HOW TO FIND YOUR POSITION WITH A SEXTANT

This booklet has been written as an introduction to your new Davis sextant. By studying its pages, you will learn how to operate your sextant, how to find the altitude of the sun, and how to use your readings to calculate location. The meridian transit method of navigation described is both easily learned and simply applied, and when you finish reading, we hope some of the mystery surrounding celestial navigation and sextant use will disappear. Before becoming an accomplished navigator, however, you will need to study those aspects of navigation which are beyond the scope of this booklet.

HOW TO READ THE VERNIER

There are two scales on the sextant. The scale on the frame is called the “are”, while the scale on the index arm is called the “vernier”. Each division of the arc equals one degree; each division of the vernier equals two minutes (2′). To read the number of degrees, find the lines on the arc which are closest to the zero mark on the vernier. The zero mark is usually somewhere between two lines. The correct arc reading is always that of the lower value, i.e., the line to the right of the zero mark. To read fractions of a degree, find the division of the vernier which is in alignment with a division of the arc.

To get a clear picture of how this works, set the zero on the vernier exactly beneath any whole degree mark on the arc – let’s say 300. Now move the index arm very slightly to the left until the first vernier mark to the right of the zero lines up exactly with a mark on the arc. Since the marks on the vernier are 2′ apart, you have actually moved the index arm 2′ beyond 30~; your sextant reads 30~ 02′. Now, move the index arm slightly further to the left so that the next division of the vernier comes into alignment with a division of the arc. Your sextant now reads 30~ 04′ (Fig. I). As you continue moving the index arm, successive divisions of the vernier will come into alignment with a division of the arc. When the last mark on the vernier (60′) is in alignment with a division of the arc, the sextant will read 3l~. In Figure 2 below, the sextant reads 430 26′.

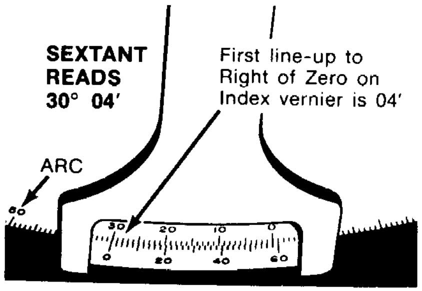


Fig. 1

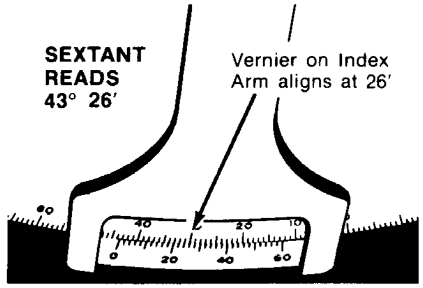


Fig. 2

SEXTANT
READS
30” 04’

First line-up to
night of Zero on
Index vernier is 04’
/

SEXTANT
READS
430 26’

vernier on index
Arm aligns at 26’
II

MARK 3 SEXTANT ADJUSTMENT

Adjusting your Mark 3 Sextant is easy and should be done each time it is used. All adjustments are made with the index mirror, the large movable mirror at the pivot of the index arm. (It is not necessary to adjust the small horizon mirror as the unit construction makes it impossible to be very much in error.) On a correctly adjusted sextant, the index mirror is perpendicular to the frame and becomes parallel to the horizon mirror when the sextant reads zero.

First, adjust the index mirror for “side error” by making it perpendicular to the frame. Holding the sextant in your right hand, raise the instrument to your eye. Look at any horizontal straight edge (for example, the sea horizon or the roof of a building at least one mile away) and move the index arm back and forth. The real horizon will remain still while the mirror horizon will appear only when the scales read close to zero. Line up the mirror horizon and the real horizon so that both appear as a single straight line (Fig. 3).

mirror horizon and the real horizon so that both appear as a single straight
line (Fig. 3).

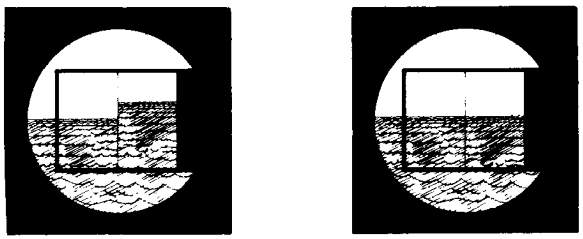


Fig. 3

(a) Mirror horizon is not aligned with real horizon — index arm is not in proper position.

