The History of the Sextant



New 2025

Photo by David Smith

By Peter Ifland

Introduction

"Where are we?" Normally, this is a routine question answered several times a day while saling along safely in mid ocean. But the question has a different urgency when the ship is

approaching a rocky coast and the life of the ship and its crew depends on a fast and accurate fix of position. It's the Navigator's job to provide the answer.

So what do navigators need to find their position on the earth's surface by observing the stars?

They need an Almanac prepared by the astronomers to forecast precisely where the heavenly bodies, the sun, moon planets and selected navigational stars, are going to be, hour by hour, years into the future, relative to the observatory that prepared the almanac, Greenwich, England in modern times.

They need a chronometer or some other means of telling the time back at the observatory that was the reference point for the data in the almanac,

It is the cartographer's job to provide accurate charts so that navigators can establish their position in latitude and longitude or in reference to landmasses or the hazards of rocks and shoals.

The navigators need a quick and easy mathematical method for reducing the data from their celestial observations to a position on the chart

Finally, navigators need an angle-measuring instrument, a sextant, to measure the angle of the celestial body above a horizontal line of reference.

How <u>do</u> navigators use the stars, including our sun, the moon, and planets to find their way? Well, for at least two millennia, navigators have known how to determine their latitude-their position north or south of the equator. At the North Pole, which is 90 degrees latitude, Polaris (the North Star) is directly overhead at an altitude of 90 degrees. At the equator, which is zero degrees latitude, Polaris is on the horizon with zero degrees altitude. Between the equator and the North Pole, the angle of Polaris above the horizon is a direct measure of terrestrial latitude. If we were to go outside tonight and look in the northern sky, we would find Polaris at the latitude where we are at that moment.

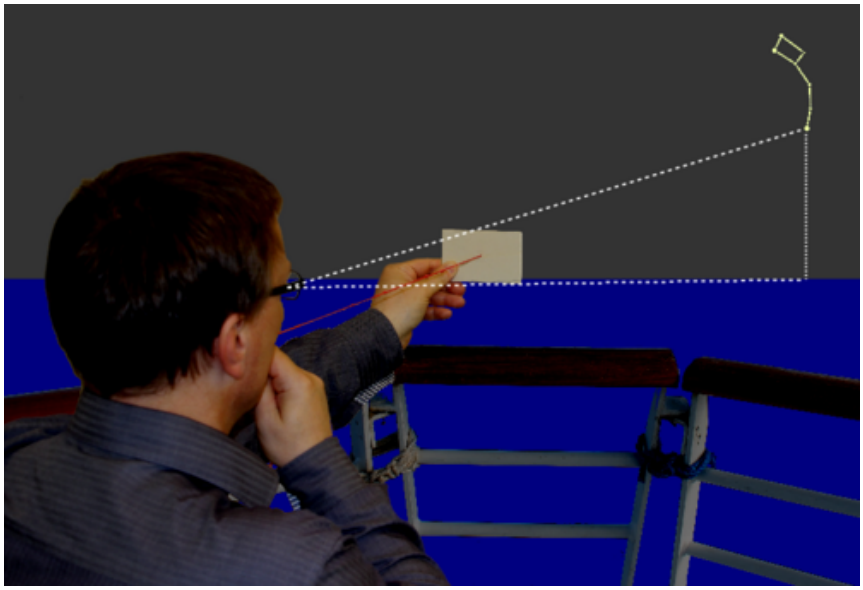
In ancient times, the navigator who was planning to sail out of sight of land would simply measure the altitude of Polaris as he left homeport, in today's terms measuring the latitude of home port. To return after a long voyage, he needed only to sail north or south, as appropriate, to bring Polaris to the altitude of home port, then turn left or right as as appropriate and “sail down the latitude,” keeping Polaris at a constant angle.

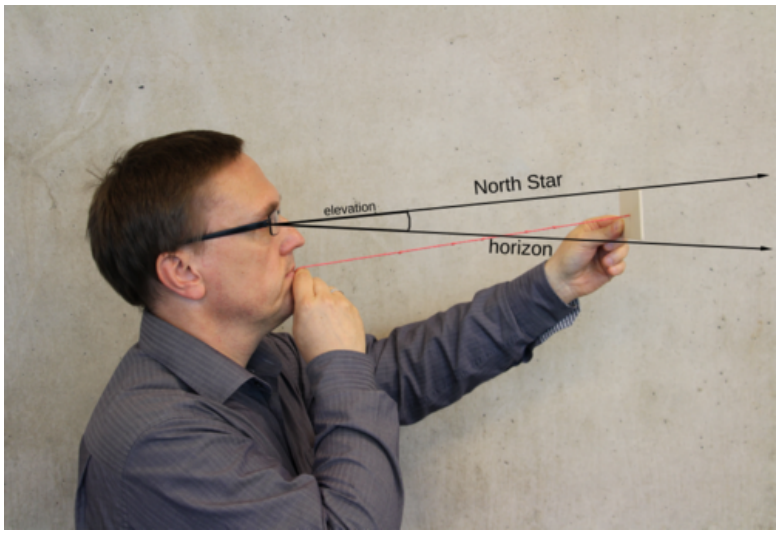
The Arabs knew all about this technique. In early days, they used one or two fingers width, a thumb and little finger on an outstretched arm or an arrow held at arms length to sight the horizon at the lower end and Polaris at the upper end.



An Arabic Kamal

In later years, they used a simple device called a ***kamal*** to make the observation. The ***kamal*** shown here actually is a modern piece that I made, but it's very much like the ones used a 0thousand years ago, and probably much earlier. Notice the knots in the cord attached to the carved mahogany transom. Before leaving homeport, the navigator would tie a knot in the cord so that, by holding it in his teeth, he could sight Polaris along the top of the transom and the horizon along the bottom.





To return to homeport, he would sail north or south as needed to bring Polaris to the altitude he'd observed when he left home, then sail down the latitude. Over time, Arab navigators started tying knots in the string at intervals of one ***issabah***. The word ***issabah*** is Arabic for finger, and it denotes one degree 36 minutes, which was considered to be the width of a fing5er. They even developed a journal of different ports that recorded which knot on the ***kamal*** corresponded to the altitude of Polaris for each port they frequently visited.

