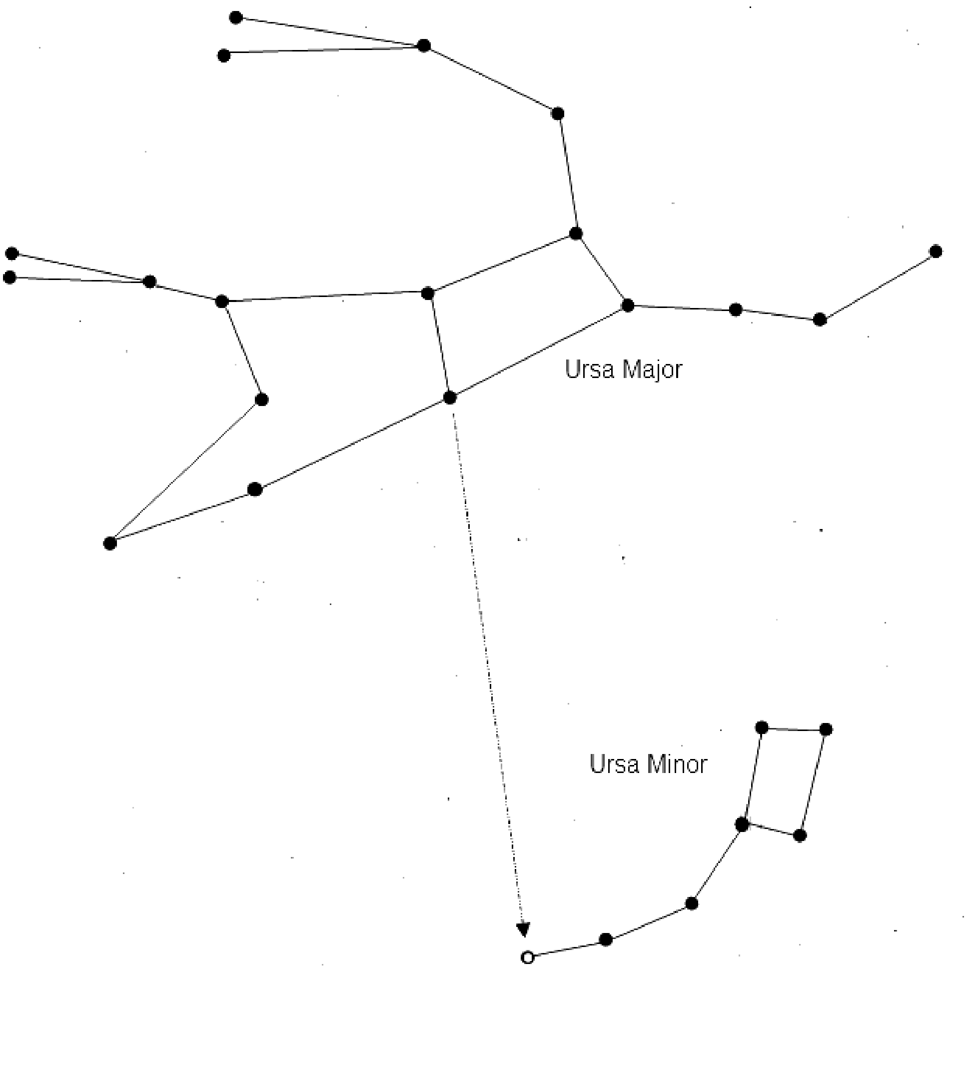
Celestial Navigation



Commander Geoff Lewis MBE

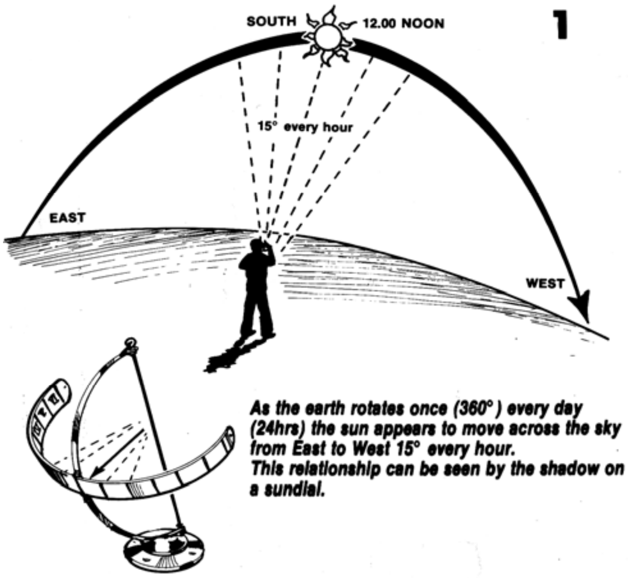
First Steps

Finding one's way by means of the Sun and stars is arguably one of the oldest of all sciences; the birds probably did it long before mankind walked this earth and wondered at the skies. They still do so whenever they migrate, though I doubt whether even now anyone understands exactly how they do it. The earliest ship-navigators too found the way around their then-known seas more easily when the sky was visible than when it was obscured by cloud. In this present century there is still, despite the upsurge of electronic aids to navigation, a great interest in celestial position-finding for large ships and for small. And rightly so, because of its world-wide cover, its reliability, its elegant simplicity and not least because of the very modest cost of the necessary equipment. So why should 'astro' be seen by some skippers as a black art? The instruments are simple enough to use, and the mathematics no more difficult than most sixteen-year-old youngsters can cope with.

Certainly do not start by spending a lot on equipment. We'll see later that we can find a usefully accurate position in mid-ocean with nothing more than an almanac and a wrist-watch. Our first need is a working know ledge of the geography of the world and the motions (real and apparent) of objects in the skies around it. We'll be working with ***time*** and with ***angles***, and we must learn to measure them accurately, for otherwise our efforts will be wasted.

The earth rotates 360 deg on its polar axis every 24 hours, and we'll repeatedly meet this relationship. Fifteen degrees in one hour, one degree in four minutes of time **Fig 1**.

The Sun and stars appear to move west-ward through the heavens at that rate, though in fact it's our vantage-point which does the rotating in the opposite direction. The Moon and planets move about the sky in rather more complex but entirely predictable paths; the ever-changing positions of all heavenly bodies, useful for navigation, are catalogued in all current nautical almanacs. Many of us will already possess a copy of *Reed's* or *Macmillan* or the *Admiralty Nautical Almanac.*

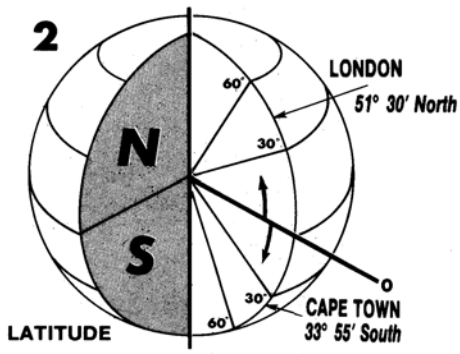


As the earth rotates once (360°) every day (24hrs) the sun appears to move across the sky from East to West 15° every hour. This relationship can be seen by the shadow on a sundial.

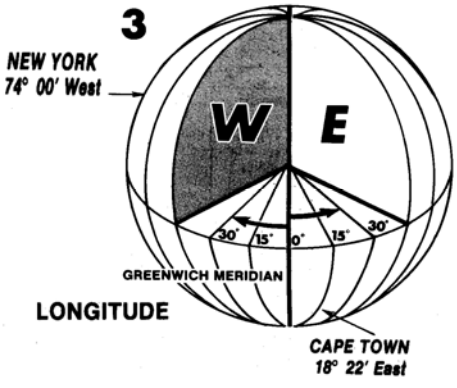
ANGULAR **POSITIONS**

Positions on the earth and in the skies are best described in terms of angles. On earth we divide the sphere into northern and southern hemispheres by drawing an imaginary line around its middle: the equator. From the equator to either pole is an angular distance of 90 deg, and intermediate angles ***parallels of latitude***, **Fig 2**.

Central London has a latitude of 51 deg 30 min north of the equator,
Capetown is 33 deg 55 min south
and **New York** 40 deg 45 min north.

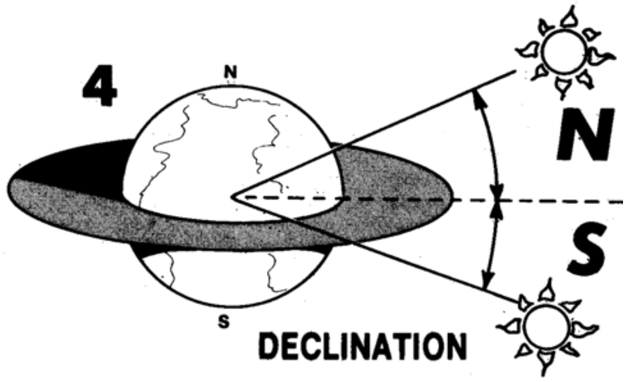


In the east — west direction we measure our positions by ***longitude***, arrived at by dividing the earth vertically through the north and south poles like the slices of an orange, **Fig 3**. Those vertical divisions we call ***meridians***, and as a baseline from which to measure longitude we adopt the ***prime meridian*** which runs from the North Pole through the old Royal Observatory at Greenwich to the South Pole. Longitude is measured eastward and westward to the 180deg meridian in mid-Pacific. The centre of London is slightly to the west of the Greenwich meridian, and its longitude is 0 deg 5 min west. Cape Town is 18 deg 22 min east and New York 74 deg 00 min west of the prime meridian.



DECLINATION

Everybody knows about latitude and longitude, but I recap on them here because of the similarity to the way in which we define and measure the positions in the sky of bodies like the Sun and stars. If we imagine a plane surface through the earth's equator extending out in all directions into space we can measure the angle by which a body is north or south of that plane, like earthly latitude. We call that angle *declination,* so as not to confuse a heavenly position with an earthly one. At midsummer in the northern hemisphere the Sun has a declination of 23 deg 27 min north, at midwinter the same angle south. **Fig 4**.



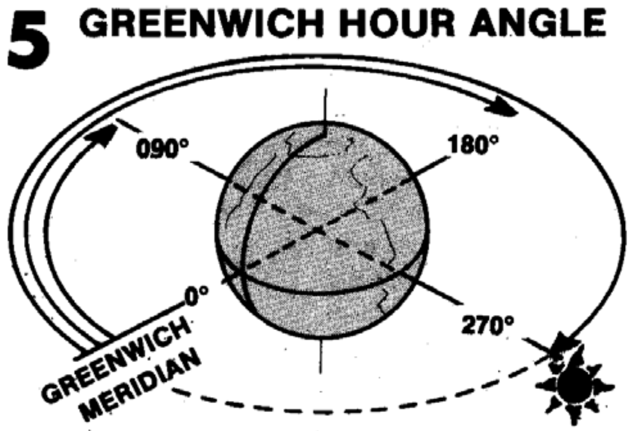
The stars (but not the planets or Moon) are so far from the earth that their declination is hardly seen to change with the seasons, so we call them the fixed stars. The Pole Star ***(Polaris)*** is very nearly 90 deg north of the celestial equator; its declination is given in the almanacs as 89 deg 12 min north. The well known bright star ***Capella*** has a declination of 45 deg 59 min north, and the Dog-Star, ***Sirius***, the brightest star in the sky, 16 deg 41 min south.

The various almanacs list the changing declinations of the Sun, Moon and planets and the (nearly) fixed declinations of the stars. The rate at which the declinations change determines the intervals at which the values are given in the almanacs; in *Reed's* the Sun's declination is tabulated for every two hours and we can estimate intermediate values when necessary by interpolation. In contrast it takes six months for the declination of ***Capella*** to change 0.3 min, a change which all but the most exact navigators might ignore.

HOUR ANGLES

Just as we measure the longitude of a plate on earth by its angle east or west • of the meridian of Greenwich, we similarly measure the east - west position of a celestial object by its angle from a reference meridian which may or may not be Greenwich. We always measure these angles '*westwards.* If measured from the Greenwich meridian, we call the angle

Greenwich Hour Angle (GHA). (**Fig 5)**

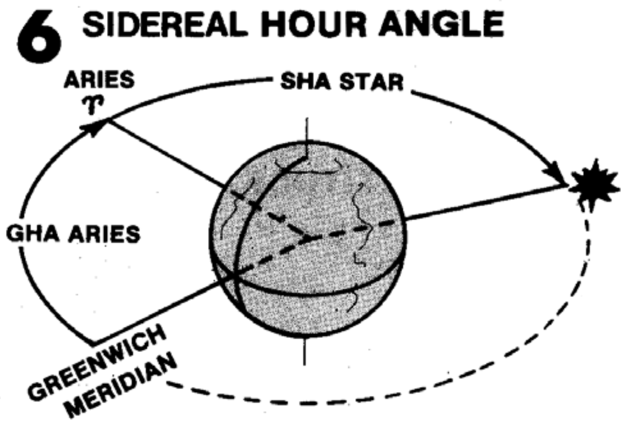


The GHA of Sun, Moon and planets is tabulated in the almanacs. When the Sun is overhead on the Greenwich meridian it obviously has a GHA of zero; at midnight GMT its GHA will be 180 deg and at 6am 270 deg.

(These are approximations; we'll come to the exact differences later).

SIDEREAL HOUR ANGLE

Now, since the stars are virtually fixed in their celestial positions in Hour Angle as well as in declination, they all appear to rotate through the sky together as a fixed pattern. There is therefore no need to tabulate their Greenwich Hour Angles separately, and that would be a formidable task for up to sixty stars. Instead we record the fixed angle between each star and a celestial reference meridian which was originally chosen centuries ago by early astronomers: that of the **First Point of Aries**. (This once passed through the constellation of **Aries** but over the centuries it has moved into the adjacent constellation of **Pisces**.)



That angle we call the star's ***Sidereal Hour Angle*** (SHA) the SHA of the stars normally useful for navigation is in the almanacs. To determine the position of any star at any time we have only to find the GHA of Aries and add it to the star's SHA; to make this possible the almanacs tabulate the GHA of Aries in the same way as the Sun. (**Fig 6**).

LOCAL HOUR ANGLE

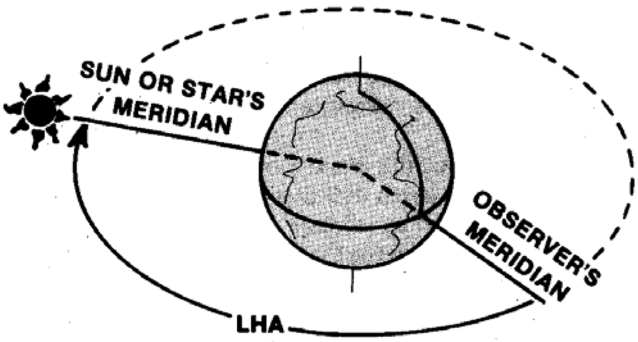
There is a further Hour Angle of great importance in celestial navigation: ***Local Hour Angle*** (LHA). This is simply the angle (measured again westwards) between our own ship's (local) meridian (our longitude) and that of the Sun or star. We'll deal with this in more detail later. We should remember too that hour angles are not fixed like longitudes; they increase at the rate of 15 deg per hour, the rate at which the earth is revolving (**Fig 7**).

KEEPING TIME

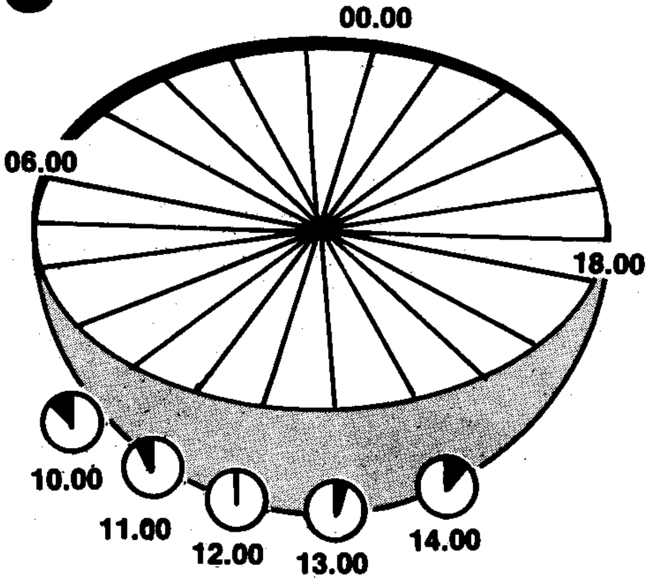
There is only one standard of time is used in celestial navigation. Irrespective of the time kept by the local clocks we always use **Greenwich Mean Time** (also known as **Universal Time**, and **Zone Time Zulu**,) wherever we may be in the world. Almanac data are always given in GMT, and we'd confuse ourselves quite unnecessarily if we attempt to use any other time standard (**Fig 8**).