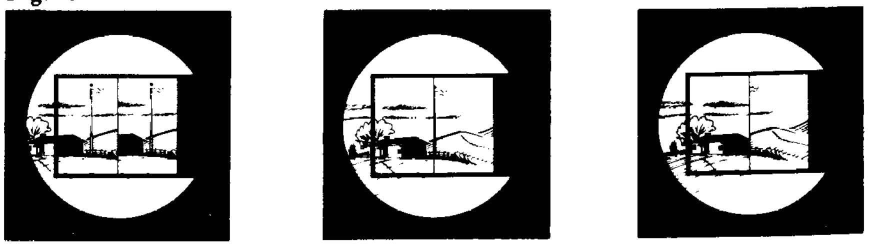
(b) Mirror horizon and real horizon form a single straight line — index arm is properly positioned.

(a) Mirror horizon is not aligned with
real horizon — index arm is not in proper
position.

(b) Mirror horizon and real horizon
form a single straight line — index arm
is properly positioned.

Now, without changing the setting, look through the sextant at any vertical line (for example, a flag pole or the vertical edge of a building) and swing the instrument back and forth across the vertical line. If the index mirror is not perpendicular to the frame, the line will seem to jump to one side as the mirror passes it. To correct this, slowly tighten or loosen the screw closest to the frame at the back of the index mirror until the vertical line no longer appears to jump (Fig. 4).

Fig. 4



(a) Index mirror screw too tight.

(b) Index mirror screw correctly adjusted.

(c) Index mirror screw too loose.

(a) Index mirror screw
too tight.

(b) Index mirror screw
correctly adjusted.

(c) Index mirror screw
too loose.

Finally, remove the index error. Set the sextant at zero and look at the horizon. With the sextant still held to your eye, turn the screw that is furthest from the frame at the back of the index mirror until the two horizons move together and form one straight line. The index mirror is now parallel to the horizon mirror (Fig. 5).

Fig. 5

(a) Index mirror not parallel to horizon mirror.

(b) Index mirror parallel to horizon mirror.

(a) Index mirror not parallel to
horizon mirror.

(h) Index mirror parallel to
horizon mirror.

Fig. 6

On a correctly adjusted sextant, the real and mirror horizons remain in a single line when the instrument is rocked from side to side.

On a correctly adjusted sextant, the real and mirror horizons remain in a single line when the instrument is rocked from side to side.

While you should knox~ how to adjust your sextant for index error, it is not necessary to remove it entirely. It is standard practice to simply note the error and then correct one's readings for this amount each time the sextant is used. (As much as 6′ index error is allowable.) To check for index error. hold the sextant in your right hand and look at the sea horizon. By moving the index arm, line up the real and mirror horizons so that both appear as a single straight line. Now, look at the scale. If it reads zero, there is no index error. If the scale reads anything but zero, there is an index error which must be added to or subtracted from each reading. For example, if the scale reads +6′ when the horizons are aligned, the 6′ is subtracted; if the reading is below the zero mark, for example -6′, the 6′ is added. (Note: for an index error of -6′, the scale actually reads 54′.)

MEASURING THE SUN'S ALTITUDE

When looking at the sun through the sextant, be sure to use a sufficient number of shades to protect your eyes from the direct rays of the sun. Choose the combination of index and horizon shades that gives you a clear image of the sun without glare.

To measure the sun’s altitude, stand facing the sun with the sextant in your right hand. With your left hand on the index arm, look through the eyepiece at the horizon and move the index arm until the sun is visible through the two mirrors and index shades. Rock the entire sextant from side to side so that the sun’s image travels in a half-arc. Now, adjust the index arm to bring the sun’s image down to just touch the horizon (Fig. 7). Being careful not to disturb the setting, read the sun’s altitude from the scales on the sextant. Since all calculations in the Navigation Tables use the center of the sun or moon, this lower limb reading must be adjusted for semi-diameter correction, as shown later.

I

Fig. 7

The sun’s image travels in a short arc which just touches the horizon.

