Chapter 13

SEXTANTS AND ERRORS OF OBSERVATION

Section 13A—Sextants

13.1. Introduction. For hundreds of years, mariners have navigated the seas keeping track of their positions by use of the sextant. This instrument measured the altitude of celestial bodies (angular distance above the horizon) and the information derived from this measurement was used to determine the position of the vessel. All celestial navigation follows this rule. Today's navigator measures the altitude of the celestial bodies in much the same manner as Magellan or Columbus.

13.1.1. However, there is a difference between air and marine celestial navigation. Because marine navigators are on the surface of the ocean, they can establish their horizon by referring to the natural horizon. In an aircraft, this is impossible because altitude and aircraft attitude induce error. In the sextant designed for air navigation, a bubble, like the one in a carpenter's level, determines an artificial horizon, which is parallel to the celestial horizon. The bubble chamber is placed in the sextant so the bubble is superimposed upon the field of view. Both the celestial body and the bubble are viewed simultaneously, making it possible to keep the sextant level while sighting the body.

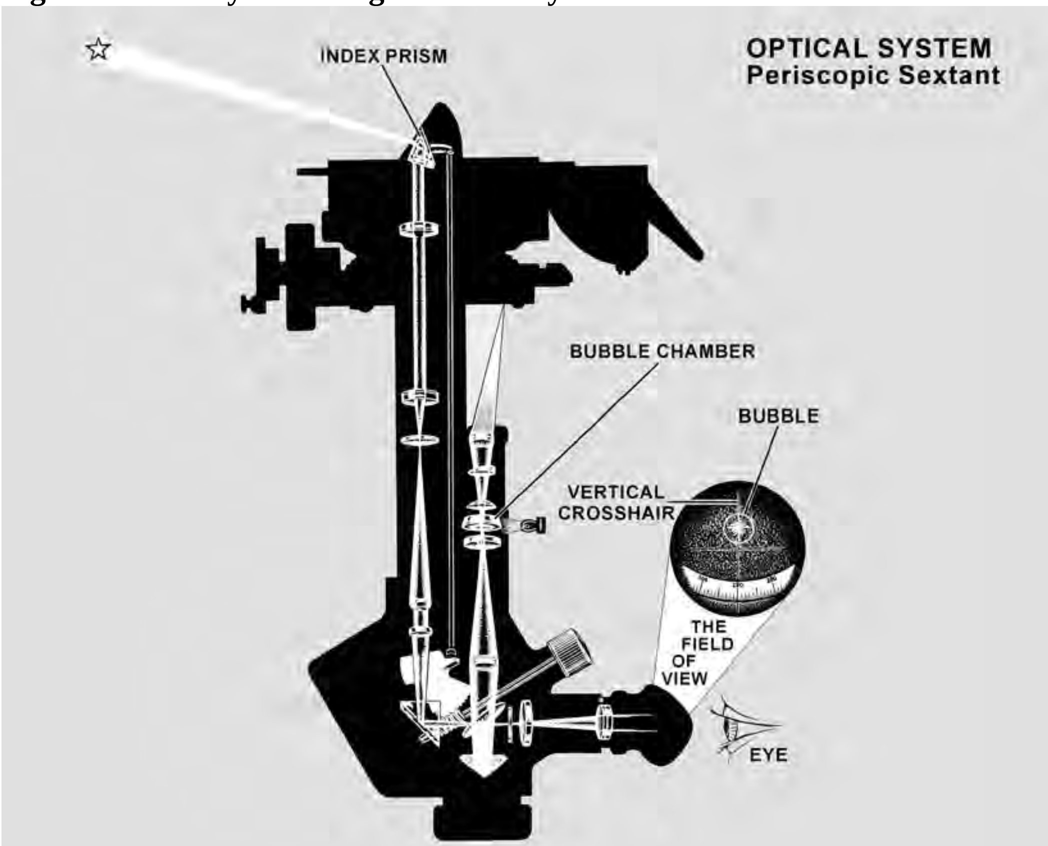
13.1.2. Sextants are subject to certain errors that must be compensated for when determining an LOP. Some of these errors are instrument errors while others are induced by the various in-flight conditions. The first half of this chapter discusses the sextant and the second half explains sextant errors.