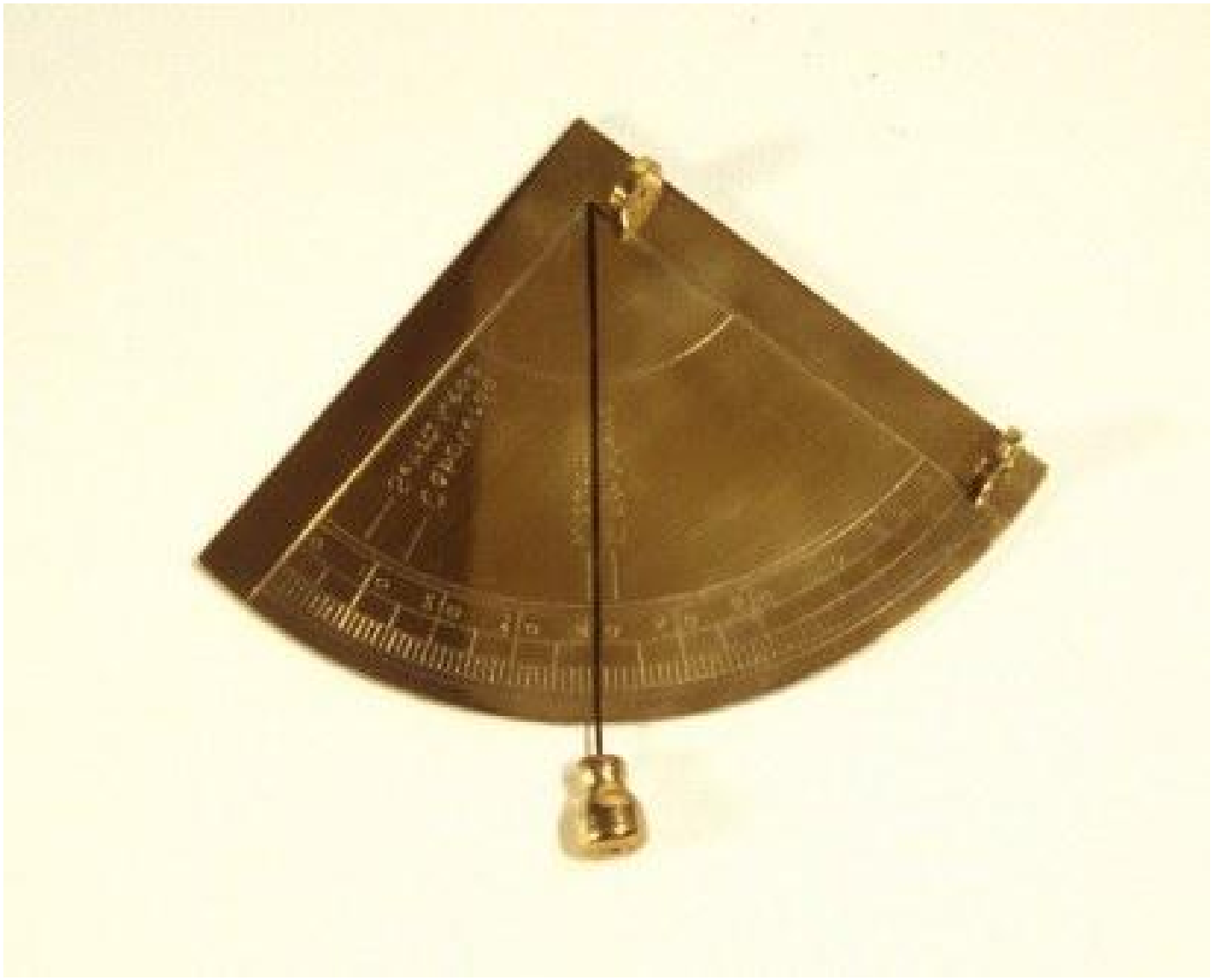
Throughout antiquity, the Greeks and Arabs steadily advanced the science of astronomy and the art of astrology. About a thousand years ago, in the 10th century, Arabs introduced Europe to two important astronomical instruments-the quadrant and the astrolabe.



Astronomers Astrolabe

In the word "*astrolabe*" - "*astro* means `star' and "*labe*" roughly translates as `to take' or 'to find.' Here is a photograph of a relatively recent Arabic astronomer's astrolabe made by Hajji Ali of Kerbala around 1790. It's about three and one-half inches in diameter. It was used to find the time of rising and setting of the sun and the altitude of the sun and selected stars. Importantly, it was used to find the direction of Mecca for the devout Moslem's morning and evening prayers.

The astronomer's beautiful, intricate and expensive astrolabe was the grandfather of the much simpler, easy to use mariner's quadrant and astrolabe. The mariner's quadrant-a quarter of a circle made of wood or brass--came into widespread use for navigation around 1450, though its use can be traced back at least to the 1200s.



Mariner's brass quadrant

Here is photograph of a mariner's brass quadrant. The scale spans 90 degrees and is divided into whole degrees. A plumb bob establishes a vertical line of reference.

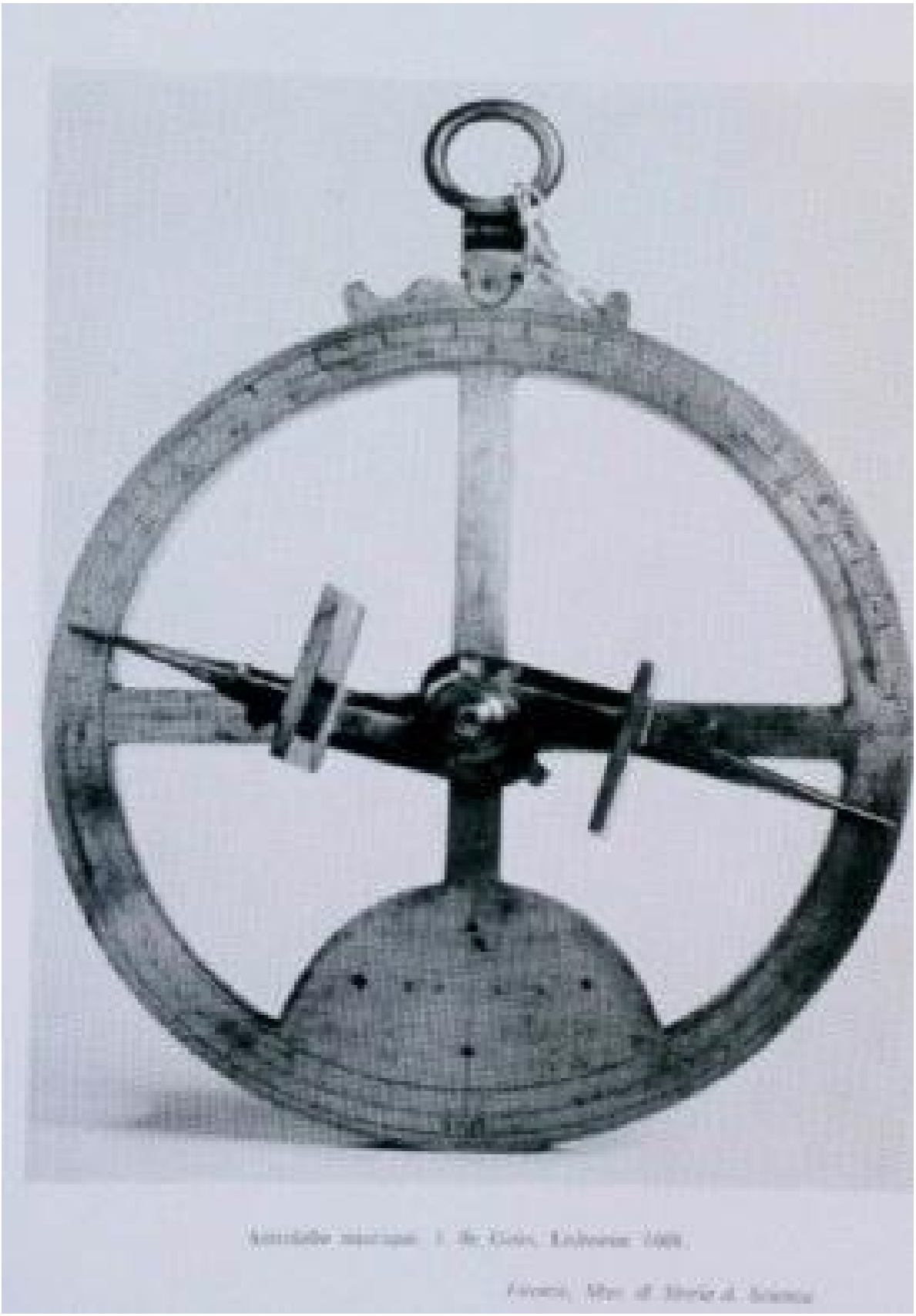
The quadrant was a popular instrument with Portuguese explorers. The one you see in the slide is a replica of the type Columbus might have used on his voyages to the New World. Columbus would have marked the observed altitude of Polaris on his quadrant at selected ports of call just as the Arab seaman would tie a knot in the string of his ***kamal***. This one is marked off at the latitudes of Lisbon, Cabo Verde and Serra Leoa, down near the Equator where Columbus is known to have visited.