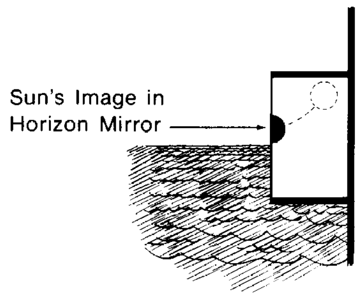


Fig. 7

The sun’s image travels in a short arc
which just touches the horizon.

Sun’s Image in
Horizon Mirror –

HEIGHT OF EYE

When measuring the altitude of the sun, we want to measure the angle formed by a ray from the sun and a plane tangent to the earth at the point where the observer is standing. However, due to the height of the eye of the observer, the visible horizon actually falls below this theoretical plane (Fig. 8). To correct for the height of the eye, one must apply a “dip correction”. Dip correction increases as the eye is raised further above the surface of the water (Table 1) and must always be subtracted from the sextant reading.

Height of Eye Correction

Feet	Meters	Dip
5	1.5	2′
10	3.0	3′
15	4.5	4′
25	7.5	5′
40	12.0	6′

Table I

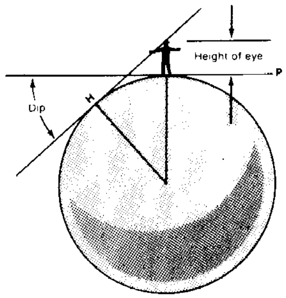


Fig. 8

Due to the height of the eye of the observer, the visible horizon (H) falls below the plane (P) tangent to the earth at the point where the observer is standing.

6

Fig. 8

Due to the height of the eye of the observer, the visible horizon (H) falls below the plane (P) tangent to the earth at the point where the observer is standing.

6

LATITUDE, LONGITUDE, AND THE NAUTICAL MILE

A great circle is a circle on the surface of the earth, the plane of which passes through the center of the earth. A small circle is a circle whose plane does NOT pass through the center of the earth. The equator and the meridians are great circles, while parallels of latitude are small circles which become progressively smaller as the distance from the equator increases. At the poles (900 N or 5), they are but single points (Fig. 9).

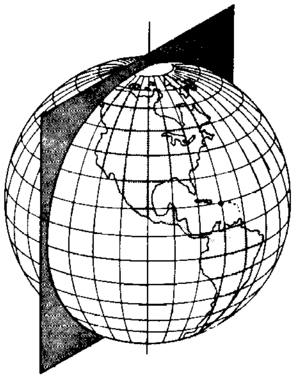
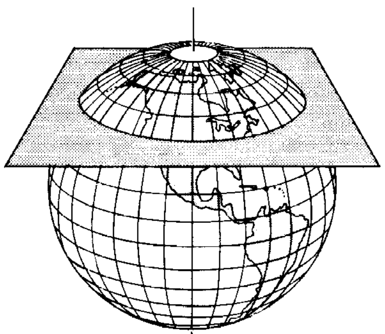


Fig. 9

(a) The plane of a meridian (a great circle) divides the earth into two equal halves.

Fig. 9

(a) The plane of a meridian (a great circle) divides the earth into two equal halves.

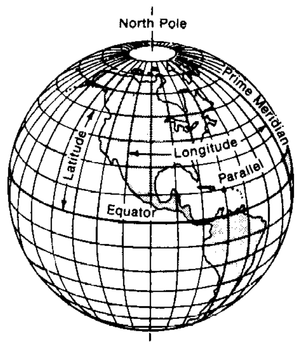


(b) The plane of a parallel of latitude (a small circle) divides the earth into two unequal parts.

(b) The plane of a parallel of latitude (a small circle) divides the earth into two unequal parts.

A nautical mile is equal to one minute of arc of a great circle. Since latitude is measured north or south from the equator, it is measured along a meridian (a great circle); one minute of latitude equals one nautical mile anywhere on the earth. Since longitude is measured east or west from the prime meridian (zero degrees) at Greenwich, England, it is measured along a parallel of latitude (a small circle); one minute of longitude equals one nautical mile only at the equator. Approaching the poles, one minute of longitude equals less and less of a nautical mile (Fig. 10).