13.2. The Bubble Sextant. The aircraft bubble sextant measures altitude above a horizontal plane established by a bubble. Aviators use several types of bubble sextants, all of which are indirect sighting. This means the navigator does not look directly toward the celestial body, but always looks in a horizontal direction as shown in Figure 13.1. The image of the body is reflected into the field of view when the field prism is set at the correct angle. In the bubble sextant, the bubble and body are visible in the same field of view. The sextant system consists of four parts: the mount, the sextant, the electrical cables and the carrying case.

13.3. The Mount. The mount, as shown in Figure 13.2, is fastened permanently to the top of the fuselage of the aircraft. A shutter door is built into the mount to close the opening for the tube of the periscopic sextant. This shutter door is controlled by the sextant port lever (1) on the mount. The mount has a gimbal mechanism, which allows the sextant to be tilted from the vertical in any direction. This permits a celestial body to be observed throughout the normal oscillations of an aircraft. A drain plug (2) is provided at the low point in the shutter well for draining out water, which may have collected in the mount.

NOTE: The numbers in parentheses in 13.3, 13.3.1, and 13.3.2 refer to the parts indicated in Figure 13.2.

Figure 13.1. Body Is Not Sighted Directly.

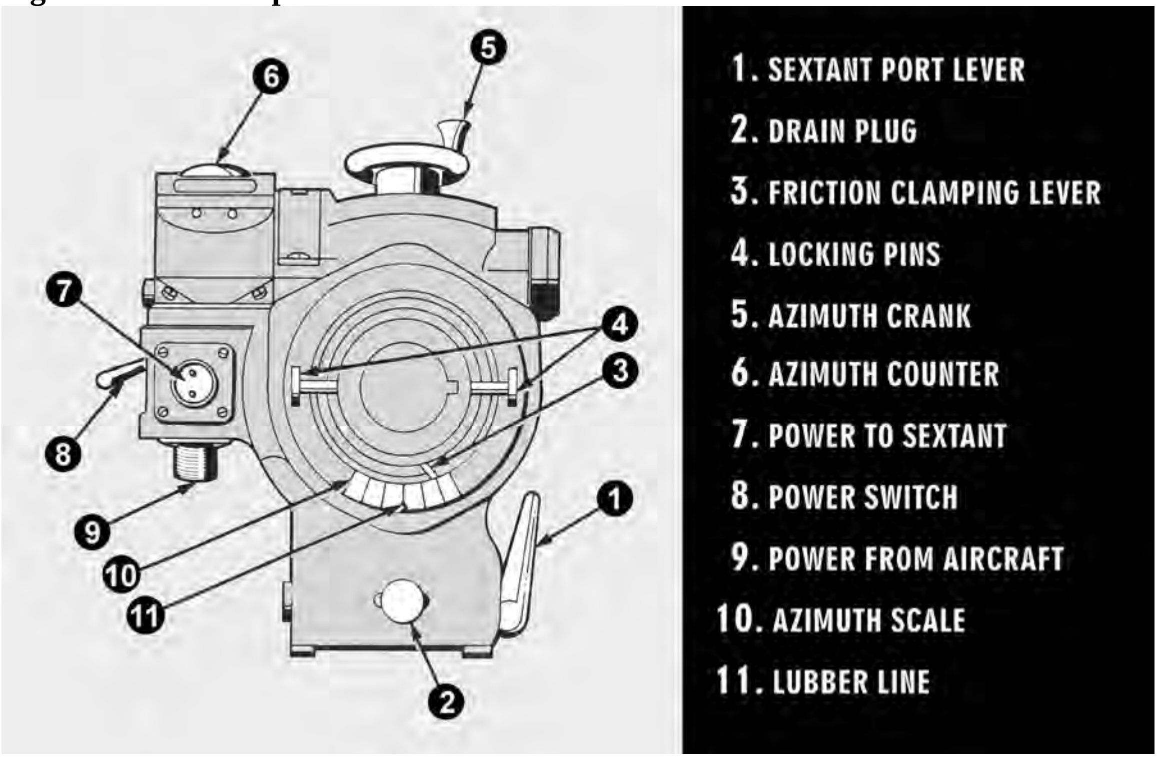