The accuracy of the time we keep is important too. Until John Harrison invented his chronometer in the 18th century the determination of longitude was very difficult indeed, but nowadays we are fortunate in having cheap and accurate - quartz clocks and watches which can reliably show GMT within a few seconds for long periods. We are also fortunate in that time signals are broadcast by radio all over the world to enable us to check the accuracy of the time keepers we use for navigation. Even the best quartz clocks can gain or lose, and we should not miss an opportunity of checking their accuracy. An unsuspected timing error of only ten seconds can cause an error of **1.6 miles** in longitude if applied to a sun-sight in the latitude of the English Channel; at the equator it's an error of **2.5 miles** (**Fig 9**).

7 LOCAL HOUR ANGLE



8 GREENWICH MEAN TIME



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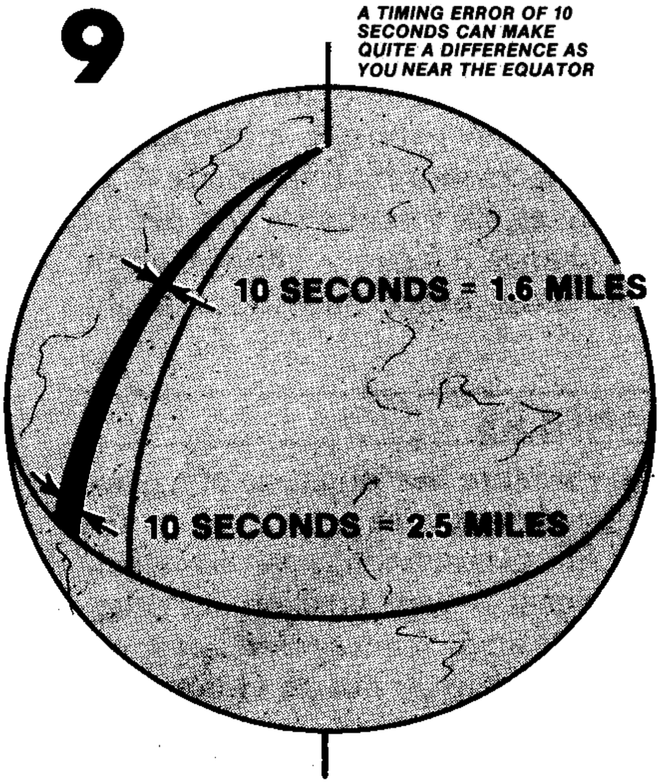
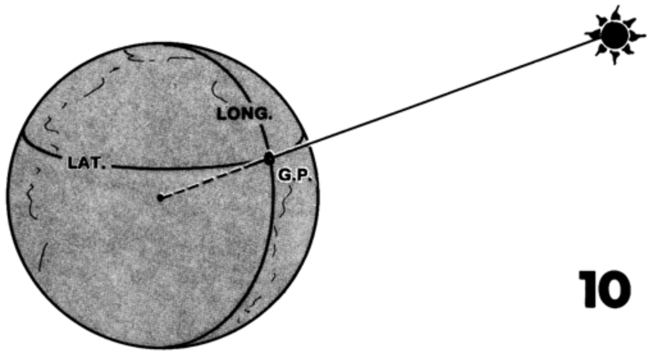


So How Do We Use Those Angles?

GEOGRAPHICAL POSITION

If at any instant in time we draw an imaginary line from the centre of the earth towards a heavenly body that line will pass through the earth's surface at a certain point. If then we stand on that point we will find the star or what ever directly overhead, in what we call our ***zenith***. The point is our ***geographical position*** (GP) and also that of the star. Every heavenly body has an instantaneous GP which of course changes as the earth revolves. (**Fig 10)**. We can define its position in terms of latitude and longitude.



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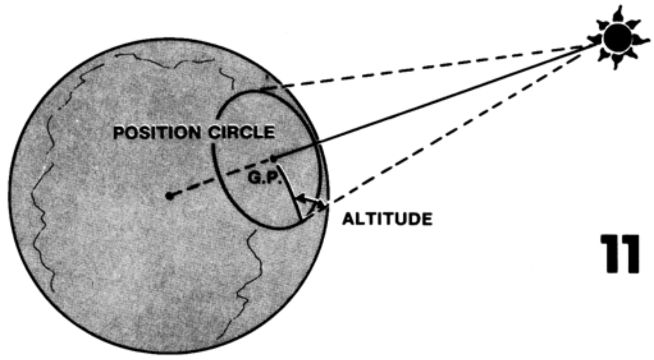
Were we able to move rapidly several hundred miles from the GP we would then see the body at a lower angle of elevation (we call it ***altitude)*** than its previous 90 deg. That would be so no matter in which direction we move away from the GP. Thus we might be standing anywhere on a circle centred on the GP; we call it a ***position circle*** and from any point on it the altitude of the body is the same. We can accurately measure with a sextant the angle between the body and our local horizon, noting at the same instant the exact time of the observation if it is to mean anything (**Fig 11**), but this doesn't define unambiguously our exact position on earth. We might however repeat the process with a different star, and then draw a second position circle which would intersect with the first, but in two places (**Fig 12**) so we are still uncertain at which intersection we stand. We resolve this by noting the directions of each of the two stars; from only one of the two possible positions will we see the stars on those bearings, so we can eliminate the other. We call each bearing the ***azimuth*** of each star: another angle which is important in finding our position by celestial navigation.



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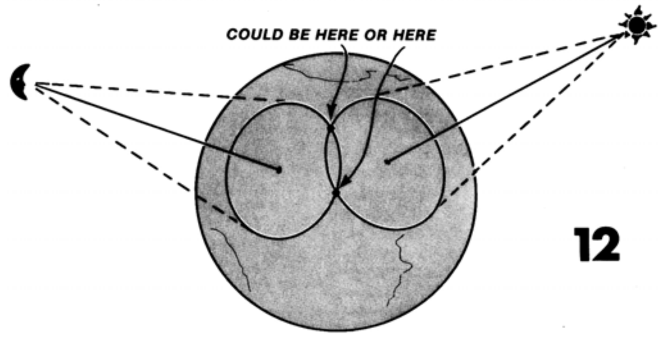

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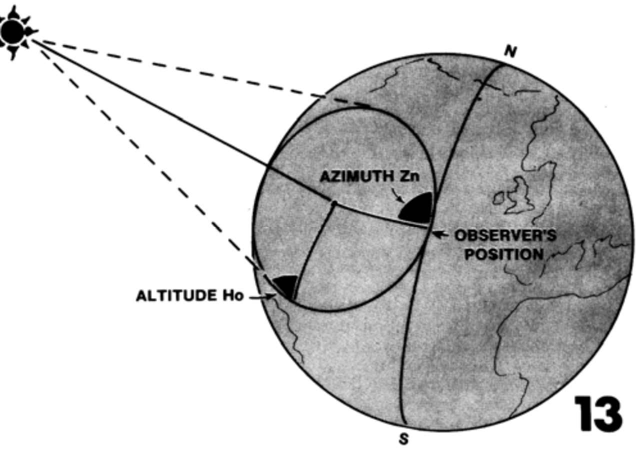
POSITION LINES IN PRACTICE

Now all the foregoing is theoretical, for in real life no chart of a suitable scale would be large enough to enable to enable us to draw in the whole of two huge position circles. In practice we just draw a short section of each position circle in the region where it intersects with the other. These position lines are strictly arcs of the position circles, but the radius of the circles is so great that a straight line is a reasonable approximation to a short arc. If we can obtain a third position line from yet another star it will give us confidence in the first two, in the same manner as when we take visual or radio bearings.

IN A NUTSHELL

To obtain a position line we must find the altitude and azimuth of a suitably placed body whose own position in the sky is known from the almanac, and to obtain that we must know the date and exact time of our observation (**Fig 13**).

To obtain a position we must make at least two such observations.



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THE IRONMONGERY

The hardware and software needed for basic celestial navigation is neither extensive nor very expensive.

A clock, this year's nautical almanac, a sextant and either a set of sight reduction tables or a scientific calculator. A quartz clock should keep time to within a second or two a week, and should preferably have a separate sweep second hand. Pressing buttons with cold fingers can give curious results. It should be permanently set to GMT and checked against radio time signals regularly, and when not in immediate use should be kept locked away from meddling fingers. You *can* use your ordinary wristwatch but then be doubly alert for time-keeping errors.

THE ALMANAC

The almanac may be the one with which we are already familiar; all almanacs give the ***ephemerides*** (the time-tables of the heavenly bodies) as well as much other useful data. We need to be able to find the declination and Greenwich Hour Angle of each body at the exact time we observe it by sextant. *Reed's* and the *Admiralty Nautical Almanac* tabulate these figures in degrees and minutes of arc; *Macmillan* does this in degrees and decimals of a degree, which some navigators find convenient when using a pocket calculator for sight reduction. The *Admiralty* Almanac gives data at more frequent intervals of time, so needs less interpolation when working out examples of declination and GHA. The choice is yours.

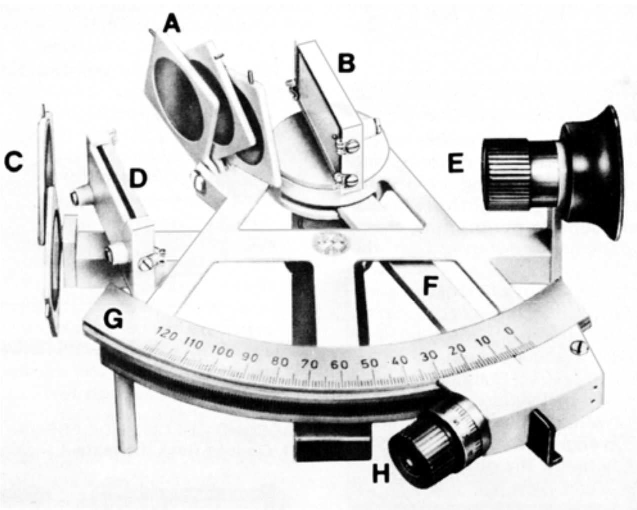


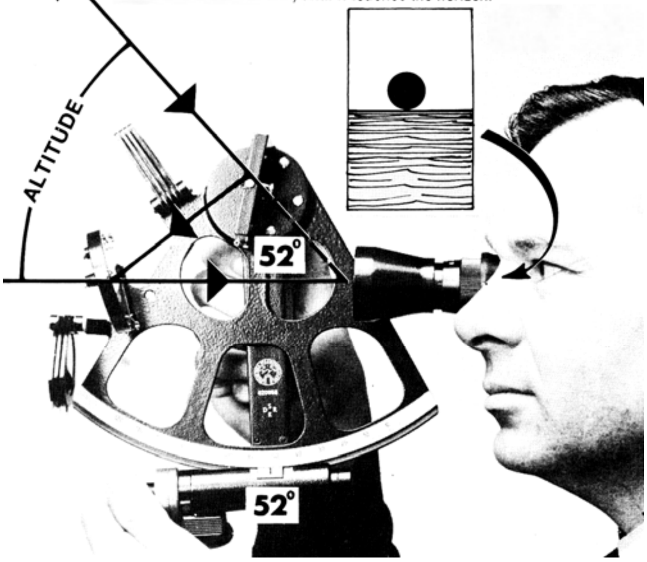
FIG 14 PARTS OF THE SEXTANT
(A) Index Mirror Shades (B) Index Mirror (C) Horizon Glass Shades (D) Horizon Glass (E) Telescope (F) Index Arm (G) Arc — Scale in Degrees (H) Micrometer Drum — Scale in Minutes

THE SEXTANT

A good quality sextant is obviously capable of giving better results in skilled hands than a cheaper one, but skill and practice is more important than cost. A medium priced metal one, like the ZEISS DRUM SEXTANT, **(Fig 14)** will last a lifetime, if looked after. Quite adequate positions may be obtained with a low-cost plastic sextant, like the DAVIS MK15, if we understand its limitations and allow for its errors. We should know what these errors are, and spend a little time considering what a sextant is and what it does.

KNOW YOUR SEXTANT

A typical instrument shown in **Fig 14**; is a very delicate and precisely constructed optical device capable of measuring angles up to 120 deg with a high degree of accuracy (to fractions of a minute of arc) between the horizon and heavenly bodies, and between landmarks prominent in coastal navigation. The optical path traced by a ray of light from the Sun or star is via the movable index mirror and the fixed horizon glass to the telescope and so to the observer's eye (**Fig.15**). In older patterns of sextant the horizon glass is reflective on the right-hand half only; the left-hand side remains transparent. Some modern sextants have full-view mirrors which are both reflecting and transparent for the whole width of the horizon glass. In both types the object is to adjust the index bar until the reflection of the heavenly body is level with the horizon; when that happens the angle indicated on the arc of the sextant is equal to the altitude of the body (**Fig 15**). Whole degrees are measured on the arc itself and minutes on the micrometer drum. The reason the arc goes beyond 90 deg is so that the instrument may be used to measure angles between coastal landmarks; not an 'astro' feature at all. A set of graduated filters for both the index mirror and the horizon glass enables us to reduce the glare from the Sun and/or the horizon for the comfort and safety of the observer's eye. The telescope is useful when sighting on a faint star; in some sextants several telescopes of different powers are

Fig 15. *Both the Sun and horizon are viewed, at the same time, through the sextant. The reflection of the sun is brought down, by moving the index arm, until it touches the horizon.*


interchangeable to suit the conditions. Sometimes a star which is invisible to the naked eye at twilight may be visible through the telescope.

LOOK AFTER IT

If it is to remain accurate, a sextant must be handled gently and stored with care. The slightest blow will distort the optical system and make nonsense of the measurement it makes. Keep it in its box except when in actual use and stop compulsive fiddlers from playing with it. Keep it clean and dry, especially wiping rain and spray from the mirrors with a clean handkerchief or chamois spectacle cleaner. The adjustment screws must *never* be moved unless you know exactly how to correct sextant errors.

INDEX ERROR

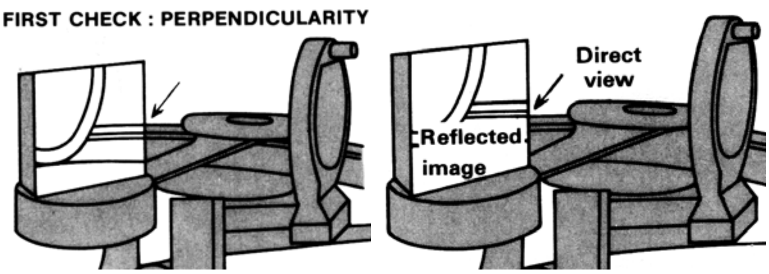
The main error to know about is ***index error;*** this is the difference between the actual angle measured by the sextant and its scale reading. If we look at the same distant object directly through the horizon mirror and indirectly through the optical system the angle measured on the arc should ideally be zero. But this rarely happens in practice, and it is sometime difficult to remove an index error of less than a few minutes of arc. As long as this error is known (up to, say, four or five minutes) it can be allowed for in calculating the true altitude.

Before we take any sight we should check the index error and write it down there and then in the sight form or log book. Some plastic sextants may change index error while in use in warm sunshine; with these it's wise to check the error before *and after* taking sights and to make allowances accordingly.

Index error may be in such a direction as to make the scale reading too high or too low. When checking the error before taking a sight we bring that distant object (perhaps the horizon line) into coincidence with itself in both images. If the scale reading is ***below*** the zero graduation (to its right, and 'off the arc') the error will be ***positive*** (plus) and must be added to the scale reading. If above zero (to its left, 'on the arc') it is ***negative*** (minus) and must be subtracted.