NOTE: the nautical mile (6076 feet; 1852 meters) is longer than the statute mile (5280 feet; 1609 meters) used on land. The earth measures 21,600 nautical miles in circumfere nee.



DEC I .IN ATI ON

Every star and planet. including the sun. has a ground position, i.e., the spot on the earth directly beneath it. Standing at the sun's 6. P. (ground position), you would have to look straight up to see the sun; if you were to measure its altitude with a sextant, you would find the altitude was 900.

From the earth, the sun seems to move across the sky in an arc from east to west. During certain times of the year. it is ~'moving" around the earth directly above the equator or. in other words, the sun's G.P. is running along the equator. Declination of the sun at this time is zero. However, the sun's G.P. does not stay at the equator throughout the year. It moves north to a maximum of 23 ~ N in the summer of the northern hemisphere, and south to a maximum of 2317,0 S in the winter. The distance of the sun's G.P. from the equator, expressed in degrees north or south, is known as the declination of the sun (Fig. II).

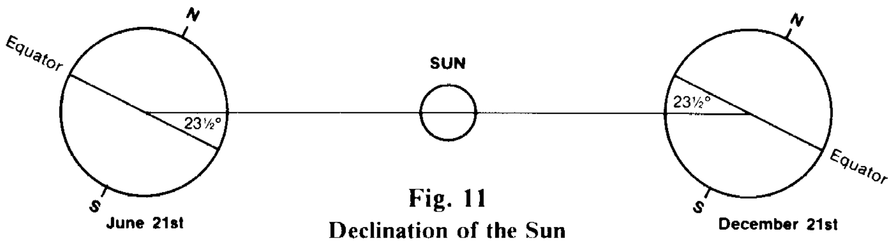
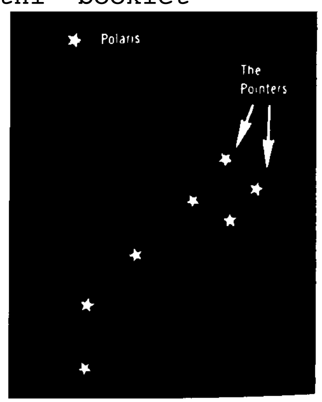


Fig. 11
Declination of the Sun

In like manner, each star has a ground position and a declination. The declination of Polaris is 890 05'N; it is nearly directly above the North Pole. In the northern hemisphere, you can find your approximate position by taking a sight on Polaris. The reading will vary depending upon the time of night but will never be more than 55 miles off. This is a useful check each evening; the altitude of Polaris will be your approximate latitude without adding or subtracting anything. If you were to find the altitude of Polaris in the evening and again at dawn, your true latitude would be between the two measurements, providing you did not change latitude between the two sights. It is, of course, possible to calculate one's exact latitude from Polaris with the aid of the Nautical Almanac, but such a discussion is beyond the scope of thi' booklet



To find Polaris, locate the pointers of the Big Dipper (Fig. 12). Find a point in line with the pointers and five times the distance between them. There, shining alone, is Polaris.

The Big Dipper revolves around
Polaris so be prepared to see the
diagram in any position.

FINDING LOCAL NOON & THE SUN'S ALTITUDE AT MERIDIAN PASSAGE

A meridian is an imaginary line drawn on the earth's surface from pole to pole; a local meridian is one which passes through the position of an observer. When the sun crosses the local meridian, it is at its highest point. It is said to be in meridian passage and the time is local noon. Local noon may vary a half an hour (and in daylight savings time, one and one half hours) from the noon shown on the clock, due both to the equation of time (to be discussed later) and to the fact that our clocks are set to zone time. All clocks in a zone ISO wide show the same time.

To find local noon, follow the sun up with a series of sights, starting about half an hour before estimated local noon. Note the time and the sextant reading carefully. Take a sight about every three minutes until the sun's altitude is no longer increasing. During meridian passage, the sun will seem to "hang" in the sky for a short period at its highest point, going neither up nor down. Carefully note the sextant reading. This is the sun's altitude at meridian passage. To determine the exact time of local noon, set your sextant at the same altitude as your first sight. Wait for the sun to drop to this altitude, and note the time again. The time of local noon is exactly half way between the times of the two sights.