13.3.1. The sextant is held in the mount by two locking pins (4), located in a movable collar on the bottom of the mount. One pin locks the sextant into the mount and holds it in the retracted position; the other pin locks the sextant in the extended position. These pins are spring-loaded and must be pulled out to release the sextant. Located next to these locking pins is a friction clamping lever (3), which provides the observer with the option of locking the sextant at a fixed azimuth or, when the tension is released, the sextant may be rotated through 360^{o} of azimuth. The azimuth scale (10) and azimuth counter (6) will move when the azimuth crank (5) is rotated. The azimuth scale can be read against a lubber line or index (11). The azimuth scale read against the lubber line and the azimuth counter reading should be the same.

13.3.2. Power is supplied from the aircraft through a cable connection (9) on the side of the mount. A switch (8) on the side of the mount controls power to both the mount and the sextant. The mount has one lamp that illuminates the azimuth counter window. Another cable (7) is connected to the socket on the underside of the mount and supplies power to the sextant itself.

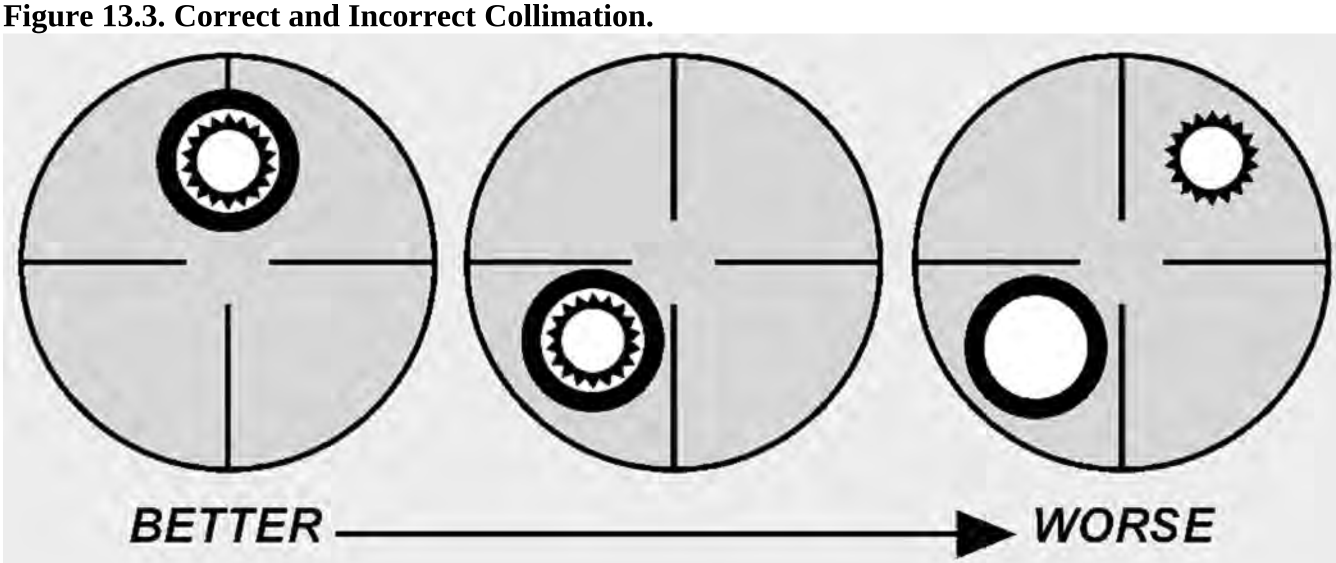
13.4. The Periscopic Sextant. The periscopic sextant is an optical instrument which enables the navigator to determine true azimuth (Zn), relative bearing (RB), and altitude angle of a celestial body and aircraft true heading (TH). The sextant provides an angle of observation from below the horizon to directly overhead, as compared to an artificial horizon.