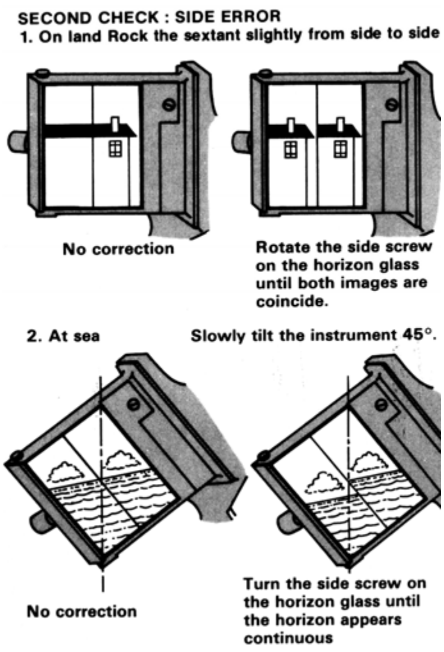
The other possible errors are of perpendicularity (the index mirror is not exactly perpendicular to the frame) and side error (the horizon glass not being perpendicular to the plane of the sextant). These errors are adjustable by means of the screws at the back of the mirrors, but it is not advisable to alter these until one has some knowledge of sextants.

SEXTANT ERRORS



FIRST CHECK : Perpendicularity

Set the index arm in the middle of the arc, between 50 and 60 degrees, and hold the sextant with the Index mirror up and towards you. You might have to take off the telescope to perform this check properly. Closing one eye, turn the sextant until you see in the index mirror the reflected image of a part of the graduated arc and, on the right of the mirror, the arc itself. If both are joined in a straight line, the instrument is set up correctly. If the reflected image is above the direct view, the mirror is inclined forward. Unwinding the screw will bring the image in alignment. Do the reverse if the image is below the direct view.



SECOND CHECK : Side Error

When you have brought both images at the same level, rock the sextant slightly from side to side. You should see one clear image of the house or bridge. If you see two separate images, turn the side screw on the horizontal glass until they coincide as one.

At sea, the only way to perform this check with the horizon is to slowly tilt the instrument 45 degrees. The horizon should still appear continuous. If it does not, keep the sextant tilted and turn the side screw on the horizon glass until it lines up exactly with its reflected image.

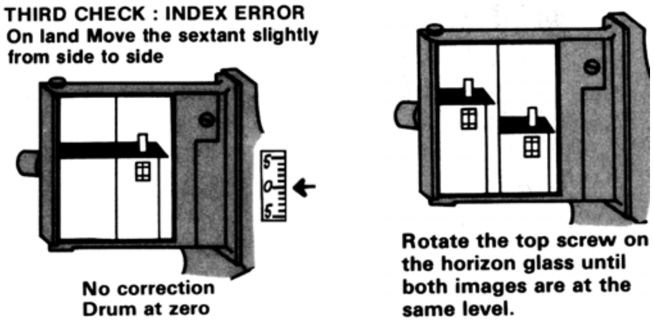
As this adjustment also involves the position of the horizon glass, the other adjustments might become altered. Accordingly, both adjustments should be rechecked several times until both are satisfactory.

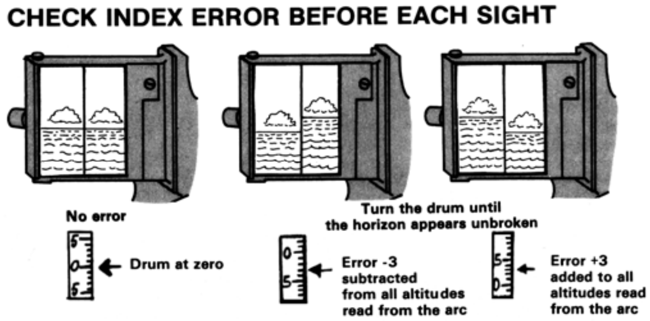
THIRD CHECK : Index Error

If you have removed the telescope, put it back on the sextant. Set the index arm on zero and sight an object with sharply defined contours and at least one mile distant, like a bridge or a roof of a large house. Adjust the telescope to your sight. If the reflected image is at the same level as the direct image, the instrument is set up correctly. If it appears above or below the latter, rotate the top screw on the horizon glass until they are at the same level. At sea, an alternative method is to sight the horizon.

While these adjustments are easy to perform, the less adjusting done the better, for if the screws become loose, the instrument will not subsequently stay in adjustment.

Let's stick to our first rule: check the index error each time you take a sight and apply the correction to the reading rather than attempting to adjust it aboard a boat in motion. However, if adjustments are needed at frequent intervals or if index error varies much, the sextant should be sent to a professional for repairs.





WHEN AND HOW DO WE TAKE SIGHTS?

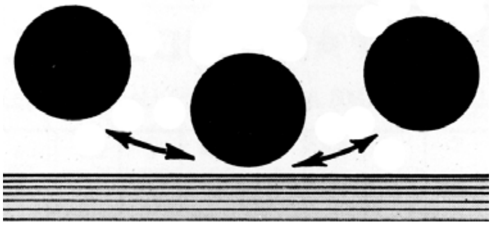
Sights are possible whenever we can clearly see the horizon at the same time as an identifiable celestial body. Generally speaking, the horizon is not visible at night, and the only bodies visible by day are the Sun and perhaps the Moon if she happens to be up. In practice therefore we are usually limited to taking Sun-sights by day and all other sights during the short period of twilight at dawn when the horizon is just becoming visible but the stars haven't yet faded, and at dusk when the stars are coming out but we can still see the horizon. Sometimes the planets *Venus* and *Jupiter* are bright enough and suitably placed in the morning or evening sky for us to sight them after dawn and before dusk. The almanacs will tell us if and when we have this option.

A partially-overcast sky doesn't necessarily prevent us from snatching a quick sight through a temporary break in cloud cover, but this needs skill and practice, especially with star-shots when we may not be certain of the identity of a star in the absence of its neighbours. When the horizon is hazy or ill-defined it's rarely worth the effort of taking sights for they can never be very accurate. The easiest shot of all is to find our latitude by the Sun's altitude at local noon; we'll consider that in detail on a later page.

STAND FIRM

It's not easy to take accurate sights from a small boat in a seaway. We can gain useful experience from taking practice shots ashore where the horizon stays level and the ground doesn't pitch and roll and yaw. Anyone living inland and unable to see a true sea horizon can practice by using a distant skyline instead; the altitudes won't be correct but the technique of 'bringing the star down' will be the same as at sea. Further practice from a boat at her mooring will begin to teach us how to compensate for the boat's motion when we tackle the job in earnest. In all these exercises our stance is important; we stand firmly but in such a position that our upper bodies can sway and swivel in the opposite direction to the boat's movements if we are to keep the Sun or star visible in the horizon glass. In most small craft there are two positions where we can do this: one is on deck with an arm round the shrouds and the sextant on a lanyard round the neck for safety. The other is in the cock' pit, wedged against the after end of the cabin top, or perhaps in the hatch itself.

The higher position is better if there is any sea running, as it reduces the chances of the line of the horizon being broken by intervening waves. In calmer weather the lower height of eye gives a firmer horizon, since it is nearer than when seen from higher up. From both standpoints we should be sure that we are not sighting on a false horizon made by a wave top, and in really lumpy conditions the boat should be hove-to to minimize her motion. The sextant must be absolutely upright at the moment we take the altitude; to achieve that we rock it a few degrees on either side of the vertical while adjusting the micrometer until we are sure that the body is just in contact with the horizon.



THE HEAVENS IN MOTION

We have also to deal with the problem that not only is the boat and our sextant in constant motion but so as well are all the heavenly bodies, and we have to measure their changing altitudes at a precisely known instant in time if our sights are to be of any use. The best aide in this is a colleague who has charge of the chronometer and can be trusted to write down correctly the time to the nearest second when the chap with the sextant says ***'Now'***, after a preliminary warning to ***'standby'***. That's what we say when we're confident that we've brought the body to the horizon and are satisfied that despite all the movements of boat and stars the angle obtained is accurate. The timekeeper should always write down the seconds first before he's lost track of them; the minutes and hours can follow at comparative leisure.

An alternative method is to use a stop watch which has been synchronized with the chronometer at an exact minute shortly before beginning to take a sight. If the watch is stopped at the moment of truth its reading added to the time at which it was synch'ed will be the time of the sight. For the single handed sight taker there are small quartz stop-watches which may be clamped to the handle of the sextant; they can be operated without having to release one's grip on the instrument. Whichever method is used, the sextant reading should immediately be recorded alongside its time before the numbers get lost.

It's a good idea to keep a sight book or a pad of sight forms on which to record the times and altitudes of all astro sights taken; this not only makes it easier to remember the next step in the calculations but also eliminates errors in transcribing data from the deck log or a scrap of paper.

AVERAGES GIVE BETTER ANSWERS

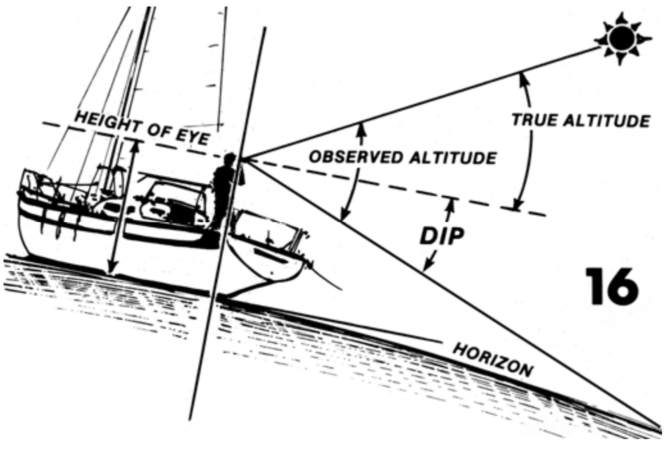
A useful trick to remember when sights are taken of a body which is rising or setting fast (ie not near the meridian) is to set the sextant to a reading just above (for a rising body) or below (for one which is setting) and to await the moment the body touches the horizon and record that time without having to fiddle with the micrometer. In this way several readings may be taken of the same body in quick succession; if the readings and the times are averaged the answer obtained should be better than any angle reading. It also eliminates any 'rogue' reading of the chronometer or sextant when (with a little practice) we can spot a time or altitude which is not 'in line' with the others, and leave it out of the averaging process.

OBTAINING TRUE ALTITUDE

We might think that having taken an accurate sight with a good sextant we have only to correct it for index error to obtain the true altitude of a celestial body, but there's more to it than that, and it's not due to the observer or his sextant. There are further corrections to be made for the ***dip of the horizon***, for atmospheric ***refraction*** and in the case of the Sun and Moon for ***semi diameter***. For the Moon and planets there's a correction for ***parallax*** as well. We'd better consider all these extra corrections separately:

DIP

The dip of the horizon is due to the fact that since our eye level is always above ground (or sea) level we must be looking downwards at a small angle when scanning the visible horizon. Our line of sight is below the true horizontal, which is 90 degrees from the zenith, so the angle our sextant measures between a body and the visible horizon is greater than it should be by that angle of dip. We must subtract it to obtain true altitude. The size of this angle depends on our height of eye; the greater the height the larger the angle, (**Fig 16**). There are suitable tables in *Reed's* and *Macmillan*.



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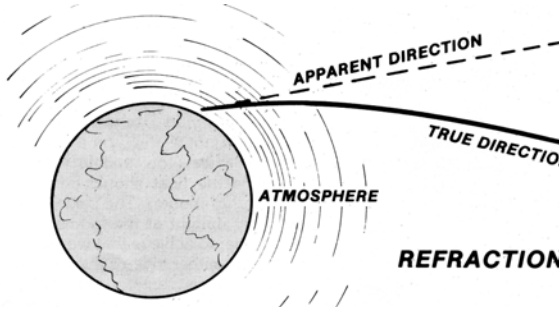
REFRACTION

Refraction is the amount by which light rays are bent as they pass through mediums of differing density, as a stick appears bent when partly-immersed in water. The earth's atmosphere is most dense near the surface but decreases with height, so that the light from the Sun and stars passes through air of increasing density and the rays are bent as they approach us, but the sextant has no way of knowing this, and it measures the ***final*** angle of approach (**Fig 17**).



REFRACTION 17

Refraction is greatest at low angles of elevation, because those rays take a longer path through the atmosphere; we try to avoid taking sights on bodies whose altitude is less than about 15 degrees. There are refraction tables in *Reed's* and a formula is *Macmillan* which achieves the same end. The correction is always subtracted from the observed altitude, and has the same value for all heavenly bodies.

We can save ourselves a small amount of calculation by using the various Altitude Correction Tables in the almanacs; these combine the effects of dip and refraction into a single table. The most widely used of those is the **Sun Altitude Total Correction Table** in *Reed's* and *Macmillan* and there are similar tables for the Moon the stars and the planets. The word '**total**' is slightly misleading in this context, for we still must correct our Sun and Moon altitudes for monthly change of semi-diameter.

SUN ALTITUDE TOTAL CORRECTION TABLE

LOWER LIMB.ADDITIVE.(+) Height of the eye above the sea. Top line metres, lower line feet

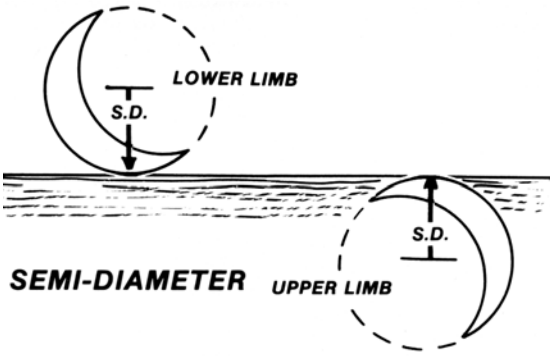
Obs. Alt.		0.9	1.8	2.4	3	3.7	4.3	4.9	5.5	6	7.6	9	12	15	18	21
	0	3	6	8	10	12	14	16	18	20	25	30	40	50	60	70
	'	'	'	'	'	'	'	'	'	'	'	'	'	'	'	'
10	10.8	9.1	8.5	8.1	7.9	7.5	7.2	7.0	6.7	6.6	6.0	5.5	4.7	3.9	3.3	2.7
11	11.3	9.6	9.0	8.6	8.3	8.0	7.7	7.4	7.2	7.0	6.4	6.0	5.2	4.4	3.7	3.1
12	11.7	10.0	9.4	9.0	8.7	8.4	8.1	7.8	7.6	7.4	6.8	6.4	5.6	4.8	4.1	3.5
	12.0	10.3	9.7	9.3	9.0	8.7	8.4	8.2	7.7	7.9	7.2	6.7	5.9	5.2	4.5	3.9
		10.6	10.0	9.6	9.3	9.0	8.7	8.5	8.2	8.0				5.5	4.8	4.2
		10.9	10.2	9.9	9.5	9.2	9.0	8.7	8.5		9.6	9.1			5.0	4.4
			10.5	10.1	9.7	9.5	9.2	8.9		10.3	9.8	9.4	8.5		5.2	4.6
38				10.3	10.0	9.7			10.8	10.5	10.0	9.5	8.7			4.9
42								11.2	10.9	10.7	10.2	9.7	8.9	8.2		5.0
46	15.2						11.5	11.3	11.0	10.8	10.3	9.8	9.0	8.3		5.2
50	15.3	13.6				11.9	11.6	11.4	11.1	10.9	10.4	9.9	9.1	8.4		
55	15.4	13.7	13.0	12.6	12.3	12.0	11.7	11.5	11.3	11.0	10.5	10.0	9.2	8.5	7.8	
60	15.5	13.8	13.1	12.8	12.4	12.1	11.9	11.6	11.4	11.1	10.6	10.2	9.3	8.6	7.9	
65	15.6	13.9	13.2	12.9	12.5	12.2	12.0	11.7	11.5	11.2	10.7	10.3	9.4	8.7	8.0	
70	15.8	14.1	13.3	12.9	12.6	12.3	12.0	11.8	11.6	11.3	10.8	10.3	9.5	8.8	8.1	7.5
80	15.9	14.2	13.5	13.1	12.8	12.5	12.2	11.9	11.7	11.5	11.0	10.5	9.7	8.9	8.3	7.7
90	16.0	14.3	13.6	13.2	12.9	12.6	12.3	12.1	11.9	11.6	11.1	10.6	9.8	9.1	8.4	7.8

MONTHLY CORRECTION	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	+0.3	+0.2	+0.1	0.0	-0.1	-0.2	-0.2	-0.2	-0.1	+0.1	+0.2	+0.3

All corrections except index error are included in this Table; observed altitude in the left hand column, height of eye across the top, and *change* in semi-diameter at the foot. Dip. refraction and parallax are allowed for automatically, as is most of the Sun's semi-diameter.