Record the local time and the sextant reading when the sun was at the highest point. These two readings will serve to locate your position. The time is used to determine longitude and the sextant reading to determine latitude.

THE COMPLETE SIGHT

Let us assume for this example that your ship is sailing from San Francisc0 to Hawaii and that you have been using the sun to find your position each day. To allow plenty of time to follow the sun up to its highest point, make sure that you have completed all your preparations by 10:00 am. local time. Your chart shows yesterday's position. From this position, draw a line in the direction you are traveling equal in length to the estimated number of miles to be traveled by noon today. This is your "dead reckoning position" (DR.), which will be compared with your "noon sight".

Note that you will be standing on deck in such a manner that your eye is ten feet above the water (for Dip correction) and that the index error of your sextant is +5′.

At about 11:20 a.m., you begin taking sights. At 11:23:30, your first sextant reading is 820 56′. You continue recording the sun's altitude approx-imately every three minutes until the sun seems to "hang" in the sky, dropping to a lower altitude at your next sight. The maximum altitude of the sun, 840 56′, is the altitude of the sun at meridian passage. You continue taking sights until 12:03:30, when the sun has dropped to your original reading of 820 56′.

You know now that the sun reached its meridian at 11:43:30 (exactly half the time between 11:23:30 and 12:03:30). Next, you find the Greenwich Mean Time (GMT) of your local noon by listening to the radio time signal, correcting any error your watch may have had. In this example, you tune in the time signal and find that GMT is now 22:10:00. Your watch reads 12:10:00, so it has no error. You now know that your local noon occurred at GMT 21:43:30 (26 minutes 30 seconds ago).

You now have enough facts to work out your noon sight: the date, the time of meridian passage (local noon), the altitude of the sun at meridian passage, the height of your eye above the surface of the sea, and the index error of the sextant you are using.

FINDING LONGITUDE

Meridians of longitude are measured east or west from the prime meridian (zero degrees) at Greenwich. England. Because the ground position of the sun moves around the earth at an average speed of 150 per hour (IS nautical miles per minute). longitude may be calculated by comparing local noon with Greenwich Mean Time (Fig. I 3a). For example, if local noon occurred at 2:00 GMT, your longitude is approximately 30~ west of Greenwich (2 hours x 50 hour 300).

To determine one's exact position. the equation of time must be applied. The earth in its orbit around the sun does not travel at a constant speed. Clocks and watches, therefore, keep the time of a fictitious or mean sun which travels at the same average speed throughout the year, and the position of the true sun (as seen from the northern half of the earth) is not always due south or 1800 true at noon by the clock. The difference in time between the true sun and the mean sun is called the "equation of time". The equation of time for any given day may be found in a Nautical Almanac; its approximate value may be found in the student tables at the end of this booklet.

Example: The Longitude Calculation Longitude: 2 June

Example: The Longitude Calculation **Longitude: 2 June**

21 h 43 m 30 s	GMT of local noon (from observation above)
- 12 h 00 m 00 s	Greenwich noon
09 h 43 m 30 s	Time from Greenwich to your ship
× 60	Minutes/hour conversion
583.5 m	Minutes from Greenwich to your ship
× 15	G.P. of sun travels 15 minutes of arc/minute of time
8752.5 m	Minutes of arc (nautical miles) from Greenwich
÷ 60	Minutes/degree conversion
145° 52′.5 W	Longitude position of mean sun
+ 33′.0 W	Equation of time for 2 June (from student tables)
146° 25′.5 W	Longitude of observer

21 h 43 m 30 s	GMT of local noon (from observation above)
- 12 h 00 m 00 s	Greenwich noon
09 h 43 m 30 s	Time from Greenwich to your ship
60	Minutes hour conversion
583.5 m	Minutes from Greenwich to your ship
IS	G.P. of sun travels IS minutes of arc minute of time
8752.5 m	Minutes of arc (nautical miles) from Greenwich
60	Minutes degree conversion
1450 52′.5 W	Longitude position of mean sun
+ 33.0 W	Equation of time for 2 June (from student tables)
1460 25.5 W	Longitude of observer

FINDING LATITUDE

The altitude of the sun at local noon may also be used to calculate latitude. First, the measured altitude must be corrected for index error, height of eye, refraction, and semi-diameter. Refraction correction is negligible for altitudes above 25~, while the semi-diameter correction averages +00 16′. (Semi-diameter correction adjusts the sextant reading from an observation of the lower limb of the sun to one of the center of the sun; 16′ equals one-half the sun's diameter.) After the corrections are made, determine the declination of the sun from the Nautical Almanac or from the approximate declination values at the end of this booklet.