Figure 13.2. Periscopic Sextant Mount.



13.4.1. Proper collimation techniques and the correct size bubble are essential ingredients of accurate celestial observations. Collimation is effected when the body is placed in the center of the bubble. For greatest accuracy, the bubble should be in the center of the field, with the body in the center of the bubble. The error will be small if the bubble is anywhere on the vertical line of the field, as long as it does not touch the top or bottom of the bubble chamber. Figure 13.3 shows examples from better to worse collimation.

Figure 13.3. Correct and Incorrect Collimation.



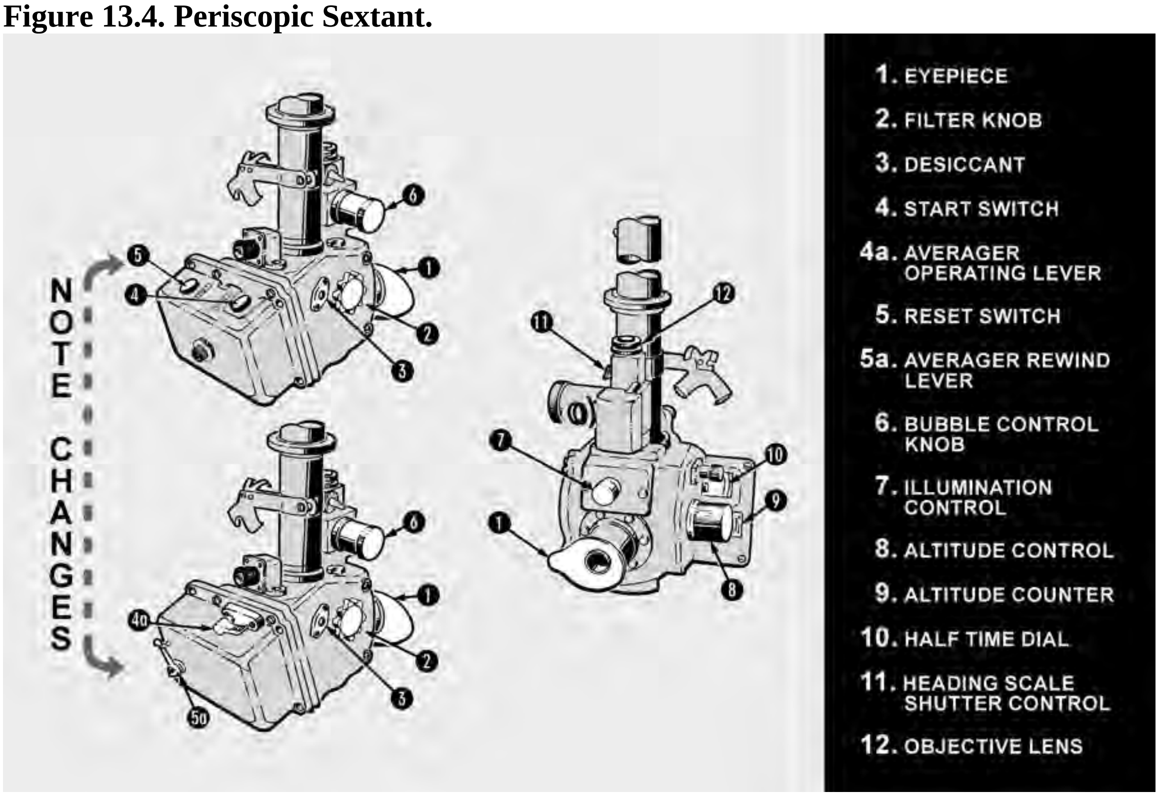
13.4.2. Bubble size affects the accuracy of a sextant observation. The ideal situation for collimation is to have a small bubble for ease in determining the center. A bubble that is too small will stick to the lens, decreasing accuracy. A bubble that is too large will move like a creature from a science fiction movie, making it difficult to find the center. Experience shows that best results are obtained with a bubble approximately one and a half times the apparent diameter of the sun or moon, or about the size of a Cheerio. The field prism is geared to an altitude scale so that when the body is collimated the altitude can be read from the scale.