Alternatively, the navigator could record the ***altura***, or altitude, of Polaris quantitatively in degrees at Lisbon and at other ports to which he might wish to return. It wasn't long before lists of the ***alturas*** of many ports were published to guide the seafarer up and down the coasts of Europe and Africa.

During the 1400's, Portuguese explorers were traveling south along the coast of Africa searching for a route to the orient. As a seafarer nears the equator heading south, Polaris disappears below the horizon. So, in southern seas, mariners had to have a different way of finding their latitude. By 1480, Portuguese astronomers had figured out how to determine latitude using the position of the sun as it moved north and south of the equator with the seasons, what we now call its "declination." In simple terms, the navigator could determine his ***altura***, his latitude, by using his quadrant to take the altitude of the sun as it came to it's greatest altitude at local apparent noon, and then making a simple calculation using the declination of the sun north or south of the equator according to the date.

The mariner's quadrant was a major conceptual step forward in seagoing celestial navigation. Like the knots-in-a string method of the Arab ***kamal***, the quadrant provided a quantitative measure, in degrees, of the altitude of Polaris or the sun, and related this number to a geographic position - the latitude - on the earth's surface. But for all its utility, the quadrant had two major limitations: On a windy, rolling deck, it was hard to keep it exactly vertical in the plane of a heavenly body. And it was simply impossible to keep the wind from blowing the plumb bob off line. The solution was the mariner's astrolabe.

Here is a beautiful mariners' astrolabe made in Lisbon by J. de Goes in 1608, now in the Museum of the History of Science, Florence, Italy:



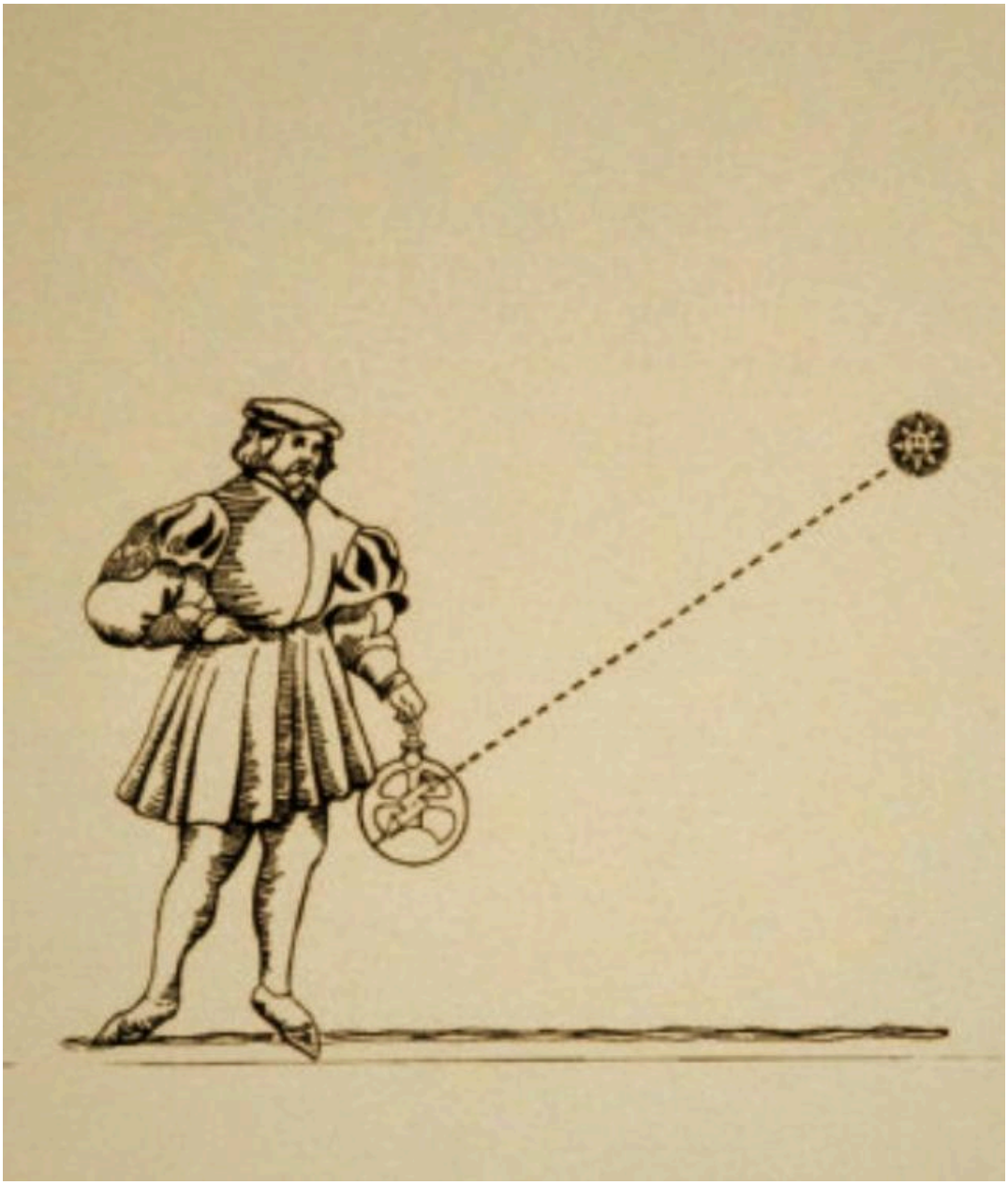
Astrolabe nocturne. J. de Gein, Enkhuizen 1601.