Finally, calculate latitude by combining the altitude of the sun at local noon with the declination of the sun from the navigation tables (Fig. 13b). Assuming you are north of the sun, the following formula is used in northern latitudes:

Latitude = 900 - Corrected Altitude ± Declination of the Sun

When the sun is north of the equator, ADD the declination; when it is south of the equator, SUBTRACT the declination.

Example: The Latitude Calculation **Latitude: 2 June**

Step One: Finding corrected altitude of the sun.

hs	84°	56′	Lower limb observation (your sextant reading at local noon)
- IC		5′	Index correction
	84°	51′	
- DIP		3′	Height of eye correction (see Fig. 8)
	84°	48′	
+ ☉		16′	Semi-diameter correction
Ho	85°	04′	Corrected altitude

Step Two: Applying the above formula for latitude

	89°	60′	Altitude of the sun at G.P. (89° 60′ = 90°)
- Ho	85°	04′	Corrected altitude of the sun (from "Step One" above)
	4°	56′	Distance from the sun's G.P.
+	22°	08′ N	Declination of the sun, north of the equator on June 2 (from student tables)
	27°	04′ N	Latitude of observer

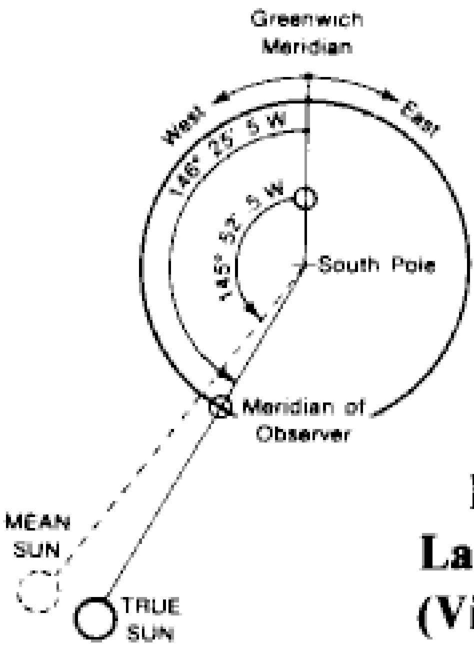
Example: The Latitude Calculation Latitude: 2 June
Step One: Finding corrected altitude of the sun.
hs 84~ 56′ Lower limb observation (your sextant reading at local noon)
- IC 5′ Index correction
840 51~

- DIP 3′ Height of eye correction (see Fig. 8)
840 48′
+ 16′ Semi-diameter correction
Ho 85~ 04′ Corrected altitude

Step Two: Applying the above formula for latitude

	890	60′		Altitude of the sun at G.P. (89~ 60′ 900)
- Ho	850	04′		Corrected altitude of the sun (from “Step One” above)
	40	56′		Distance from the sun’s G.P.
+	22~	08′	N	Declination of the sun, north of the equator on June 2 (from
	270	04′	N	Latitude of observer student tables)

The presentations here are commonly used by navigators to help insure the accuracy of their calculations.