SEMI-DIAMETER

When we take a Sun-sight we bring the Sun's 'lower limb' (its bottom edge) into contact with the horizon, because that's easier and more accurate than trying to judge the exact centre, which is really the point we should sight on. Now the Sun and the Moon both have diameters of about 30 minutes of arc, and both change slightly as the distance between them and the earth varies with time and season. So we have to allow for the effect of the Sun's variable semi-diameter on its true measured altitude. This semi-diameter is 15.8 min at ***aphelion*** (its greatest distance from the earth) in early July, and 16.3 min at ***perihelion*** (its least distance) in January. To ignore this difference would be to introduce a half-mile error in our sights before any other error is taken into account. The secondary table at the foot of the **Sun Altitude Total Correction Table** in *Reed's* gives the monthly change in semi-diameter. The ephemeris pages in *Macmillan* give the same data.



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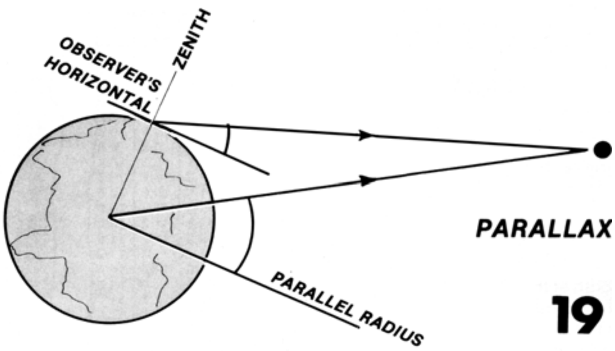
Note: that while the correct semi-diameter of the Sun is always **added** to its observed altitude, the monthly change is **negative** between May and September.

We deal in a similar way with the semi diameter of the Moon, but there is the added complication that at certain phases the lower limb is invisible, (**Fig 18**). So we then have to sight on whichever limb is visible to be 'brought down' to the horizon, the visible limb always being the one nearest to the Sun. If the lower limb, we add the semi-diameter for the day (it changes very rapidly), and if the upper we must subtract it. The monthly pages of the almanacs give SD values for every day of the month. The stars and planets offer no difficulty in this respect; we can regard them as point sources and their SD is negligible for the purposes of celestial navigation.

HORIZONTAL PARALLAX

The trigonometry on which we base our position calculations assumes that we take our altitudes from the centre of the earth, when in fact wherever we are on its surface we are nearly 4000 miles away from the centre. Unless the Sun or star is directly overhead we see it from a slightly different angle than from the centre; we call that difference ***parallax*** (**Fig 19**). In practice, the stars are so distant that the angular error is negligible for our purposes, but it cannot be ignored with the much nearer Moon and planets, and for maximum accuracy the Sun as well. The Moon's parallax can be as much as 60 minutes of arc, varying with its altitude, for the nearer planets about half a minute and the Sun up to 0.15 min, always at their lowest altitudes but reducing to zero in the zenith. The almanacs tabulate the values for different altitudes (and additionally for the planets *Venus* and *Mars* in the *Admiralty Nautical Almanac.)*



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Summarizing all this . . .

The completely corrected true altitude of a body is therefore:

(i) our ***sextant reading*** plus-or minus its ***index error***.

(ii) minus the ***dip*** of the horizon for our particular height of eye.

(iii) minus the angle of ***refraction*** appropriate to the approximate altitude of the body.

For the Sun we must also add

(iv) ***semi-diameter*** for the current month

(v) plus (if we wish) ***parallax*** for the altitude.

Most sight forms are printed with labelled slots for all these numbers, and so act as aides memoire for obtaining true altitude.

STAR OR PLANET ALTITUDE TOTAL CORRECTION TABLE

ALWAYS SUBTRACTIVE (–)

Height of Eye above the Sea. Top line metres – lower line feet

Obs Alt.	1.5	3	4.6	6	7.6	9	10.7	12	13.7	15	16.8	18	21.3
	5	10	15	20	25	30	35	40	45	50	55	60	70
9°	8.0	8.9	9.6	10.3	10.7	11.2	11.6	12.0	12.4	12.8	13.1	13.5	14.1
10°	7.4	8.4	9.1	9.7	10.2	10.6	11.1	11.5	11.8	12.2	12.5	12.9	13.5
11°	7.0	7.9	8.6	9.2	9.7	10.2	10.6	11.0	11.4	11.8	12.0	12.4	13.0
[illegible]	[illegible]	[illegible]	[illegible]	8.8	9.3	9.8	10.2	10.6	11.0	11.4	11.6	12.0	12.6
40°	3.3	[illegible]	[illegible]	[illegible]	[illegible]	9.4	9.9	10.3	10.6	11.0	11.3	11.6	12.3
50°	3.0	3.9	4.6	[illegible]	[illegible]	[illegible]	9.6	10.0	10.3	10.7	11.0	11.3	12.0
60°	2.7	3.6	4.4	4.9	5.5	[illegible]	[illegible]	9.7	10.1	10.4	10.8	11.1	11.7
70°	2.5	3.4	4.1	4.7	5.3	5.7	[illegible]	[illegible]	9.9	10.2	10.5	10.9	11.5
80°	2.3	3.3	4.0	4.6	5.1	5.5	6.0	[illegible]	[illegible]	[illegible]	10.3	10.7	11.3
90°	2.2	3.1	3.8	4.4	4.9	5.4	5.8	6.2	[illegible]	[illegible]	[illegible]	[illegible]	11.1

The above table contains the combined effects of Dip of the Horizon and Refraction and is therefore a total correction table for a Star or Planet. It is always subtractive.

Example: The observed altitude of a star was 32° 50′; and the height of observer's eye was 20 feet. What was the star's True Altitude?

Star's Observed Altitude .... 32° 50.0′
Correction from Table .... – 5.8′

Star's True Altitude .... 32° 44.2′

The time at which we took the sight will of course be the Greenwich Mean Time by the chronometer at the hours minutes and seconds of the '**instant of truth**' plus-or-minus the ***accumulated error*** since it was last checked against a radio time signal.

We take our first sights and use those numbers . . .

SUN SHOT FOR LATITUDE

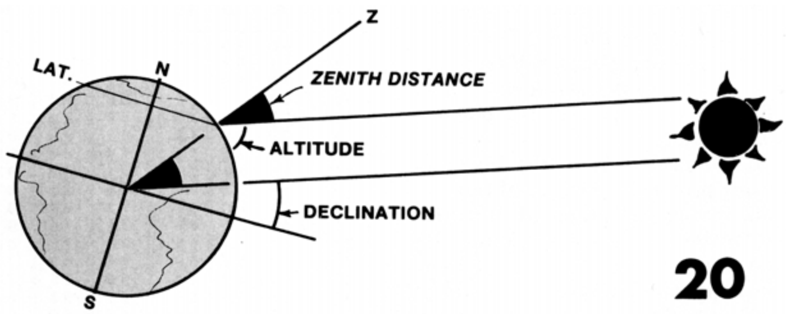
It takes more than one position line, and therefore sights on more than one body, to fix our position at sea. But a single position line can be helpful on occasion, as when we are approaching a coast after several days on passage and would like some confirmation of how far off we may be. Or we might like to know our latitude as a check on some uncomfortably large 'cocked hats' obtained by radio DF.

Finding the latitude of our position by the altitude of the Sun when it's in our local meridian is very easy indeed. It uses a single sight and in this instance needs no precise chronometer timing; but it's only valid at Local noon, i.e. when the Sun is due south (or in southern latitudes due north) of our position, irrespective of what the clock or chronometer time may be. So the first thing we have to decide when taking a **Lat – by – Mer – Alt** sight is at what clock time the Sun will be due south of our position, so that we can be on deck with the sextant ready about fifteen minutes beforehand. If we happen to be on the Greenwich meridian the Sun will lie due south at the time given in the monthly pages of the almanac as ***Greenwich Transit Time*** for the day's date. That's not necessarily at exactly noon GMT; it can be early or late by quite a few minutes known as the ***Equation of Time***. If we are not on the Greenwich meridian we must calculate the time at which it will cross our own *local* meridian, at the rate of four minutes *later* for every degree of longitude we are *west* of Greenwich, four minutes earlier for every degree east, and pro rata. (**1' long = 4 sec**.)

ON DECK WITH THE SEXTANT

We begin observing the Sun at about a quarter of an hour before the time we calculated to be its local meridian transit time. We bring its 'lower limb' (its bottom edge) down to the horizon so that it appears just to touch. The gap will open as the Sun continues to rise, but we close it until the time when the rise ceases: There will be a few seconds' 'dwell' at this point while the Sun's altitude is neither rising nor falling; this is its meridian altitude, and we must record the sextant reading immediately. When the altitude is obviously falling we can put the sextant away, but see a later paragraph about doing this trick when the sky is partly clouded.

To turn this observed altitude into a position line of latitude, we first correct the sextant reading by applying the index error and dip and refraction correction for the height of our eye above sea level and for the Sun's approximate altitude. Subtracting this figure from 90 deg gives ***zenith distance***, and adding the Sun's declination for the date and time (from the almanac) gives our latitude. **Fig.20.**



Here's a real-life example of this type of sight, taken in the western English Channel on Thursday 26 July 1984:

DR longitude: 4 deg 55 min west, equivalent to 19 min 40 sec of time. Sun's Greenwich transit time: 12h 06m. Therefore Sun's local transit time is 12h 25m 40s GMT. Plus one hour for BST so the sextant work began about 15 min before 13h 25m clock time.
Sun's declination at noon GMT = 19 deg 20.2 min, decreasing to 19 deg 19.1 min by 14h. Interpolating between these numbers gives dec at 12h 30 m as 19 deg 20.0 min.
Height of eye six feet; approximate altitude 59 deg; total correction added from table 12.9 min; index error minus 1.1 min.

	Deg	Min	
Sextant altitude :	58	55.2	
Index error : **minus**		1.1	
Total correction : **plus**		12.9	
Corrected altitude :	59	7.0	
Subtract from 90 deg (for zenith distance)	-90	00	
	30	53.0	
Add* declination	+19	20.0	
LATITUDE :	**50**	**13.0**	**North**

* because both **lat** and **dec** are north; we subtract if the 'names' are different.

SUN ALTITUD

LOWER LIMB.ADDITIVE.(+)

Obs. Alt.	0	0.9 3	1.8 6	2.4 8
	′	′	′	′
10	10.8	9.1	8.5	8.1
11	11.3	9.6	9.0	8.6
12	11.7	10.0	9.4	9.0
13	12.0	10.3	9.7	9.3
14	12.3	10.6	10.0	9.6
15	12.6	10.9	10.2	9.9
16	12.8	11.1	10.5	10.1
17	13.0	11.3	10.7	10.3
18	13.2	11.5	10.8	10.5
19	13.3	11.6	11.0	10.6
20	13.5	11.8	11.2	10.8
22	13.7	12.0	11.4	11.0
24	13.9	12.2	11.6	11.2
26	14.1	12.4	11.8	11.4
28	14.3	12.6	12.0	11.6
30	14.4	12.7	12.1	11.7
34	14.7	13.0	12.3	12.0
38	14.9	13.2	12.5	12.1
42	15.1	13.4	12.7	12.3
46	15.2	13.5	12.8	12.4
50	15.3	13.6	12.9	12.5
55	15.4	13.7	13.0	12.6
60	15.5	13.8	13.1	12.8
65	15.6	13.9	13.2	12.9
70	15.8	14.1	13.3	12.9
80	15.9	14.2	13.5	13.1
90	16.0	14.3	13.6	13.2

82 G.M.T. **JULY, 1984** (31 days)

⊙ **SUN**

DATE Day of Yr.	Mth.	Week	Equation of Time 0 h.	Equation of Time 12 h.	Transit	Semi-diam.	Lat. 52°N. Twi-light	Sun-rise	Sun-set
			m. s.	m. s.	h. m.	′	h. m.	h. m.	h. m.
183	1	Sun	+03 44	+03 50	12 04	15.8	02 56	03 44	20 23
184	2	M	+03 56	+04 01	12 04	15.8	02 57	03 45	20 23
185	3	Tu	+04 07	+04 13	12 04	15.8	02 58	03 46	20 22
186	4	W	+04 18	+04 23	12 04	15.8	02 59	03 46	20 22
187	5	Th	+04 29	+04 34	12 05	15.8	03 00	03 47	20 22
188	6	F	+04 39	+04 44	12 05	15.8	03 01	03 48	20 21
189	7	Sa	+04 49	+04 54	12 05	15.8	03 02	03 49	20 21
190	8	Sun	+04 58	+05 03	12 05	15.8	03 03	03 50	20 20
191	9	M	+05 07	+05 12	12 05	15.8	03 04	03 51	20 19
192	10	Tu	+05 16	+05 20	12 05	15.8	03 06	03 52	20 18
193	11	W	+05 24	+05 28	12 05	15.8	03 07	03 53	20 17
194	12	Th	+05 32	+05 36	12 06	15.8	03 08	03 54	20 16
195	13	F	+05 39	+05 43	12 06	15.8	03 10	03 56	20 15
196	14	Sa	+05 46	+05 49	12 06	15.8	03 11	03 57	20 14
197	15	Sun	+05 52	+05 55	12 06	15.8	03 12	03 58	20 13
198	16	M	+05 58	+06 01	12 06	15.8	03 14	04 00	20 12
199	17	Tu	+06 03	+06 06	12 06	15.8	03 16	04 01	20 11
200	18	W	+06 08	+06 11	12 06	15.8	03 17	04 02	20 10
201	19	Th	+06 13	+06 15	12 06	15.8	03 19	04 04	20 08
202	20	F	+06 16	+06 18	12 06	15.8	03 21	04 05	20 07
203	21	Sa	+06 20	+06 21	12 06	15.8	03 22	04 06	20 06
204	22	Sun	+06 22	+06 24	12 06	15.8	03 24	04 08	20 04
205	23	M	+06 25	+06 25	12 06	15.8	03 26	04 09	20 03
206	24	Tu	+06 26	+06 27	12 06	15.8	03 27	04 10	20 02
207	25	W	+06 27	+06 27	12 06	15.8	03 29	04 12	20 00
208	26	Th	+06 28	+06 28	12 06	15.8	03 31	04 13	19 59
209	27	F	+06 27	+06 27	12 06	15.8	03 32	04 14	19 58

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
′	′	′	′	′	′	′	′	′	′	′	′
+0.3	+0.2	+0.1	0.0	-0.1	-0.2	-0.2	-0.2	-0.1	+0.1	+0.2	+0.3

⊙ **SUN — July, 1984 — ARIES** **85**

G.M.T.	SUN G.H.A.	SUN Dec.	ARIES G.H.A.	G.M.T.	SUN G.H.A.	SUN Dec.	ARIES G.H.A.	G.M.T.	SUN G.H.A.	SUN Dec.	ARIES G.H.A.	G.M.T.
	Monday, 16th July				**Saturday, 21st July**				**Thursday, 26th July**			
h	° ′	° ′	° ′	h	° ′	° ′	° ′	h	° ′	° ′	° ′	h
00	178 30.4	N21 22.4	294 00.8	00	178 25.1	N20 28.9	298 56.5	00	178 23.1	N19 26.8	303 52.2	00
02	208 30.3	21 21.6	324 05.7	02	208 25.0	20 27.9	329 01.4	02	208 23.1	19 25.7	333 57.1	02
04	238 30.2	21 20.8	354 10.6	04	238 24.9	20 27.0	359 06.3	04	238 23.1	19 24.6	4 02.0	04
06	268 30.1	21 19.9	24 15.6	06	268 24.9	20 26.0	29 11.3	06	268 23.1	19 23.5	34 06.9	06
08	298 30.0	21 19.1	54 20.5	08	298 24.8	20 25.0	59 16.2	08	298 23.1	19 22.4	64 11.9	08
10	328 29.9	21 18.3	84 25.4	10	328 24.8	20 24.1	89 21.1	10	328 23.1	19 21.3	94 16.8	10
12	358 29.7	21 17.4	114 30.3	12	358 24.7	20 23.1	119 26.0	12	358 23.1	19 20.2	124 21.7	12
14	28 29.6	21 16.6	144 35.3	14	28 24.7	20 22.1	149 31.0	14	28 23.1	19 19.1	154 26.7	14
16	58 29.5	21 15.8	174 40.2	16	58 24.6	20 21.1	179 35.9	16	58 23.1	19 17.9	184 31.6	16

What if it is cloudy?