Firenze, Mus. di Storia d. Scienza

Mariner's Astrolabe by J. de Goes in 1608

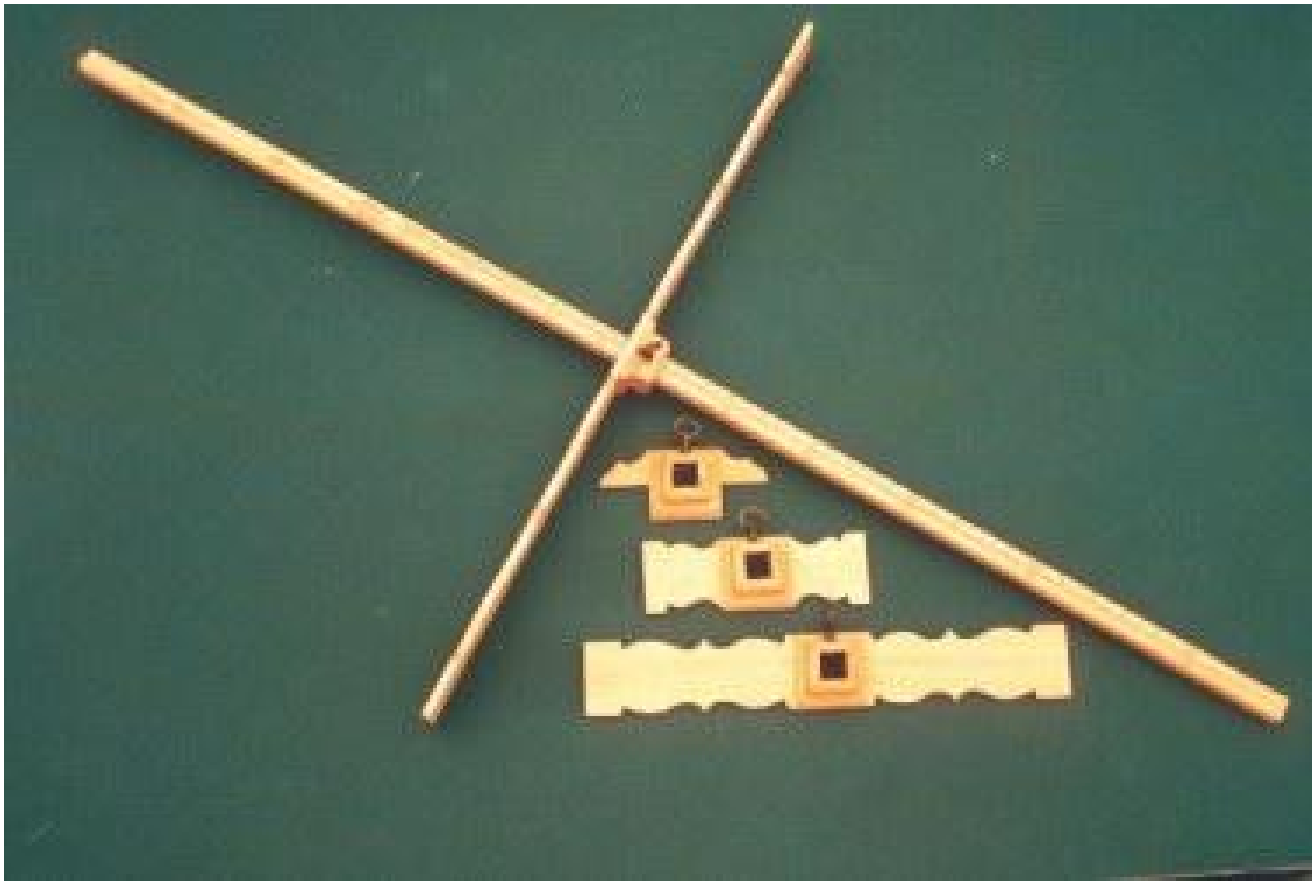
Mariner's astrolabes are now very rare and expensive - less than one hundred are known to survive and most of these are in poor condition having been recovered from ship wrecks.

The seagoing astrolabe was a simplified version of the much more sophisticated Middle Eastern astronomer's astrolabe that we saw a moment ago. All the complex scales were eliminated, leaving only a simple circular scale marked off in degrees. A rotatable alidade carried sighting pinnules. Holding the instrument at eye level, the user could sight the star through the pinnules and read the star's altitude from the point where the alidade crosses the scale.



An astrolabe in use.

For a sun sight, the astrolabe was allowed to hang freely and the alidade was adjusted so that a ray of sunlight passed through the hole in the upper vane and fell precisely on the hole in the lower vane.
The astrolabe was popular for more than 200 years because it was reliable and easy to use under the frequently adverse conditions aboard ship.



A cross-staff.

The next step in the evolution of celestial navigation instruments was the cross-staff, a device resembling a Christian cross. This one is a modern reproduction in the style popular with Dutch navigators in the eighteenth century. Interestingly, its operating principle was the same as that of the ***kamal***. The vertical piece, the transom or limb, slides along the staff so that the star can be sighted over the upper edge of the transom while the horizon is aligned with the bottom edge.

The Persian mathematician Avicenna wrote about a cross-staff in the eleventh century. The concept probably arrived in Europe when Levi ben Gerson, working in the Spanish school at Catalan in 1342, wrote about an instrument called a ***balestilla*** that he described as a being made from a “square stick” with a sliding transom.



A cross-staff in use

This drawing, from a Spanish book on navigation published in 1552, shows how the cross-staff was used to determine the altitude of Polaris. If you've ever heard the phrase "shooting the stars," it comes from the practice of holding a cross-staff up to the user's eye with one hand, with the transom grasped in the other hand so that the person looks like an archer taking aim at the star.

Early cross-staffs had only two pieces - the staff and one transom. Over time they became more elaborate. After 1650, most "modern" cross-staffs have four transoms of varying lengths. Each transom corresponds to the scale on one of the four sides of the staff. These scales mark off 90, 60, 30, and 10 degrees, respectively. In practice, the navigator used only one transom at a time.

The major problem with the cross-staff was that the observer had to look in two directions at once - along the bottom of the transom to the horizon and along the top of the transom to the sun or the star. A neat trick on a rolling deck!