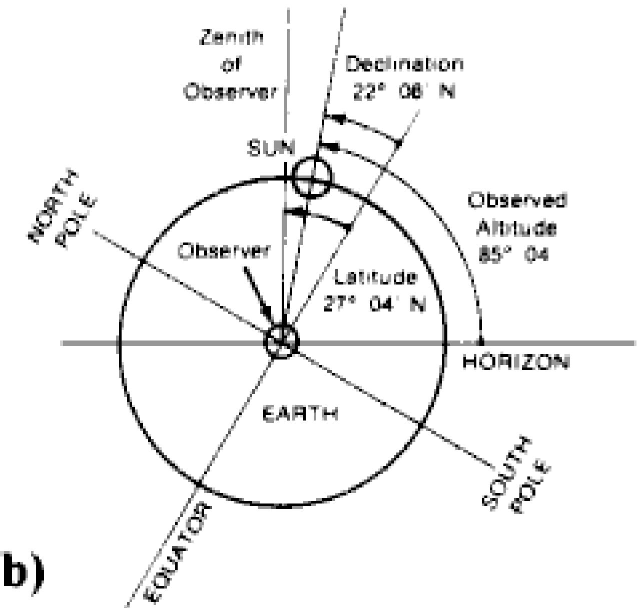


Fig. 13 (b)
Latitude Diagram
(View of Earth Looking at Equator)

Fig. 13(a) Longitude
Diagram (View of Earth
Looking at South Pole)

Fig. 13 (b) ?
Latitude Diagram
(View of Earth Looking at Equator)

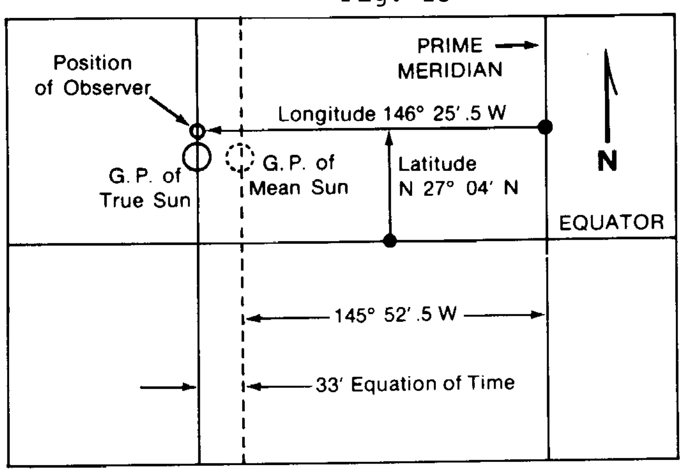
otObserver I

G. P. of K~) G. P. of Latitude N

EQUATOR

i-..-------33′ Equation of Time

(c) Position Plot on chart
Fig. 13



(c) Position Plot on chart
Fig. 13

SYSTEMS OF CELESTIAL NAVIGATION

The method described above for calculating your position is the oldest method used since the introduction of the chronometer. Please note the following:

I. Latitude may be determined at noon if you know the corrected altitude of the sun and its declination. Y~u need not know the time. The accuracy of your calculation is limited only by the accuracy of measurement of the sun's altitude and by the accuracy of the declination tables,

2. To determine longitude, you must know both the time of observation and the equation of time. While your sextant gives highly accurate measurements, practical difficulties inherent in this method normally preclude accuracy of more than 10' of longitude.

A generalized system of position determination which enables you to use observation of the sun and other celestial bodies made at times other than noon requires knowledge of the navigation triangle, circles of equal altitude, assumed position, and associated navigation tables such as the Nautical Almanac and Sight Reduction Tables. These systems of celestial navigation are thoroughly studied and extensively used by serious navigators throughout the world.

Davis Instruments publishes a complete set of work forms for the HO. 229, 249 (Vol. 1) and 249 (Vol. 11-111) Sight Reduction Tables, with step-by-step instructions. Work forms such as these are used by nearly all navigators to help prevent errors and omissions in the calculation of celestial navigation problems.

THE ARTIFICIAl. HORIZON

At times, it is not possible to see the natural horizon. Sun or moon shots may still be taken, however, with the aid of an artificial hori,on. a simple device containing water or oil shielded from the wind (Fig. 14). It may be used by individuals exploring inland far from the sea, or by students orexperienced navigators who wish to practice celestial navigation without traveling to large bodies of water.

To use the artificial horizon, position it on level ground or other steady place. One end of the artificial horizon should face directly into the sun so that a shadow is cast at the opposite end; the sides and end facing the sun should be shadow free. Looking into the center of the liquid, move your head about so that you can see the sun reflected on the liquid surface. Now, placing your sextant to your eye, move the index arm of the sextant until you see two suns - one reflected on the liquid and a double-reflected image on the mirrors. Line the two suns up by continuing to move the index arm. For a lower limb observation, the bottom of the mirror image should be brought into coincidence with the top of the image on the liquid. After the observation has been made, apply the index correction. Halve the remaining angle and apply all other corrections (except for dip or height of eye correction, which is not applicable) to find the altitude of the sun.