We might be able to take this sight even if the Sun is obscured from time to time by passing clouds. The idea is to note the altitude of the Sun at such intervals as the cloud permits, noting the time of each sight to the nearest minute or so, and continuing until well after the Sun has crossed the meridian and its altitude is decreasing. Say fifteen or twenty minutes before ***and after*** meridian transit. If we draw up a table and plot those figures on squared paper it should be possible to estimate the moment of transit even if the Sun was obscured at that instant. (**Fig 21)** gives the raw data for the sight described above, and (**Fig 22)** shows the data plotted on a suitable scale.

Time h	GMT m	Sextant deg	Altitude min	
12	00	58	29	
	05		41	
	10		44	
	15		48.5	
	20		53.2	
	23		54.0	
	25		54.0	(??)
	26		55.0	
	27		55.2	
	28		55.1	
	29		53.0	(oops!)
	31		53.5	
	32		53.1	
	33		52.0	
	37		48.5	
	40		44.9	
	45		39.0	

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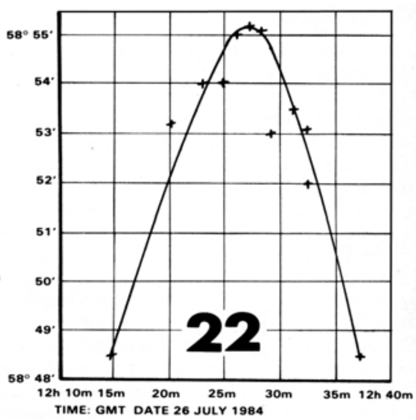
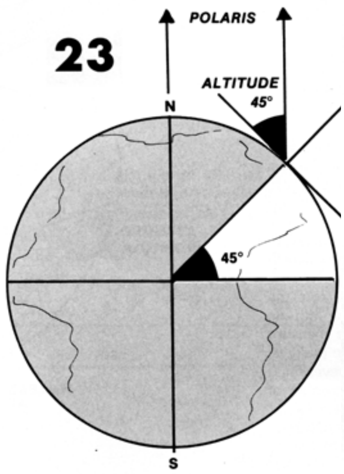
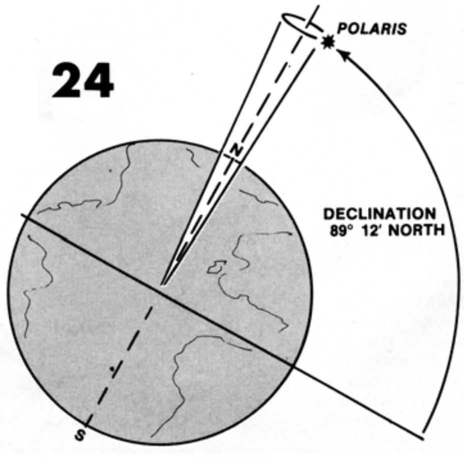


The maximum altitude reached by the Sun is more important than the time at which it happens, since any error in estimating our longitude will be reflected in the time at which the Sun will transit our local meridian, but its altitude will give us our correct latitude no matter how far wrong our longitude.



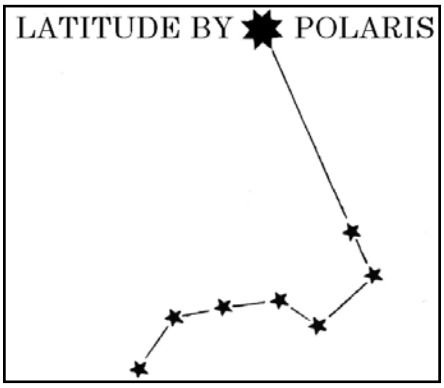


It’s a well-known idea that in the northern hemisphere **the altitude of the Pole Star above the horizon is the latitude of the observer’s position (Fig 23)**.

For navigating purposes that’s too rough an approximation, because ***Polaris*** isn’t exactly over the pole; it revolves around it at a radius of 48 minutes of arc. In other words it has a declination of 89 deg 12 min north (**Fig 24)**.

As with the Sun at local noon a single sight will give us a position line but in middle northern latitudes only; its altitude is too low in the tropics and uncomfortably high within the Arctic Circle.

However, ***Polaris*** isn’t a particularly bright star, nor easily discerned at evening twilight when the horizon is visible but the sky still bright. It’s easier to find ***Polaris*** at dawn, when it can be spotted while the sky is still dark and an eye kept on its position as the horizon becomes visible. In the evening we can sometimes find it by setting the sextant to the same angle as our DR latitude and sweeping the northern horizon until the star appears in the telescope.

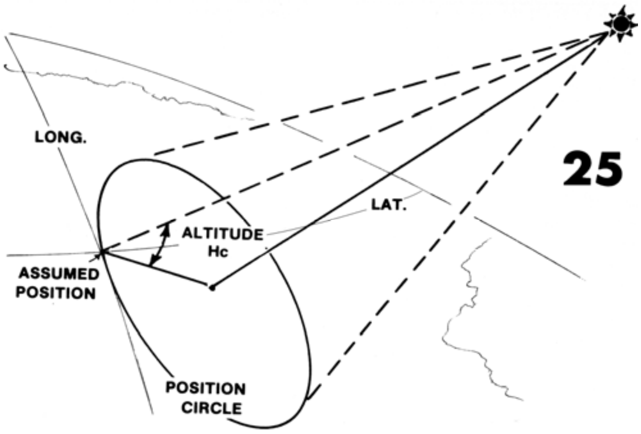


When we have taken our sextant altitude of ***Polaris*** and made the usual corrections for index error, for dip and for refraction there is a further correction to be made to determine our latitude. The effect of the star not being exactly over the pole is to make its measured altitude vary around the clock. At the time when the Local Hour Angle of ***Aries*** is 34 deg the altitude will be 48 min too low. When LHA ***Aries*** is 214 deg the altitude will be 48 min too high. Only when LHA ***Aries*** is 124 or 304 deg will the corrected sextant altitude be equal to our latitude. At intermediate times the amount of correction needed will be found in tables.

POSITION LINES IN GENERAL

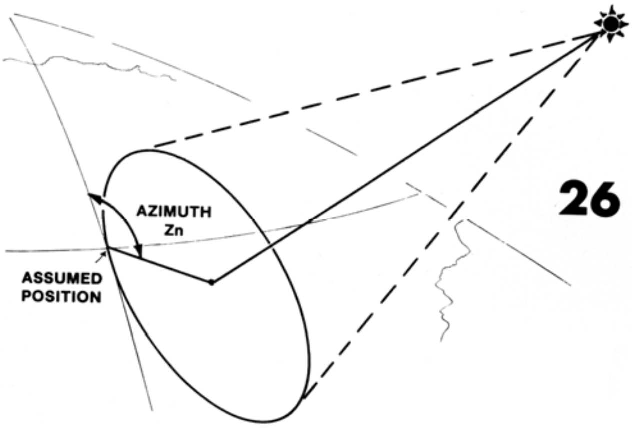
We’ve seen two different ways of finding our latitude by single sights; it’s unfortunate that we haven’t something similar and equally simple for finding longitude. True, we can find a position line of longitude when the Sun bears exactly due east or west, but unlike the latitude sights it has to be timed with precision; It is a particular example of the standard technique of plotting position lines from sights of celestial bodies. Let’s now examine that technique.

A few pages back we saw that to define a position line we must know the altitude (**Fig 25**) and azimuth (**Fig 26**) of a suitably placed body, one whose own position in the sky can be found in the almanac for the date and exact time at which we make the observation. We might find the azimuth by a compass bearing, but it would not be very accurate and in any case difficult when the Sun or star is high in the sky. We can however calculate it by a trig formula or determine it by reference to Sight Reduction tables in which the working has already been done for us. Another method is to use a programmable scientific calculator; more about that later.



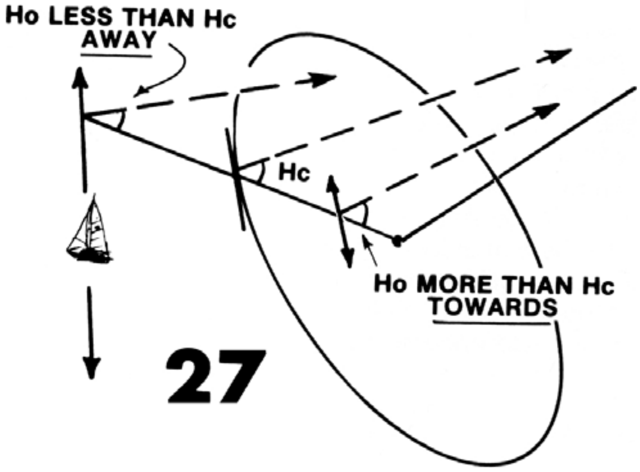
25

The azimuth, we remember, is a radius of the position circle, and it runs from the Sun or star's GP to our unknown position. Somewhere along that line we can draw our position line at right angles to the azimuth, at some as-yet unknown distance from the GP. Now, if we ***assume*** a certain position which compares reasonably well with our DR position we can calculate (or obtain from the Sight Reduction Tables) what the altitude would be from ***there***. If next we measure with the sextant what the altitude really is, the difference in minutes of arc (never mind the maths) turns out to be the number of nautical miles our true position line is distant along the line of azimuth from our assumed position. It then remains for us to decide whether we have assumed a position too far from the GP or too near.



26

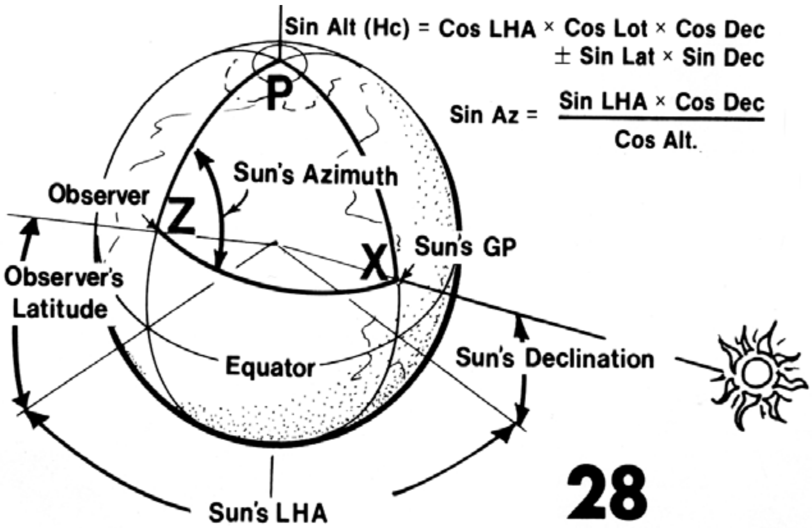
If our sextant altitude is ***greater*** than the calculated altitude we are in effect having to crane our necks to look up at a steeper angle, so our real position is evidently ***nearer*** the GP than our assumed position. But if the altitude we observe with the sextant (we call it Ho) is ***less*** than the calculated altitude (call it Hc) we must be **farther away**. We call the difference between Ho and Hc the ***intercept***, and name it ***towards*** or ***away*** from the GP, which is of course in the direction of the Sun or star (**Fig 27**).



27

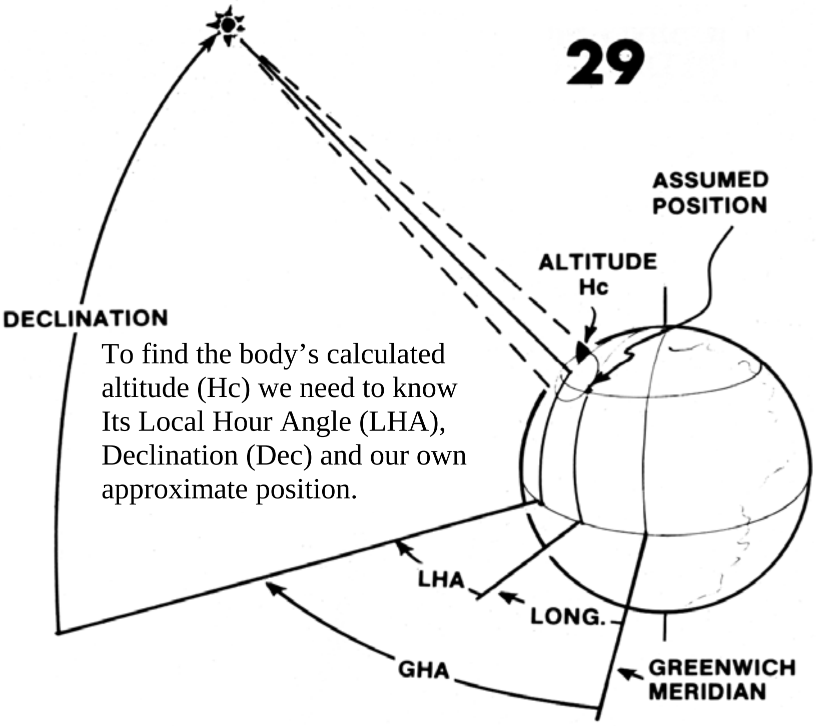
HOW TO FIND Hc.

We saw earlier how to obtain Ho, the corrected sextant altitude. We now have to find Hc, and to do that we must have a nodding acquaintance with the spherical triangle (See **Fig28**). The **PZX** triangle is like a flat triangle but stretched to conform with the surface of a sphere. All its sides lie on Great Circles; the corner P is always at the pole, the side **PZ** is along the observer's meridian of longitude and **PX** is on the meridian of Sun's GP. The angle **PZX** is the Sun's azimuth, one of the things we want to know.