13.4.3. An averaging mechanism is also incorporated which allows the navigator to take an observation over a period of time. The continuous motion of the aircraft affects the bubble and resultant artificial horizon. This movement resolves itself into a cycle in which the aircraft rolls, yaws, and pitches. To obtain an accurate reading, it is necessary to sight the body for a period of time during this cyclic movement and to average the results of a series of sightings. An averaging device has been incorporated in the sextant so an average reading can be obtained.

13.4.4. The sextant (Figure 13.4) is actually a low-power periscope with a 15° field of view. All lens surfaces in the sextant are coated to minimize light loss. To prevent condensation when the tip of the sextant is extended into cold air, the tube is filled with a dry gas and sealed. A desiccant (composed of silica gel) is used to remove moisture and check on the dryness of the gas inside the tube, and is visible in the periscopic end of the sextant, or in some models, on the sextant body. When the silica gel is pink, there is moisture in the tube and the sextant should be replaced before flight.

NOTE: The numbers in parentheses in 13.4.5 through 13.4.11 refer to the parts indicated in Figure 13.4.

Figure 13.4. Periscopic Sextant.



13.4.5. An eyepiece (1) rotates to correct the eyesight of the individual observer. Filters (2) are provided for selective use in the optical system so that the intensity of the sun's light might be adequately reduced. The filter control (2) is located on the left of the sextant.

13.4.6. Most sextants currently in use have been modified with an electronic device for accomplishing all the functions of the averaging mechanism. General differences in these and the unmodified sextants are addressed in this discussion.

13.4.7. A start switch (4) (a start and stop or averager operating lever [4A] on unmodified sextants) starts and stops the operation of the sextant. Adjacent to this switch is the reset switch (5) (the averager rewind lever, if unmodified [5A] located below the averager operating lever). The reset switch or averager rewind lever has four functions. When depressed and released, it does the following: (1) removes the shutter from the field of vision, (2) zeroes and resets (rewinds if unmodified) the timer, (3) zeroes the averager and places initial values in registers and data memory (realigns indices on unmodified sextants), and (4) disconnects the altitude control knob from the averager.

13.4.8. The bubble control knob (6) should be left in the maximum increase position after adjustments have been made. With the control in the maximum increase position, an aneroid is locked to the bubble chamber to compensate for changes in ambient pressure and temperature.

13.4.9. On the front of the sextant, there is a rheostat control (7) which varies the intensity of the light in the bubble chamber. The altitude knob (8) is located on the right side of the sextant. It keeps the observed body in vertical collimation during the period of the observation. At the end of the scheduled observation, it adjusts the altitude counter until the exact average indication appears, or to align the indices on unmodified sextants. The body's altitude is read in the altitude counter (9). Directly behind the altitude knob is the averager display (10) (half-time dial and indices if unmodified). The averager display or half-time dial is graduated from 0-60 and indicates the half time of the observation. The indices, when aligned, permit the direct reading of the observed altitude on the altitude dial.

13.4.10. In the periscope sextant, the averaging is accomplished by microprocessor (Deimel-Black ball integrator if unmodified), which effects a continuous moving averager over any observation period up to 2 minutes. This system has many advantages over other known averaging devices: it is very simple to operate. A single switch (or lever) sets or winds the mechanism and no other presetting of the sextant, timing mechanism, or averaging is necessary. It is continuously integrating altitude against elapsed time. After at least 30 seconds, it may be stopped at any time up to 2 minutes. The average altitude is read directly from the counter. A half-time clock will indicate the half time of the observation. The time indication may be added directly to the time of starting the observation to compute the mean time of the observation. At the end of the observation, the averager energizes a solenoid (actuates a lever if unmodified) which drops a shutter across the field of view, indicating the end of the observation. Although it is possible to utilize an instantaneous shot, the normal timed observation lasts for 2 minutes. It is impossible to time any observation for less than 30 seconds using the sextant timer.