Davis quadrant

One of the most popular instruments of the seventeenth century was the Davis quadrant or back-staff. Captain John Davis conceived this instrument during his voyage to search for the Northwest Passage. It was described in his ***Seaman's Secrets*** published in 1595. It was called a quadrant because it could measure up to 90 degrees, that is, a quarter of a circle. The observer determined the altitude of the sun by observing its shadow while simultaneously sighting the horizon. Relatively inexpensive and sturdy, with a proven track record, Davis quadrants remained popular for more than 150 years, even after much more sophisticated instruments using double-reflection optics were invented. An English craftsman named Walter Henshaw made the one you see in the slide in 1711. It's made of rosewood with a diagonal scale on boxwood.

One of the major advantages of the Davis back-staff over the cross-staff was that the navigator had to look in only one direction to take the sight - through the slit in the horizon vane to the horizon while simultaneously aligning the shadow of the shadow vane with the slit in the horizon vane.

The major problem with back-sight instruments was that it was difficult if not impossible to sight the moon, the planets or the stars. Thus, toward the end of the 1600's and into the 1700's, the more inventive instrument makers were shifting their focus to optical systems based on mirrors and prisms that could be used to observe the nighttime celestial bodies.

The critical development was made independently and almost simultaneously by John Hadley in England and by Thomas Godfrey, a Philadelphia glazier, about 1731. The fundamental idea is to use of two mirrors to make a doubly reflecting instrument-the forerunner of the modern sextant.

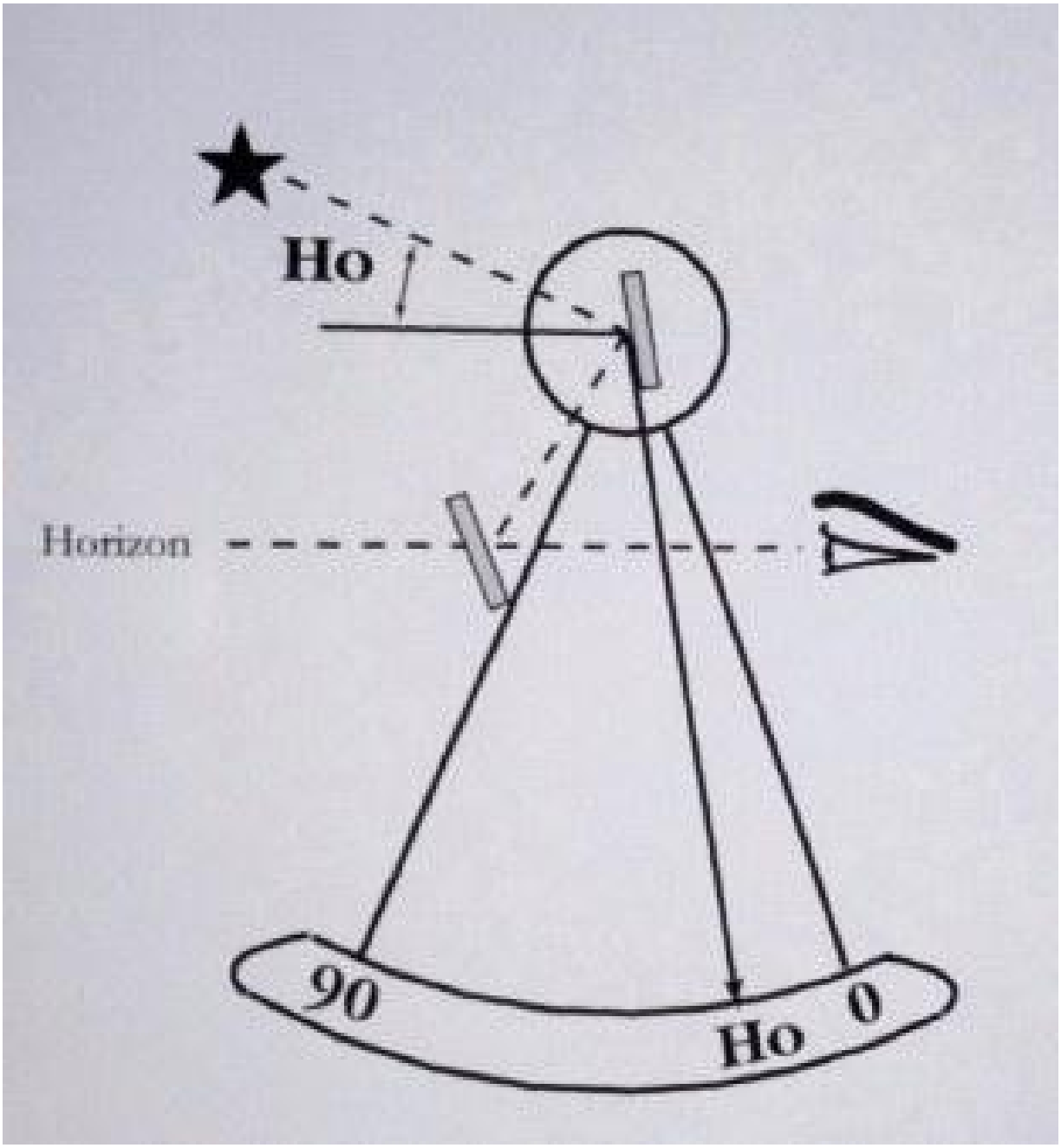


Diagram of sextant

How does such an instrument work? Hold the instrument vertically and point it toward the celestial body. Sight the horizon through an unsilvered portion of the horizon mirror. Adjust the index arm until the image of the sun or star, which has been reflected first by the index mirror and second by the silvered portion of the horizon mirror, appears to rest on the horizon. The altitude of the heavenly body can be read from the scale on the arc of the instrument's frame.

Hadley's first doubly reflecting octants were made from solid sheets of brass. They were heavy and had a lot of wind resistance. Lighter wooden instruments that could be made larger, with scales easier to divide accurately and with less wind resistance quickly replaced them.