28

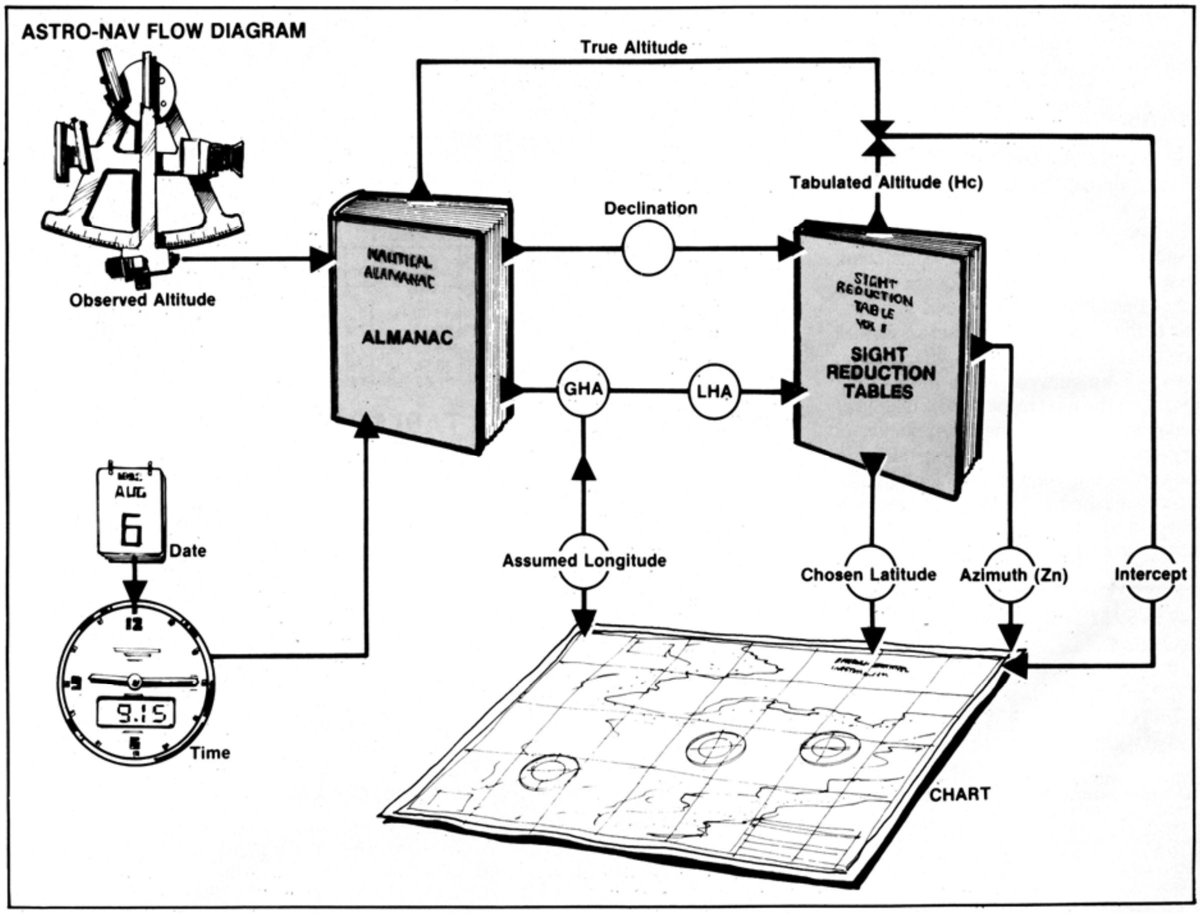
To find Hc, either by calculation or by tables, we need to know three things: the body's Local Hour Angle (LHA) and its declination (Dec) at the moment of sextant observation, and our own approximate latitude. To help us work out the LHA we need our own approximate longitude as well. Our lat and long we should already know roughly from our dead reckoning. The body's Dec at the current date and time we can find from this year's nautical almanac. Its LHA is the angle between our own longitude and that of the body's GP (angle **ZPX** in the triangle); we obtain that by finding from the almanac its Greenwich hour angle (GHA) at the time of our sight and adding our longitude (if we are east of the Greenwich meridian) or subtracting it if west.



When we know LHA, Dec and lat we're ready to tackle the rig formulae which will give us Hc and azimuth (**Fig 28 & 29**). We can do that with our scientific calculator, programmable or otherwise, or we can use the Sight Reduction Tables, which may be either the *Marine tables (NP401)* or the *Air tables (AP3270).*

There's no room here to go into the relative merits of both types of Sight Reduction Tables; suffice it to say that the *Marine tables* are compiled to the nearest tenth of a minute of arc, which is fine if we reckon to work to the nearest tenth of a mile, whereas the *Air tables* work to the nearest mile, which is possible the best that many small-craft skippers can hope to deal with. With both sets of tables we don't even need to know about those frightful formulae; we just look up the appropriate page which contains the LHA Dec and latitude in which we are interested.

The flow-diagram below shows the steps and equipment needed for each stage.



Using Sight Reduction Tables

We now have in theory enough data to obtain those desirable numbers Hc calculated altitude, and Azimuth **Z**. We have the sun's declination, its LHA and we should know our approximate latitude by dead reckoning. But the tables would be impossibly bulky if they printed data for every minute of arc of declination, Hour Angle and latitude. In fact they give data for every degree, so for simplicity we adopt an Assumed Position in the vicinity of our DR latitude and longitude which makes our latitude a ***whole number*** of degrees and our longitude such as to make LHA a whole number of degrees also. Thus we may go straight into the tables.

EXAMPLE OF DECIDING ASSUMED POSITION:

Given:

DR Lat 47° 45′ N. DR Long 05° 08′ W. GHA Sun 062° 45′

LHA Sun = GHA minus West long = 057° 37′

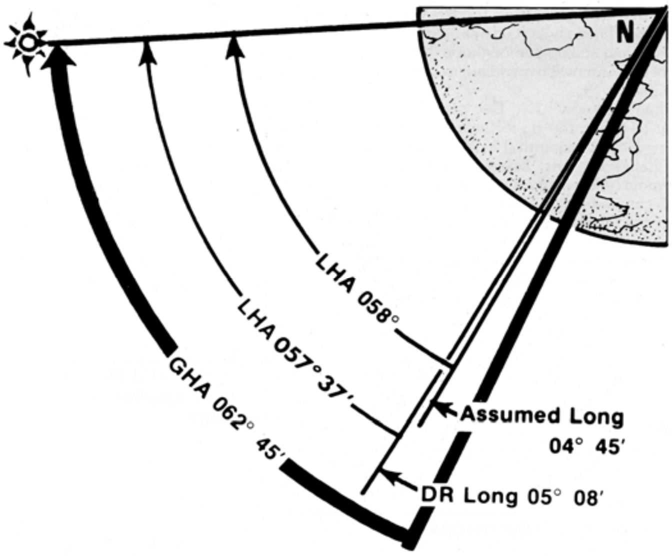
Nearest whole number LHA = 058°

Assumed long = 062° 45′ minus 058°

= 04° 45′ (which makes LHA 058° exactly)

Assumed lat = 48° 00′ N (nearest whole number to 47° 45′ N)

Picking a suitable Assumed Position.



SIGHT REDUCTION TABLES

In the Sight Reduction Tables we start at the pages for our Assumed latitude. There are several, variously labelled ***'Declination SAME NAME as Latitude', Declination CONTRARY NAME to Latitude'***, and for two bands of Declination: 0-14 degrees and 15-29 degrees. If we have been shooting the sun in the northern hemisphere during summer, both our latitude and the sun's declination will be ***North***, so we select the **SAME NAME** pages.

We have already determined the sun's declination from the almanac; in June and July it will exceed 15 degrees and will be included in the 15-29 degree pages. From mid-August it will be reducing from about 15 degrees to zero at the September equinox; it will then be found in the 0-14 degree section.

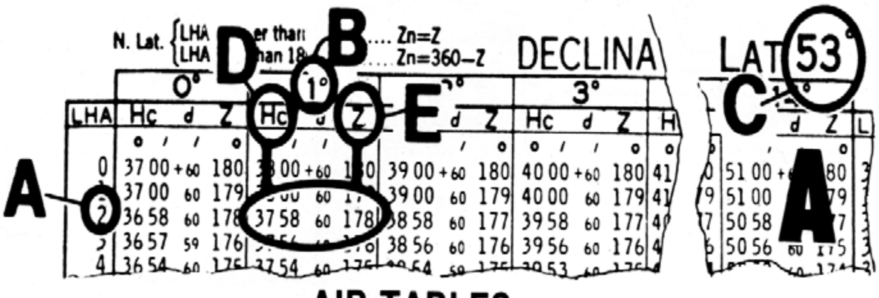
AIR TABLES

All pages of the 'Air' tables show LHA at the left and right-hand vertical edges and declination by whole degrees across the top. We read across from the calculated LHA to the column under the appropriate declination. In that column we read off values of Hc and **z**, the ***Calculated Altitude*** and ***Azimuth Angle*** of the heavenly body.

There is a small correction ***'d'*** which is the difference in minutes of arc between Hc in this column and that for the next higher whole degree of declination. **Correction *'d'***

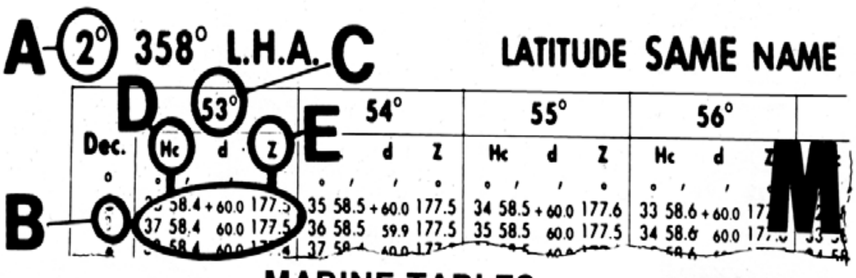
48	49	50	51	52	53	54	55	56	57	58	59	60	d ′
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	4	4	4	4	4	4	4	4	4

This aids the interpolation of intermediate angles of declination;



AIR TABLES

In both cases **A** = LHA, **B** = Dec, **C** = Lat, **D** = Calc. Alt. **E** = Az.
A, B, C, are what we know — D and E are what we want.



MARINE TABLES

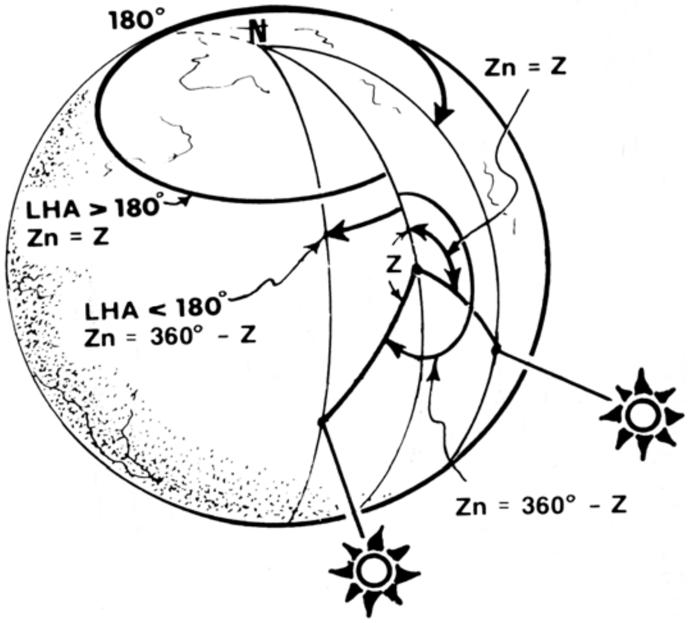
there is a loose card in the 'Air' tables which turns ***'d'*** into an adjustment to Hc.

To ignore it entirely in sun-shots entails a maximum position error of one mile.

To Find The Intercept

We now have a Calculated Alt to compare with our Observed Altitude and so obtain **Intercept**, the distance away from our **Assumed Position**.

Calculated Altitude (Hc)	35° 38′
Observed Altitude (Ho)	35° 28′
Intercept (Away)	10′

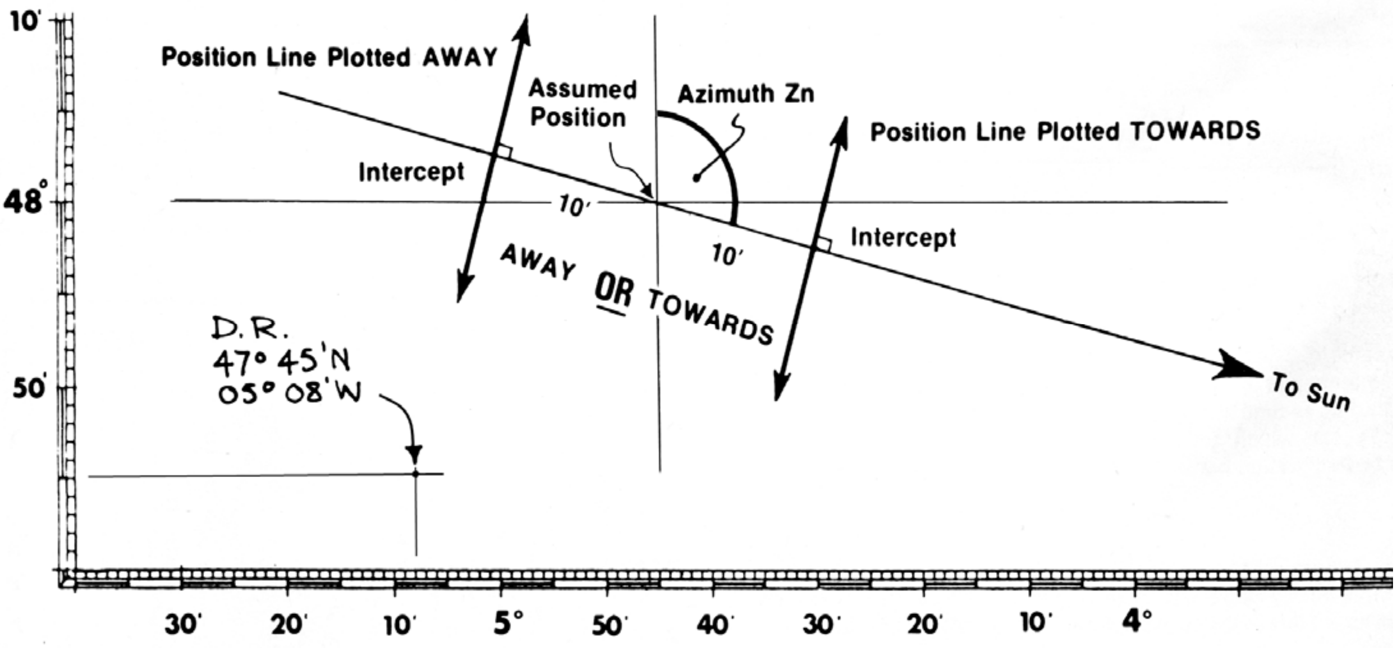


And we have an Azimuth Angle, Z, which may or may not be the True Azimuth, Zn. It is this angle Zn which we draw through our Assumed Position and along which we mark off the Intercept, and we decide which is which by the size of the LHA of the body. If LHA is *greater* than 180 degrees, Zn is equal to Z. If *less,* the required Zn equals 360 degrees minus Z. This rule applies only to the northern hemisphere; there is a comparable rule for southern latitudes.

So now we draw a line on the chart or plotting sheet, through our Assumed Position and in the direction of the True Azimuth Zn (°True). Along that line we mark off the intercept, the difference in minutes of arc between Ho and Hc. If Ho is greater than Hc we must be actually ***nearer*** the sun than our Assumed Position, so we mark off the Intercept **TOWARDS** the sun. If less, we are further off, and we measure the Intercept from the Assumed position **AWAY** from the sun. Through the resulting point of Intercept we triumphantly draw our position line at right angles to the azimuth. And there we are, *somewhere* along that position line. Or its extension in either direction .

It is a common fallacy at this stage to suppose that we now have a complete position fix. Alas it is not so, for the azimuth is not a position line. Had it been drawn from a different assumed position several miles to one side or the other the Azimuth would have been much the same, as the sun's GP is so far away. To obtain a real fix we must find at least one more position line to intersect at a good angle to cut. If that seems a chore, be assured that the second attempt is much easier than the first. What we have now covered in this part of the course is the most difficult of the whole; we're over the worst hurdle and I hope nobody's fallen too heavily.

WHICH WAY DO WE DRAW THE AZIMUTH?
If LHA is GREATER than 180 degrees, Zn is equal to Z. If LESS, the required Zn equals 360 degrees minus Z. This rule applies only in the northern hemisphere; there is a comparable rule for southern latitudes.



SIGHT REDUCTION FORM

Date 1982 MAY 10 Body observed SUN'S LOWER LIMB

D R Position Lat 46° 45' N Long 5° 15' W

Assumed Lat 47° 00' N

STEP ONE (TIME)

Deck Watch Time (GMT)	10h	15m	35s	
Deck Watch Error	−		05s	
Correct GMT =	10h	15m	30s	

STEP TWO (SEXTANT READING)

Sextant Altitude		51°	06.5'
Index Error	+		4.8'
Apparent Altitude (height of eye 8ft.)		51°	11.3'
Total Corr'n (Sun)	+		12.4'
True Altitude		51°	23.7'

STEP THREE (LHA & DECLINATION)

Tabulated GHA for 10h	330°	54.5'	Reed's p 72
Increment for 15m 30s	+ 3°	52.5'	Reed's p 127
GHA	334°	47.0'	
Chosen Long (W− E+)	− 4°	47.0' W	
LHA	330°	00'	
Tabulated Dec (& 'd')*	17°	35.1' N	Reed's p 72
Corr'n for d (increasing +)	+	0.2	Estimated
Declination (N or S)	17°	35.3' N	

STEP FOUR (INTERCEPT & AZIMUTH)

Tabulated Alt Hc (& 'd')*	51°	08' (+50)		Air Tables p 47
Corr'n for d	+	07'		Air Tables p 338
Corrected Tab Alt and Z	51°	15'	130°	
True Altitude	51°	23.7		From above
Corrected Tab Alt (Hc)	51°	15.0'		From above
Intercept =		8.7'		Towards/~~Away~~

Zn (= Z)† 130°

All the previous steps can be worked out on a SIGHT REDUCTION FORM. There are various pre-printed styles or you can make up your own. But which ever you choose, they act as an excellent 'aide-mémoire' when your mind gets a bit muddled!

