to take local compass variation into account and make the card indicate true north. This practice caused problems, especially when mariners tried to sail unfamiliar vessels or when coasting vessels made transoceanic voyages. (Compasses adjusted for the easterly variation found in Great Britain, for example, gave unsatisfactory readings in parts of North America with westerly variation.) Using several interchangeable cards with needles mounted at different angles for different degrees of variation did little to reduce confusion.

Instruments for measuring time

Accurate time is essential to dead reckoning. Water clocks (clepsydras) and portable sundials suffered obvious disadvantages aboard ship, so the sandglass or hourglass was the timepiece most often used in navigation. The most common glasses were the four-hour and half-hour sizes. Days at sea were divided into six four-hour shifts or watches. A ship's boy carefully tended the half-hour glass, turning it as soon as the sand had run through and calling out or striking a bell for all aboard to hear. At the end of four hours, he turned the four-hour glass. (Hence the system of bells and watches still used aboard many vessels.) The texture of the sand could affect its rate of flow, as could condensation within the glass, so several glasses were used together for accuracy.

The glass was used in combination with the log, a piece of wood attached to a line knotted at uniform intervals. A sailor heaved the log from the stern of the ship and let the line pay out freely as the ship pulled away. When the sailor felt the first knot pass through his fingers, he shouted a signal to another sailor, who turned a one-minute glass. The first sailor counted aloud the number of knots that passed until the sand ran out. A timer of one minute (one-sixtieth of an hour), knots spaced one-sixtieth of a nautical mile apart, and simple arithmetic easily gave the speed of the ship in nautical miles per hour ("knots").

The nocturnal consisted of two concentric plates of brass or wood, the larger divided into twelve equal parts corresponding to the months of the year, the smaller into 24 parts corresponding to hours of the day. By lining up a sighting mechanism with Polaris or certain stars in Ursa Major or Ursa Minor, the user could determine the time of night with reasonable accuracy.

Other tools

Charts not only gave the mariner an idea of where he was going, but also a means of plotting his past and present positions. Cartographers and mariners endured many of the same problems, such as inability to determine precise longitude. Consequently, most 16th-century charts were not very accurate by modern standards. To make matters worse, cartographers often copied from one another, used information from unreliable sources, and relied on their own imaginations to fill in gaps in coverage.

The traverse board was used to approximate the course run by a ship during a watch. It consisted of a circular piece of wood on which the compass points had been painted. Eight small holes were evenly spaced along the radius to each point, and eight small pegs were attached with string to the center of the board. Every half-hour one of the pegs was stuck into the next succeeding hole for the compass point closest to the heading the ship had maintained during that half hour. At the end of that watch, a general course was determined from the position of the pegs. With speed information from the long and line, the traverse board served as a crude dead-reckoning computer reminiscent of those used to this day aboard aircraft.

Used to find depth and seabed characteristics, the lead and line was an ancient, but highly useful navigational aid. It consisted of a sounding lead attached to a line with evenly spaced knots or bits of colored cloth worked into it. The lead was tossed overboard and allowed to sink to the sea floor. Each mark was distinctive, and the distance between successive marks was constant; so water depth could easily be measured ("by the mark") or estimated ("by the deep"). When hauled aboard, the lead, by virtue of tallow packed into a small depression in its bottom, brought up a sample of the sea bed, useful in finding a safe anchorage.

Albeit not a navigational instrument, the boatswain's pipe was a tool of great value. This peculiarly shaped whistle was used by the boatswain (the contraction bos'n was not used in the 16th century) to pipe orders throughout the ship. Its high-pitched sound was usually audible, even above the howling of the wind, to crewmen working high in the rigging.

The ship's log contained a record of courses, speeds, soundings, and other relevant information. A good log was sufficiently accurate and comprehensive to allow the navigator to check his dead reckoning