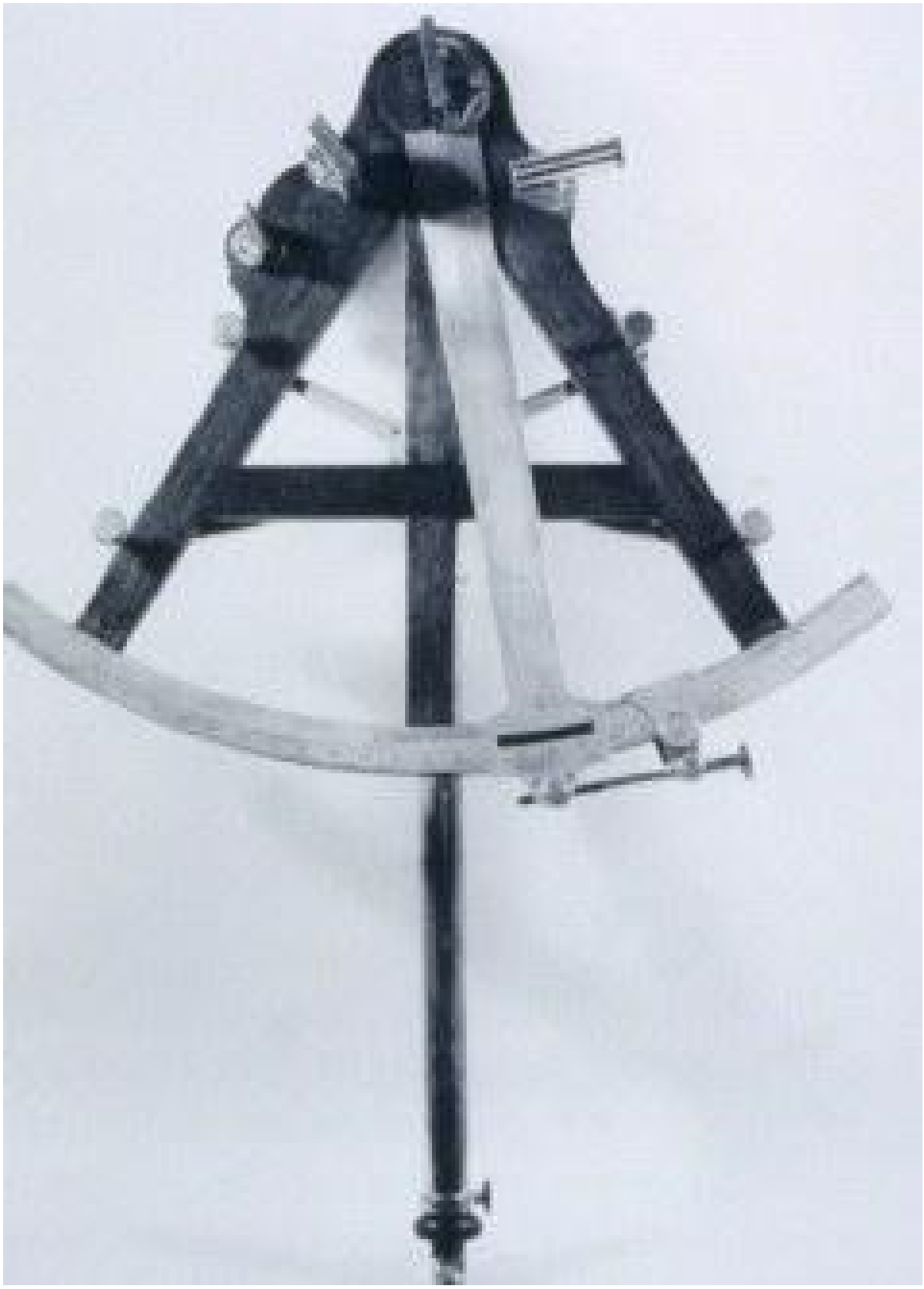
An Early Hadley octant.

This mahogany octant was made about 1760 by the famous London maker, George Adams.

Hadley' octant of 1731 was a major advancement over all previous designs and is still the basic design of the modern sextant. It was truly a “point and shoot” device. The observer looks at one place - the straight line of the horizon sighted through the horizon glass alongside the reflected image of the star. The sight is easy to align because the horizon and the star seem to move together as the ship pitches and rolls.

We have seen how navigators could find their latitude for many centuries but ships, crews and valuable cargo were lost in shipwrecks because it was impossible to determine longitude accurately. Throughout the seventeenth century and well into the eighteenth century, there was an ongoing press to develop techniques for determining longitude. The missing element was a way to measure time accurately. The clock makers were busy inventing ingenious mechanical devices while the astronomers were promoting a celestial method called "lunar distances". Think of the moon as the hand of a clock moving across a clock face represented by the other celestial bodies. Early in the 18th century, the astronomers had developed a method for predicting the angular distance between the moon and the sun, the planets or selected stars. Using this technique, the navigator at sea could measure the angle between the moon and a celestial body, calculate the time at which the moon and the celestial body would be precisely at that angular distance. This gives the time back at the national observatory at the moment that the observation was taken which is then compared with the ship's chronometer. Knowing the correct time, the navigator could now determine longitude. When the sun passes through the observer's meridian, the local solar time is 1200 noon and this is compared to Greenwich Mean Time. Remembering that 15 degrees of longitude is equivalent to one hour of time gives us the longitude east or west of Greenwich. The lunar distance method of telling time was still being used into the early 1900's when it was finally replaced by time by radio telegraph.

An octant measures angles up to 90 degrees and is ideally suited for observations of celestial bodies above the horizon. But a greater angle range is needed for lunar distance observations. It was a simple matter to enlarge Hadley's octant, an eight of a circle, to the sextant, a sixth of a circle, that could measure up to 120 degrees.



An early sextant by John Bird

The first sextant was produced by John Bird in 1759. This is a very early example of his work, now in the Nederlands Scheepvaart Museum in Amsterdam. The frame is mahogany with an ivory scale. It is so large and heavy that it needed a support that fitted into a socket on the observers belt.



A brass sextant by Dollond

Here's a fine brass sextant from the early nineteenth century by the master London instrument maker John Dollond.



An ebony sextant

In the first half of the eighteenth century there was a trend back to wooden frame octants and sextants to produce lighter instruments compared to those made of brass. Here is a very handsome example by H. Limbach of Hull of a sextant with an ebony frame. Ebony was used because of the dense wood's resistance to humidity. The scale and vernier were divided on ivory, or should we now say bone. The design was not successful because the wood tended to split over the long arc of a sextant.



Examples of sextant frame designs

Here is a sample of variations in frame design. The challenge was to produce sextant frames that were light weight, low wind resistance and with a minimum change is dimensions with changes in temperature. As you can see, some of them are quite esthetically pleasing.



Ramsden pentant.

Probably the finest 18th century instrument maker was the Englishman Jesse Ramsden. His specialty was accurate scale division. Here's a small brass sextant that Ramsden made shortly before his death in 1800. Ramsden's major achievement was to invent a highly accurate "dividing engine"-the apparatus used to divide the scale into degrees and fractions of degrees. His design was considered so ingenious that the British Board of Longitude awarded Ramsden a

prize of 615 pounds-in 18th century terms, a small fortune. His "dividing engine" now resides in the Smithsonian Institution in Washington.

The development of more precise scale division was a milestone in instrument development. Certainly, it permitted more accurate observations but it also permitted smaller, lighter, more easily handled instruments. The sextant you see here is my all-time favorite. To be correct, the instrument should be called a pentant, a fifth of a circle, rather than a sextant. This jewel is only 4 1/2 inches radius. The scale is divided on silver from minus 5 degrees to 155 degrees with each degree further divided in three to 20 arc minutes. As you can see, the scale is beveled at 45 degrees. Why set the scale at an angle to the frame - perhaps just to show that he could do it!