Here Is a worked example, with extracts from the appropriate tables.

SUN ALTITUDE TOTAL CORRE

LOWER LIMB.ADDITIVE.(+) Height of the eye above the sea

Obs. Alt.	0	0.9 / 3	1.8 / 6	2.4 / 8	3 / 10	3.7 / 12	4.3 / 14	4.9 / 16	5.5 / 18	6 / 20
10	10.8	9.1	8.5	8.1	7.9	7.5	7.2	7.0	6.7	6.6
11	11.3	9.6	9.0	8.6	8.3	8.0	7.7	7.4	7.2	7.0
			9.4				8.1			
46	15.2	13.5	12.8	12.4	12.1	11.8	11.5	11.3	11.0	10.8
50	15.3	13.6	12.9	12.5	12.2	11.9	11.6	11.4	11.1	10.9
55	15.4	13.7	13.0	12.6	12.3	12.0	11.7	11.5	11.3	11.0
60	15.5	13.8	13.1	12.8	12.4	12.1	11.9	11.6	11.4	11.1
65	15.6	13.9	13.2	12.9	12.5	12.2	12.0	11.7	11.5	11.2
70	15.8	14.1	13.3	12.9	12.6	12.3	12.0	11.8	11.6	11.
80	15.9	14.2	13.5	13.1	12.8	12.5	12.2	11.9	11.7	11.
90	16.0	14.3	13.6	13.2	12.9	12.6	12.3	12.1	11.9	11.

Jan.	Feb.	Mar.	Apr.	May	June	July
+0.3	+0.2	+0.1	0.0	-0.1	-0.2	-0

Reed's p.125

G.M.T.	SUN G.H.A.		SUN Dec.		ARIES G.H.A.
	Monday, 10th May				
00	180	54.3	N17	28.6	22
02	210	54.3	17	29.9	2
04	240	54.4	17	31.2	2
06	270	54.4	17	32.5	
08	300	54.5	17	33.8	
10	330	54.5	17	35.1	
12	0	54.6	17	36.4	
14	30	54.6	17	37	
16	60	54.7	17	3	
18	90	54.7	17		
20	120	54.8	17		
22	150	54.8	N17		

Reed's p.72

SUN G.H.A. CORRE

Min. or Sec.	Add for Minutes	Min. or Sec.	Add for Secs.
	° '		'
0	0 0.0	30	7.5
14	3 30.0	31	7.8
15	3 45.0	32	8.0
16	4 0.0	33	8.3
		34	8.5

Reed's p.127

N. Lat. {LHA greater then 180°....... Zn=Z; LHA less than 180°........... Zn=360−Z

LHA	15° Hc	d	Z	16° Hc	d	Z	17° Hc	d	Z	29° Hc	d	Z	LHA
	° '	'	°	° '	'	°	° '	'	°	° '	'	°	
0	58 00	+60	180	59 00	+60	180	60 00	+60	180	00	+60	180	360
	57 59	60	178	58 59		178	59 59	60	178	9	60	177	359
29					51								358
30	49 27	+51	132	50 18	+50	131	51 08	+50	130	51 5	+42	117	330
31	48 56	51	131	49 47	50	130	50 37	50	129	51 2	42	116	329
32	48 25	50	130	49 15	50	129	50 05	49	128	50	42	115	328
33	47 53	50	128	48 43	49	128	49 32	49	127	50	42	113	327
34	47 21	49	127	48 10	49	126	48 59	49	125	49 7	41	112	326

Air Tables p.47

Declination (Air tables p.338)

42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	d '
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5
4	4	4	4	5	5	5	5	5	5	5	5	5	6	6	6	6	6	6	6
5	5	5	5	5	5	6	6	6	6	6	6	6	6	7	7	7	7	7	7
6	6	6	6	6	6	6	7	7	7	7	7	7	7	7	8	8	8	8	8
6	6	7	7	7	7	7	7	8	8	8	8	8	8	8	9	9	9	9	9

***** Not the same '**d**'.
The first is the change of declination per hour; from It we estimate change in the odd minutes and seconds after the tabulated hour.
The second '**d**' refers us to a correction table (Appendix 5 in the Air' Tables) which corrects the Tabulated Altitude for the odd minutes of Declination between whole degrees in the Tables.

† Whether Zn (azimuth of the body) is the same as Z (azimuth angle) or not depends on the value of LHA and in which hemisphere. There is a little note about this in the corners of each page of the Sight Reduction Tables.

STEP 1 CLOCK AND SEXTANT

DAY MONTH

DATE

° ' N S

D.R. LATITUDE

° ' E W

D.R. LONGITUDE

CLOCK TIME

H	M	S
FAST + SLOW –	M	S
H	M	S

CLOCK ERROR

GMT

CORRECTED TIME

SEXTANT ALTITUDE

	°	'
INDEX ERROR		'
TOTAL CORRECTION		' +
MONTHLY CORRECTION		' ±
CORRECTED OBSERVED ALTITUDE	°	'

STEP 2 NAUTICAL ALMANAC

GHA	H	°	'
INCREMENT FOR	H M	°	'
INCREMENT FOR	S		'
GHA		°	'

DEC	H	°	'	N S
INCREMENT	H	M	±	

DECLINATION ° ' N S

CHOSEN LONGITUDE ° ' E W ±

LHA °

LAT °

DEC °

STEP 3 SIGHT REDUCTION TABLES

CALC. Alt (Hc)	°	'
'd' CORRECTION FOR.......'DEC		'
CORRECTED CALC Alt (Hc)	°	'
CORRECTED OBSERVED ALTITUDE	°	'
INTERCEPT		'
	AWAY TOWARDS	

Obs. LESS = AWAY
Obs. GREATER = TOWARDS

'd' + –

Z °

Az ° T

LHA less than 180°
True Az = 360° -Z

Here is a different format, to help you through the steps. You might like to copy it for future use.

A RUNNING FIX BY ASTRO

We can in fact use the same body more than once, as in the classic case of position-fixing by the method called **Sun-Run-Sun**.

This is useful for obtaining a fix during daylight hours, when normally the only body visible for sights is the Sun. We take two position lines from the Sun at times sufficiently separated for its azimuth to have changed significantly between the two sights. Our first position line might be at any time earlier than two hours before local noon; ideally it could be at the time when the Sun's azimuth is due east, for the position line would then be a meridian of longitude. The second could be our latitude at local noon, so that the two position lines will inter sect at right angles for maximum precision.

Suppose that at 0830 GMT on 21 June this year we are in DR position 49deg 40min north, 15deg 00min west. We're making for the south west of Ireland on a course of 045deg true, speed 6 knots.

From the almanac and with a little interpolation we find that at 0830 the Sun's dec is 23deg 27min and its GHA is 307deg (ignoring decimals).

SUN – RUN – SUN

SUN — June, 1985 — ARIES

G.M.T.	SUN G.H.A.	SUN Dec.	ARIES G.H.A.	G.M.T.	SUN G.H.A.	SUN Dec.	ARIES G.H.A.	G.M.T.
	Friday, 21st June				**Wednesday, 26th June**			
h	° ′	° ′	° ′	h	° ′	° ′	° ′	h
00	179 35.9	N23 26.5	269 08.0	00	179 19.7	N23 22.3	274 03.7	00
02	209 35.6	23 26.6	299 13.0	02	209 19.4	23 22.1	304 08.7	02
04	239 35.3	23 26.6	329 17.9	04	239 19.2	23 22.0	334 13.6	04
06	269 35.1	23 26.6	359 22.8	06	269 18.9	23 21.8	4 18.5	06
08	299 34.8	23 26.6	29 27.7	08	299 18.6	23 21.6	34 23.4	08
10	329 34.5	23 26.6	59 32.7	10	329 18.4	23 21.5	64 28.4	10
12	359 34.2	23 26.6	89 37.6	12	359 18.1	23 21.3	94 33.3	12
14	29 34.0	23 26.6	119 42.5	14	29 17.9	23 21.1	124 38.2	14
16	59 33.7	23 26.6	149 47.5	16	59 17.6	23 20.9	154 43.2	16
18	89 33.4	23 26.6	179 52.4	18	89 17.3	23 20.8	184 48.1	18
20	119 33.1	23 26.6	209 57.3	20	119 17.1	23 20.6	214 53.0	20
22	149 32.9	N23 26.5	240 02.2	22	149 16.8	N23 20.4	244 57.9	22
	Saturday, 22nd June				**Thursday, 27th June**			
00	179 32.6	N23 26.5	270 07.2	00	179 16.6	N23 20.2	275 02.9	00
02	209 32.3	23 26.5	300 12.1	02	209 16.3	23 20.0	305 07.8	02
04	239 32.0	23 26.5	330 17.0	04	239 16.0	23 19.8	335 12.7	04
06	269 31.8	23 26.5	0 22.0	06	269 15.8	23 19.6	5 17.6	06
08	299 31.5	23 26.4	30 26.9	08	299 15.5	23 19.4	35 22.6	08
10	329 31.2	23 26.4	60 31.8	10	329 15.3	23 19.2	65 27.5	10
12	359 31.0	23 26.4	90 36.7	12	359 15.0	23 19.0	95 32.4	12
14	29 30.7	23 26.3	120 41.7	14	29 14.8	23 18.8	125 37.4	14
16	59 30.4	23 26.3	150 46.6	16	59 14.5	23 18.6	155 42.3	16
18	89 30.1	23 26.2	180 51.5	18	89 14.2	23 18.4	185 47.2	18
20	119 29.9	23 26.2	210 56.5	20	119 14.0	23 18.2	215 52.1	20
22	149 29.6	N23 26.1	241 01.4	22	149 13.7	N23 17.9	245 57.1	22

CORRECTION TABLE

Min. or Sec.	Add for Minutes
	°
30	7 30.0
31	7 45.0
32	8 0.0
33	8 15.0
34	8 30.0
35	8 45.0
36	9 0.0
37	9 15.0
38	9 30.0
39	9 45.0
40	10 0.0
41	10 15.0
42	10 30.0
43	10 45.0
44	11 0.0
45	11 15.0
46	11 30.0
47	11 45.0
48	12 0.0
49	12 15.0
50	12 30.0

To get the Sun's ***Local*** *Hour Angle we Subtract our westerly longitude: 15deg from 307 which gives a LHA of 292deg.*

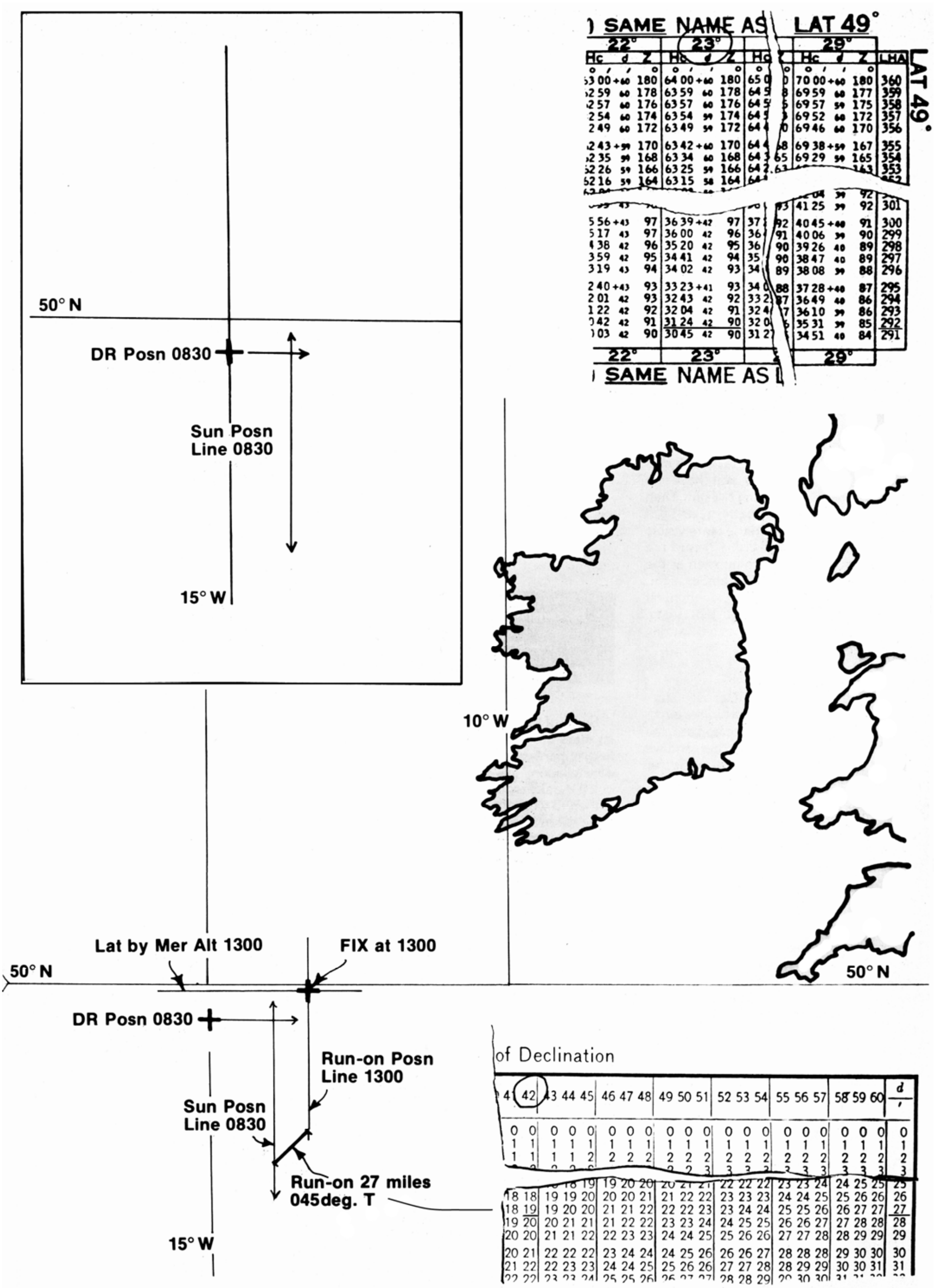
We now know the three angles needed to enter into the Sight Reduction Tables or to use with our calculator: LHA, dec and lat, and we find that the Sun's azimuth is 90deg and its calculated altitude Hc is 31deg 43min. Our corrected sextant altitude Ho at 0830 is compared with Hc to give us the intercept which we mark off along the 90deg line of azimuth drawn through our DR position.

Our 0830 position line is drawn at right angles to the azimuth, and in this instance it is a meridian of longitude, so we can if necessary revise our DR long while still being uncertain of our true latitude.

So we sail on, and just before local noon prepare to find our latitude, using the method described earlier, which turns out to be 49deg 55min north, and the time is 1300 GMT. See ***Fig 20****.*

So now we have a longitude at 0830 and a latitude at 1300. To obtain our 'fix' we have to 'run-on' the 0830 position line.

We have been sailing 4½ hours at 6 knots, a distance of 27 miles on a course of 045deg true. If we now plot that bearing and distance from any point on the 0830 line we can draw our new 'run-on' position line parallel with the original through the end of the 27-mile line. Where this intersects with the latitude we have just obtained, ***there*** *is our present position.*



We don't have to confine ourselves to examples like the above; any single sight can be '**run-on**' to cross with a later single sight, or even crossed with a visual bearing of the first land sighted to give some idea of the whereabouts of our landfall, should be in doubt after a long ocean passage.