Since the sextant reading made with an artificial horizon must be halved. the maximum altitude which may be observed with the artificial horizon is equal to one-half the maximum arc graduation on your sextant. There may be several hours around noon during which the sun is too high to take a sextant reading with the artificial horizon; thus, sights should normally be planned for the morning or evening hours.

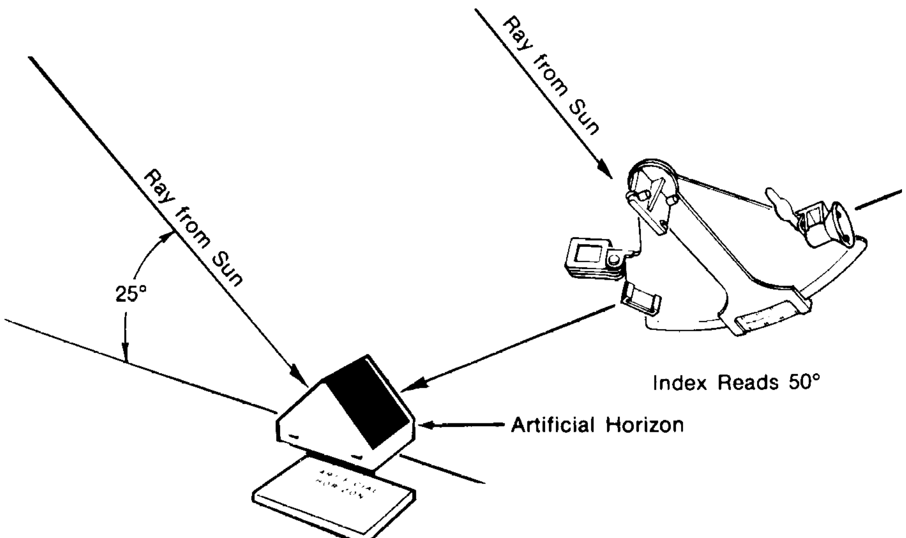


Fig. 14

THE SEXTANT AS A PELORIJS

Your sextant may also be used to find your position by sighting known land objects such as lighthouses, small harbors, or any other land features that are clearly recognizable on the chart. Pick out three features on the land. With the sextant held horizontally, measure the angle between the center feature and one of the other features, and note the angle on a piece of paper. As quickly as you can, measure the angle between the center feature and the third feature. Lay out the three angles on a piece of tracing paper so that the angles have a common center point. Move the tracing paper around on the chart until the lines are positioned so as to run through the three features. The, point of intersection of the three angles is your position (Fig. 15).

Since the sextant does not have a compass, you do not need to worry about variation or deviation. However, you must use at least three lines of

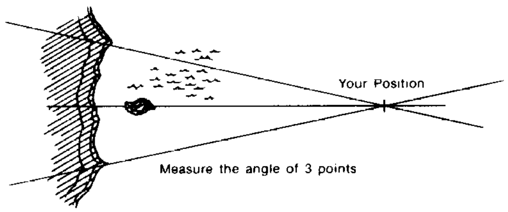


Fig. 15

THE SEXTANT AS HELIOGRAPH

The sextant mirrors may be used to flash the sun's rays several miles to attract attention, or to signal another person who is too far away for your voice to reach. If you know Morse Code, you may even send a message.

Hold the sextant so that the index mirror (the larger of the two mirrors) is just below the eye. With your other arm extended and the thumb held upright, look at the person you wish to signal. Bring your thumb to a position just below the person, so that your eye (with the mirror under it), your thumb, and the person to be signaled are in a straight line (Fig. 16). Using the mirror, flash the sun on your thumb; the sun will flash simultaneously on the distant person.

Fig. 16

Using the sextant as a heliograph.

STIJDENT NAVIGATION TABLES

The tables on the following page give the approximate declination and equation of time of the sun. Latitude calculated with these values will be accurate to about ± 15′. The tables are thus intended for study purposes only, although they may be used for emergency navigation