Modern sextant

The standard of excellence for post World War II sextants was established by the C. Plath firm in Germany. Here's an example from 1988. Among its attachments are an unsilvered horizon glass that lets the observer see the full horizon as a straight line across the round horizon glass; an astigmatizer lens that distorts the image of a star into a straight line for precision alignment with the line of the horizon; a quick-release drum micrometer that reads to one-tenth of an arc minute. There's also a battery-supplied lighting system for the drum micrometer and the

bubble artificial horizon attachment. This attachment and a monocular telescope complete the kit. But, for all the fancy modern refinements, the optical system is exactly what John Hadley proposed in 1731.

The problem of finding your location when you can't see the horizon to take a sun or star sight has challenged explorers, map makers and navigators for hundreds of years. Early in the 1730s instrument makers began developing artificial horizons for use with quadrants. Of course, the explorers and mapmakers working inland could not use the horizontal line to the natural horizon of the sea and so they needed an artificial horizon to establish a line of reference for measuring the altitude of celestial bodies.



Mercury artificial horizon

Here is a very elegant three-piece explorer and mapmaker's kit by Carey of Pall Mall, London from 1880. The instrument is a pentant, a fifth of a circle capable of measuring angles up to 170 degrees; mounted on a collapsible aluminum stand. Around the base you can see the parts of the

mercury bath artificial horizon. Mercury was poured from the iron bottle into the trough to form a shiny horizontal surface to catch the reflection of the celestial body. The triangular glass tent was placed over the trough to keep the wind from disturbing the surface.



A mercury artificial horizon in use

Here you see the famous American explorer, John Charles Freemont, using a sextant and mercury artificial horizon to find his position during his expedition of 1842 to map the Oregon Trail. The sextant had to be pointed downward to view the reflection of the celestial body on the surface of the mercury pool through the clear portion of the horizon glass while simultaneously adjusting the index system to bring the image reflected by the two mirrors alongside. The mercury artificial horizon was popular with explorers for more than a century but it was hard to use on shipboard with a rolling deck.

A little earlier, we were talking about the explorers' and mapmakers' need for an artificial horizon when they couldn't see the natural horizon. Well, there are two classes of modern navigators who absolutely need an artificial horizon - the aviators and the submariners. Aviators find the natural horizon so far below them that it is useless and furthermore, they are frequently flying above the clouds. Conversely, even on the surface, submariners are so low in the water that a sight to the horizon is unreliable. In fact, it is the unique needs of the aviator that has driven sextant innovation throughout the twentieth century.

For a while, balloonists of the late nineteenth century tried to use conventional sea-going sextants but their need for artificial horizon instruments soon became apparent.



Balloon sextants

Here are some examples: The optical concept of these instruments is to the reflect the image of a bubble from a small spirit-level into the line of sight so that the bubble and the celestial body can be viewed simultaneously. The one at the top, from 1880, is derived from an instrument invented by Captain Abney many years earlier for use in chart making. The black instrument is by Cary of London, 1900, and the one at the bottom is one of their later models with an electrical lighting system from 1910 - just about the time of the Wright brother's first powered flight.

The rapid development of heavier-than-air craft during World War I lead to airplanes with increasing range and greater need for accurate navigation instruments and techniques, all depending on artificial horizons.

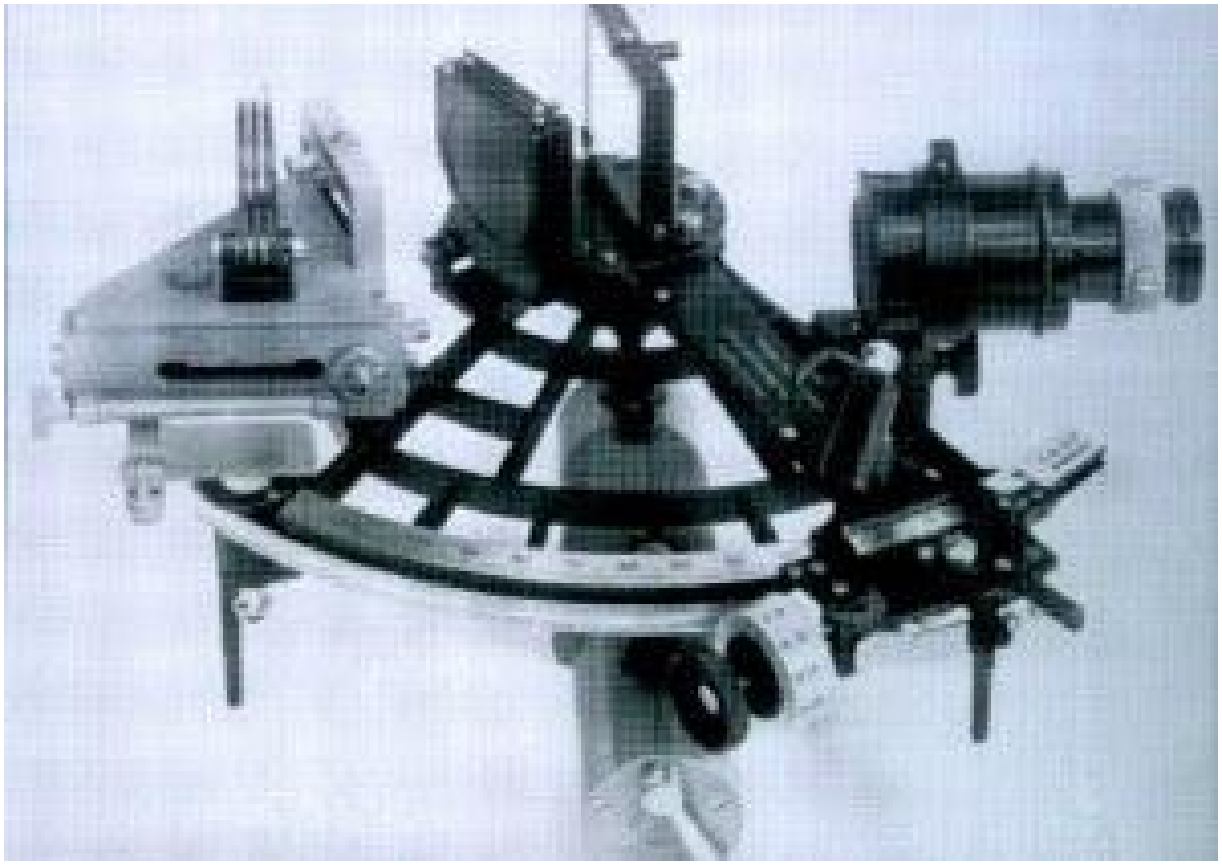


A gyroscopic aircraft sextant.