SELECT YOUR STAR

At first sight, it’s a formidable problem to decide which Star is which in the night sky. In practice, we can whittle down considerably the number of bright stars visible and suit able for astro-shots at any one time and place. Of the sixty selected stars listed in the almanacs, about a half have southerly declinations and may never be seen in middle and higher northern latitudes. Any star with a southerly declination of more than about 40 deg is never visible in England. Others may rise insufficiently high above the horizon to permit good sextant shots, and that reduces the number of southern hemisphere stars available to a navigator in British waters to about a dozen, but they do include *Sirius,* the brightest star in the sky.

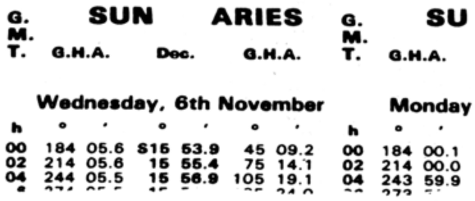
Of the 29 selected stars of northerly declination, at no time are they all visible together. If a star’s GHA is about the same as the Sun’s GHA it will rise and set at about the same time as the Sun, and so will be invisible in broad daylight. Any star which doesn’t rise until well after sunset won’t reach a useful altitude until after the horizon has disappeared; similarly a star which sets some time before sunrise will have no horizon for a shot at morning twilight. Then again the night-sky star pattern changes from month to month, and the stars visible on a June night in the English Channel are very different from those to be seen at the same time and place on a December night.

By confining ourselves to the brightest (first magnitude) stars we find that ***Vega, Arcturus*** and ***Altair*** are visible during summer nights in the Channel, and Sirius, ***Capella***, ***Rigel***, ***Procyon*** and ***Betelgeuse*** are available on winter nights. So the choice isn’t very great, and if we want our chosen stars to be at a good altitude at morning or evening twilight when we can see the horizon, the options will be reduced still further, and we may be forced to use stars of lesser magnitude.

STAR CHARTS AND GLOBES

There’s a wide choice of star charts to help us to identify the various heavenly bodies. Star globes are a little cumbersome in small craft; the *Rude* Star Finder is a better alter native. It consists of a plastic disc over printed with the northern hemisphere stars on one side and the southern on the other. The edge of the disc is calibrated in LHA *Aries.* A series of transparent grids, one for each ten degrees of latitude, is marked with curves of altitude and azimuth.

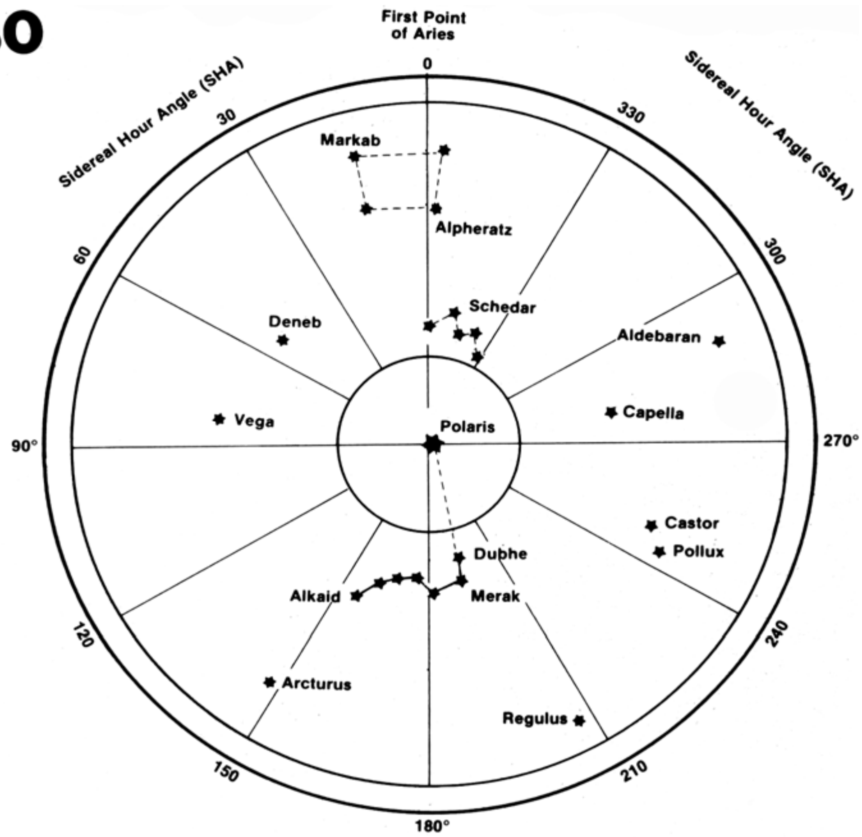
The appropriate grid is superimposed on the correct side of the star disc and rotated to align with our present value of LHA Aries, (GHA Aries plus-or-minus our DR longitude.) The approximate altitude and bearing of our chosen star are read off the grid, or if the star is unknown the reverse procedure will identify it.



G.M.T.	SUN G.H.A.		Dec.		ARIES G.H.A.		G.M.T.	SU G.H.A.	
	Wednesday, 6th November							Monday	
h	°	′	°	′	°	′	h	°	′
00	184	05.6	S15	53.9	45	09.2	00	184	00.1
02	214	05.6	15	55.4	75	14.1	02	214	00.0
04	244	05.5	15	56.9	105	19.1	04	243	59.9

Some of the principal northern circumpolar stars are shown in **Fig 30**. We normally find a particular star by first locating its constellation; this may sometimes be difficult if the sky is part-clouded. Our technique is then to work out in advance the approximate altitude and azimuth of the star we seek; by setting the sextant to that altitude and scanning the horizon in the required direction the star should appear in the telescope, unless it too is obscured by cloud.

30



Markab and **Alpheratz** lie in the constellation of **Pegasus**.
Alkaid, **Merak** and **Dubhe** lie in the constellation **Great Bear** (or **Plough**).
Merak and **Dubhe** are the ‘pointers’ to the **Pole Star** (**Polaris**).
Schedar lies in the W-shaped constellation **Cassiopeia**.
All the stars shown are very bright.
First Point of Aries lies on an **imaginary meridian** from which the SIDEREAL HOUR ANGLE of stars is measured, like earthly longitudes from Greenwich.
It rotates at the same rate as the stars.

PUSH-BUTTON ASTRO

The simplest and cheapest pocket calculators can save effort and reduce the risk of error if we use them for the elementary adding-and subtracting operations in a sight reduction exercise. The multiply-and-divide functions can simplify interpolations between adjacent numbers in a almanac or sight reduction table. There's much to be said for this method, because it allows us to remain in control of each operation as it progresses; if we make a mistake it's easy to check back to see where we went wrong.

There are too the costly microcomputers which we can programme to calculate our lat and long if fed with quite a lot of data. Some of them store the ephemerides of the heavenly bodies and the hour angle of ***Aries*** until the end of the century and beyond. But most of us will buy almanacs anyway for such other vital data as the tide tables and radio beacons.

Between those extremes there is a wide choice of many 'scientific' calculators; their great advantage is that for a very low cost they provide the trig ratios, sines; cosines and tangents of angles, together with the inverse functions 'sine-minus-one' (or arc sin) and so on. With the aid of such an instrument we can quickly discover Hc and Zn from the basic formulae without recourse to sight reduction tables. Such a calculator may of course be used for the many other useful navigating functions like laying off a course to offset a tidal stream and similar geometrical problems.

Somewhere in the middle there are those calculators which are programmable to a small degree; mini-micro-computers in fact. Given enough memories and programme steps they can usefully replace the sight reduction tables (eg. *the Texas TI-57 with Mike Cook's 'Vega' programme), and the nautical almanac as well (the Sharp EL -512 with the 'Merlin' programme).* These and others are splendid aids to astro-sight reduction, but in the end the accuracy of our results depends mainly on the precision with which we took and timed our sextant-shots.

Garbage in, garbage out . . . If we begin by understanding how to do it in long-hand, we're less likely to be deceived by daft deductions from an electronic calculator.

Hack Astro Down To Size

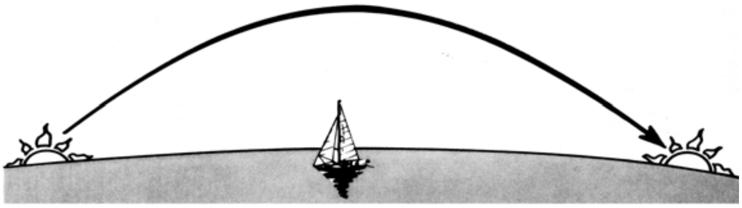
It isn't black magic. Here's how to get a fair notion of our lat and long at sea with no instruments but a wrist-watch and a current nautical almanac. Finding our latitude depends on measuring the interval between sunrise and sunset; between sunset and sunrise will do equally well. In only one latitude will that duration apply to the date in question, though the accuracy of the method will vary at different seasons of the year. The almanacs quote the times of sunrise and sunset for each day of the month in a certain latitude *(Reed's* p.46 etc for lat 52 deg north, *Macmillan* p.80 for 50 deg north.)

On the same almanac pages there is a table of corrections to be applied to the times in latitudes other than 52 deg north *(Macmillan* 50 deg). Knowing the difference between the interval we measured in our unknown latitude and what it would have been were we in lat 52 (or 50 deg) north, we scan the correction table for the latitude which would give that difference. With a little practice in interpolation it should be possible to find our latitude to half a degree or better except at the equinoxes, when the change of duration varies very little with change of latitude. The accuracy of our watch is unimportant when measuring the ***interval*** of time between sunrise and sunset provided that it doesn't gain or lose several minutes during that period. But it does matter if we also wish to find our approximate longitude from the same sunrise-and-sunset times.

LONGITUDE TOO . . .

The Sun must be on our local meridian midway between local sunrise and sunset. Split the difference between them and that gives its local transit time in GMT or as near to it as the accuracy of our watch will permit. Now the almanacs record the time of the Sun's meridian passage at Greenwich (the column headed 'transit'). The difference between the Sun's Greenwich transit time and its ***local*** transit time is our longitude in terms of time; we can convert it to angle at the rate of 15 deg per hour. Our longitude will be west if local transit time is ***later*** than Greenwich transit time, east if earlier. Not dead accurate but better than nothing.

Here’s an example:
On Friday 15 November 1985 we timed sunrise somewhere in the North Atlantic at 10h 06m and sunset at 18h 03m GMT.



What is our latitude and longitude?

Duration of time between local sunrise and sunset is 7h 57m.
On the Greenwich meridian and in lat 52 north sunrise is at 07h 19m and sunset at 16h 09m, a duration of 8h 50m, which is 53 minutes longer than in our unknown position at sea.
The latitude correction table shows that only in ***latitude 58 deg north*** *does the Sun rise 26min later and set 26min earlier than in lat 52 deg,* ***so that must be our approximate latitude****.*
The Sun’s local meridian transit time is midway between 10h 06m and 18h 03m, at 14h 04m GMT, and Greenwich transit time is at 11h 45m, a difference of 2h 19m.
At 15 deg per hour that’s equivalent to an angle of 34 deg 45min, and since the Sun passed us later than Greenwich ***we must be in the approximate longitude 35 deg west.***

106 **NOVEMBER, 1985**

G.M.T. (30 days) G.M.T.

⊙ SUN ⊙

DATE			Equation of Time		Transit	Semi-diam.	Lat. 52°N.			
Day of										
Yr.	Mth.	Week	0 h.	12 h.			Twi-light	Sun-rise	Sun-set	Twi-light
			m. s.	m. s.	h. m.		h. m.	h. m.	h. m.	h. m.
305	1	F	−16 23	−16 24	11 44	16.1	06 19	06 55	16 32	17 07
306	2	Sa	−16 25	−16 25	11 44	16.1	06 21	06 56	16 30	17 05
307	3	Sun	−16 25	−16 25	11 44	16.2	06 23	06 58	16 28	17 03
308	4	M	−16 25	−16 25	11 44	16.2	06 24	07 00	16 26	17 02
309	5	Tu	−16 24	−16 24	11 44	16.2	06 26	07 01	16 24	17 00
310	6	W	−16 23	−16 21	11 44	16.2	06 28	07 03	16 22	16 59
311	7	Th	−16 20	−16 18	11 44	16.2	06 29	07 05	16 21	16 58
312	8	F	−16 16	−16 14	11 44	16.2	06 31	07 07	16 19	16 56
313	9	Sa	−16 12	−16 09	11 44	16.2	06 33	07 09	16 17	16 54
314	10	Sun	−16 07	−16 04	11 44	16.2	06 34	07 11	16 16	16 53
315	11	M	−16 01	−15 57	11 44	16.2	06 36	07 12	16 14	16 51
316	12	Tu	−15 54	−15 50	11 44	16.2	06 38	07 14	16 13	16 50
317	13	W	−15 46	−15 42	11 44	16.2	06 39	07 16	16 12	16 49
318	14	Th	−15 37	−15 33	11 44	16.2	06 41	07 17	16 10	16 47
319	15	F	−15 28	−15 23	11 45	16.2	06 43	07 19	16 09	16 46
320	16	Sa	−15 18	−15 12	11 45	16.2	06 44	07 21	16 08	16 45
321	17	Sun	−15 06	−15 00	11 45	16.2	06 46	07 23	16 06	16 44
322	18	M	−14 54	−14 48	11 45	16.2	06 48	07 25	16 05	16 43
323	19	Tu	−14 42	−14 35	11 45	16.2	06 49	07 27	16 04	16 42
324	20	W	−14 28	−14 21	11 46	16.2	06 51	07 28	16 02	16 41
325	21	Th	−14 14	−14 06	11 46	16.2	06 52	07 30	16 01	16 40
326	22	F	−13 59	−13 51	11 46	16.2	06 53	07 32	16 00	16 39
327	23	Sa	−13 43	−13 34	11 46	16.2	06 55	07 33	15 59	16 38
328	24	Sun	−13 26	−13 17	11 47	16.2	06 57	07 34	15 58	16 37
329	25	M	−13 08	−12 59	11 47	16.2	06 58	07 36	15 57	16 36
330	26	Tu	−12 50	−12 41	11 47	16.2	07 00	07 37	15 56	16 36
331	27	W	−12 31	−12 21	11 48	16.2	07 01	07 39	15 55	16 35
332	28	Th	−12 11	−12 01	11 48	16.2	07 02	07 41	15 54	16 34
333	29	F	−11 51	−11 41	11 48	16.2	07 04	07 42	15 53	16 34
334	30	Sa	−11 30	−11 19	11 49	16.2	07 05	07 44	15 53	16 33

Equation of Time is the excess of Mean Time over Apparent Time
(See explanation and examples on p. 15.)

Lat. Corr. to Sunrise, Sunset, etc.				
Lat.	Twi-light	Sun-rise	Sun-set	Twi-light
°	h. m.	h. m.	h. m.	h. m.
N70	+1 27	+2 27	−2 27	−1 27
68	+1 09	+1 52	−1 52	−1 10
66	+0 56	+1 27	−1 26	−0 57
64	+0 44	+1 07	−0 07	−0 45
62	+0 34	+0 51	−0 51	−0 35
N60	+0 26	+0 38	−0 38	−0 26
58	+0 19	+0 26	−0 26	−0 18
56	+0 12	+0 17	−0 16	−0 12
54	+0 06	+0 08	−0 08	−0 06
50	−0 06	−0 07	+0 07	+0 06
N45	−0 17	−0 22	+0 22	+0 16
40	−0 26	−0 34	+0 34	+0 26
35	−0 34	−0 45	+0 45	+0 34
30	−0 42	−0 54	+0 54	+0 42
20	−0 56	−1 10	+1 10	+0 57
N10	−1 ·09	−1 24	+1 25	+1 10
0	−1 21	−1 37	+1 38	+1 22
S10	−1 36	−1 50	+1 51	+1 35
20	−1 52	−2 05	+2 06	+1 51
30	−2 10	−2 21	+2 23	+2 10
S35	−2 22	−2 31	+2 33	+2 22
40	−2 36	−2 42	+2 44	+2 36
45	−2 52	−2 55	+2 57	+2 53
S50	−3 14	−3 12	+3 13	+3 13

NOTES

The Lat. Corr. to Sunrise, Sunset, etc., is for the middle of November. Examples on the use of the above data are given on page 11 onwards.