13.4.11. A heading scale shutter (diffuser lever) control (11) provides a convenient means of blocking out the bright illumination on the azimuth scale for night celestial observations. The objective lens (12) is located just above the heading scale shutter control. The lens aligns the azimuth scale of the sextant with the longitudinal axis of the aircraft. The lens can be rotated with the fingers in order to calibrate the azimuth scale on a known bearing while looking through the eyepiece. The objectives lens can remove up to 2^{o} azimuth error in the azimuth ring. A locking ring beneath the lens prevents accidental movement. A dial lamp located on the right side of the sextant provides three beams of light to illuminate the averager indicators, the altitude counter, and the watch clip. The watch clip is made to hold an old-fashioned pocket watch.

13.5. Electrical Cables. Cables provide power for sextant operation and illumination. One "Y" cable provides power from the mount to the sextant for illumination and averager operation.

13.6. Sextant Case. The case provides shock-absorbent storage for the sextant when it is not in use. The sextant fits into formfitting foam blocks and is secured by straps. The case also contains spare bulbs for sextant illumination and provides storage for the electrical cable.

Section 13B—Errors of Sextant Observation

13.7. Basics. If collimation of the body with the bubble and reading the sextant were all that had to be done, celestial navigation would be simple. This would mean LOPs that are accurate to within 1 or 2 miles could be obtained without any further effort. Unfortunately, considerable errors are encountered in every sextant observation made from an aircraft. A thorough understanding of the cause and magnitude of these errors, as well as the proper application of corrections to either Hc or Hs, will help minimize their effects. Remember that any correction applied to the Hs may be applied to the Hc with a reverse sign. Accuracy of celestial navigation depends upon thorough application of these corrections together with proper shooting techniques. The errors of sextant observation may be classified into four groups: (1) parallax, (2) refraction, (3) acceleration, and (4) instrument.

13.8. Parallax Error. Parallax in altitude is the difference between the altitude of a body above a bubble horizon at the surface of the earth and its calculated altitude above the celestial horizon at the center of the earth. All Hcs are given for the center of the earth. If the light rays reaching the earth from a celestial body are parallel, the body has the same altitude at both the center and the surface of the earth. For most celestial bodies, parallax is negligible for purposes of navigation.

13.8.1. Parallax Correction for the Moon. The moon is so close to the earth that its light rays are not parallel. The parallax of the moon may be as great as 1^{o}; thus, when observing the moon, a parallax correction must be applied to the Hs. This correction is always positive (+) and varies with the altitude and with the distance of the moon from the earth. The correction varies from day to day because the distance of the moon from the earth varies. Corrections for the moon's parallax in altitude are given on the daily pages of the *Air Almanac* and are always added, algebraically, to sextant altitudes. The values of parallax for negative altitudes are obtained from the *Air Almanac* for the equivalent positive altitudes.

13.8.2. Semidiameter Correction. This correction is found on the daily pages of the *Air Almanac*. Apply it when shooting the upper or lower limb of the moon or the sun.

13.8.2.1. It is more likely to occur on observations of the moon because, when the moon is not full (completely round), the center is difficult to estimate. Shoot either the upper or lower limb and apply the semidiameter correction listed on the *Air Almanac* page for the time and date of the observation. Subtract the correction from the Hs when shooting the upper limb; add the correction to the Hs when shooting the lower limb. Reverse the sign if applying the correction to the Hc.

13.8.2.2. Listed on the same page is the semidiameter correction for the sun, which is applied the same way as for the moon.