During the 1920's, the Europeans were very much involved in the innovation of instruments for aircraft navigation. Here is an early 1920's gyroscope sextant by a Parisian company with the descriptive name of La Precision Moderne. A spinning mirror, mounted on the

top of an air driven gyroscope reflects in image of the celestial body into the line of sight, much as with the old-fashioned mercury artificial horizon.

One of the most important pioneering trans-Atlantic flights was by the famous Portuguese aviators, Sachadura Cabral, pilot, and Admiral Gago Coutinho, navigator, in 1919. They flew 11 and one half hours from Cape Verde Islands to Rio de Janeiro carrying an artificial horizon sextant designed by Admiral Coutinho.



The System Gago Coutinho.

The design was based on two spirit level tubes - one to keep the sextant horizontal and the other to keep the sextant vertical. The sextant proved itself again in a flight from Lisbon to Rio de Janeiro in 1927 with Captain Jorge Castilho as navigator. The Portuguese Navy, who had rights to the development, contracted with the prestigious German firm of C. Plath for production. In 1929 Captain Wittenman navigated the Graf Zeppelin around the world using a Coutinho sextant. With this spectacular record, the design was the hit of the 1930 Berlin Air Show. It was used by many of the major airlines of the world throughout the 1930's.



Early bubble sextants with averagers

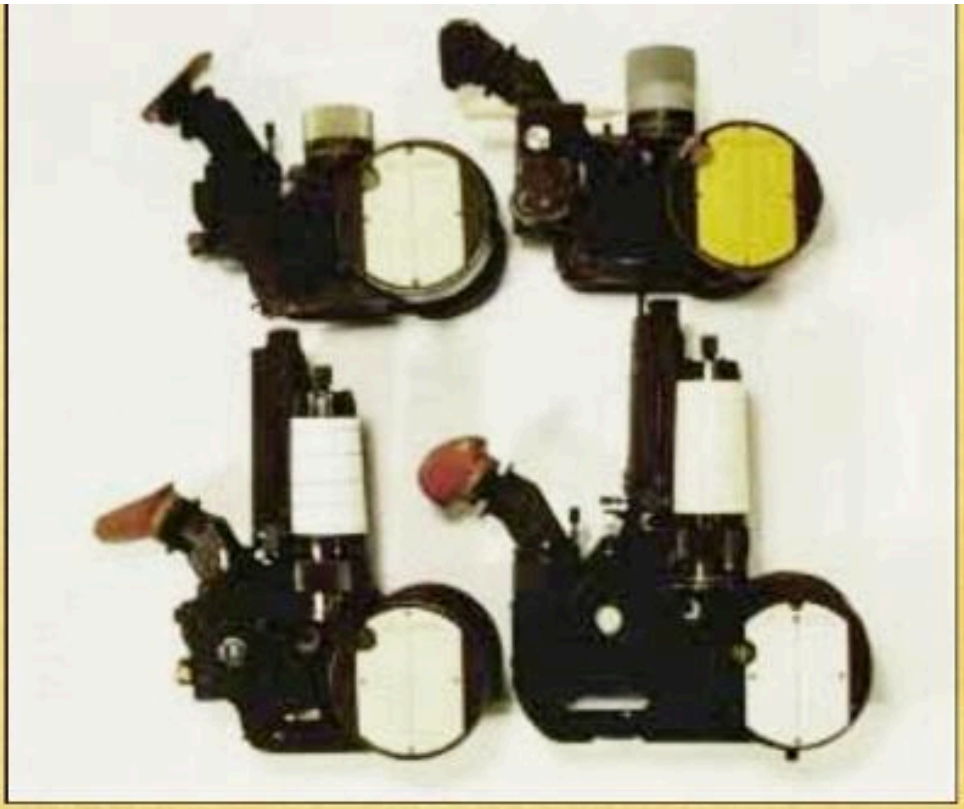
In addition to an artificial horizon, aircraft sextants needed a device to average the values of six or eight sights taken in succession to average out the small errors in aligning the sight and to compensate for the rapid movement of the aircraft. Here are some prewar examples.



WWII Aircraft sextants

Of course, World War II was a powerful influence that produced an explosion of designs and a number of U.S. instrument makers Fairchild, Link, Pioneer and Agfa-Ansco made important improvements. C. Plath in Germany and Tamaya in Japan supplied the Axis

There has been very little evolution of hand-held celestial navigation instruments since the end of World War II. Faster flying aircraft lead to the development of periscope instruments that minimized wind resistance but Radio Direction Finding and then inertial guidance became the standard for aircraft navigation and celestial was no longer needed.



Early bubble sextants with averagers

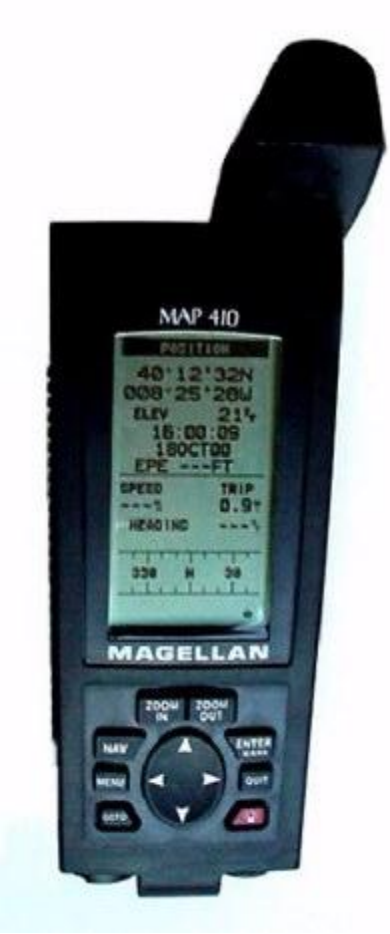


WWII Aircraft sextants

A Gemini IV sextant

The early space flights used an especially designed sextant. In the remoteness of space there is no such thing as "horizontal" or "vertical". Instead, the instrument was designed to measure the angle between the edges of the earth or the angle between celestial bodies to determine the space craft's position in space. But again, electronic techniques for positioning in space became the standard.

So, where are we?



A GPS Instrument.

This little Global Positioning System, or GPS receiver will tell us instantly and with great accuracy. Instead of measuring angles of the celestial bodies above the horizon, it computes our position by measuring the time it takes for radio signals to arrive from three or four of the many man-made satellites that are in known positions in orbit around the earth.

A significant part of the romance of the hand held instruments for taking the stars that we have seen this evening is that they all soon will be obsolete, outmoded by GPS. Yes, there are still quite a few old-line navigators that refuse to give up their nautical almanac, their chronometer and their sextant for this new fangled electronic stuff. What if the batteries go dead or the thing falls overboard? But finally, there is the simple satisfaction of shooting a star, noting the time, reading the almanac and making the calculations to find out where you are.