Frank Holden

Offshore Navigation

A course in nine chapters
for the
Cruising Helmsman / Lowrance Australia Offshore Navigation certificate

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CELESTIAL BASICS

FRANK HOLDEN kicks off the Cruising Helmsman/Lowrance Australia Offshore Navigation certificate course with a look at the motion of sun, earth and stars and how they are viewed and their positions defined by the sailor.

1 Celestial Basics

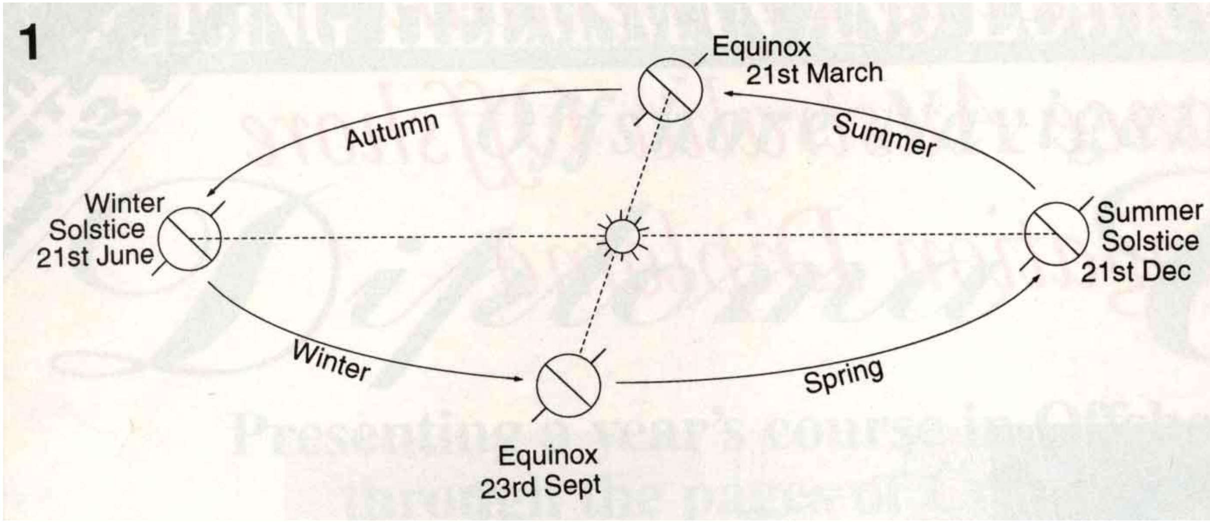
With the advent of world wide electronic position fixing in the form of the Global Positioning System accurate offshore navigation is now within the reach of everyone. This, however, should not mean that old and well tried skills should be allowed to fall into disuse. A good -as opposed to an adequate- navigator should be able to draw on quite a number of different methods of fixing his position, be able to use them either separately or together depending on the circumstances, and then be able to make a considered judgment as to where he really is.
Unfortunately celestial navigation has long been considered a black art by many people. Some have got by for years simply on the ability to fill in a pro-forma sight form while understanding few if any of the principles. Others espouse a certain method of finding their way around, be it “Longitude by Chronometer”, pocket computer or a magic box such as a GPS, the workings of which are a great mystery but whose results rarely fail to please. Usually the louder they trumpet the merit of their particular method the less it transpires they know about any alternative.

The truth of the matter is that celestial, or indeed any offshore navigation, isn’t that difficult, all you require is to be reasonably numerate (i.e. can add, subtract and have the ability to extract information from tables) and be able to use a bit of lateral thinking to master a few abstract but simple concepts.

To successfully navigate offshore a few tools of the trade are required - charts for the voyage you intend to undertake, parallel rule or roller rule, pilot books, clock, sextant, almanac - paper or electronic -and tables. The traditional almanac and tables may seem superfluous in this electronic age but, take my word for it, they will always come in handy. In Europe a number of special yachtsman's almanacs are available which include , as well as the basic almanac, all the neccesary tables for both offshore and inshore navigation. In Australia a copy of dedicated tables are required and either Norie's or Burton's tables are the two most commonly found afloat. For the purpose of these articles I shall stick with Norie's whenever tables are used.

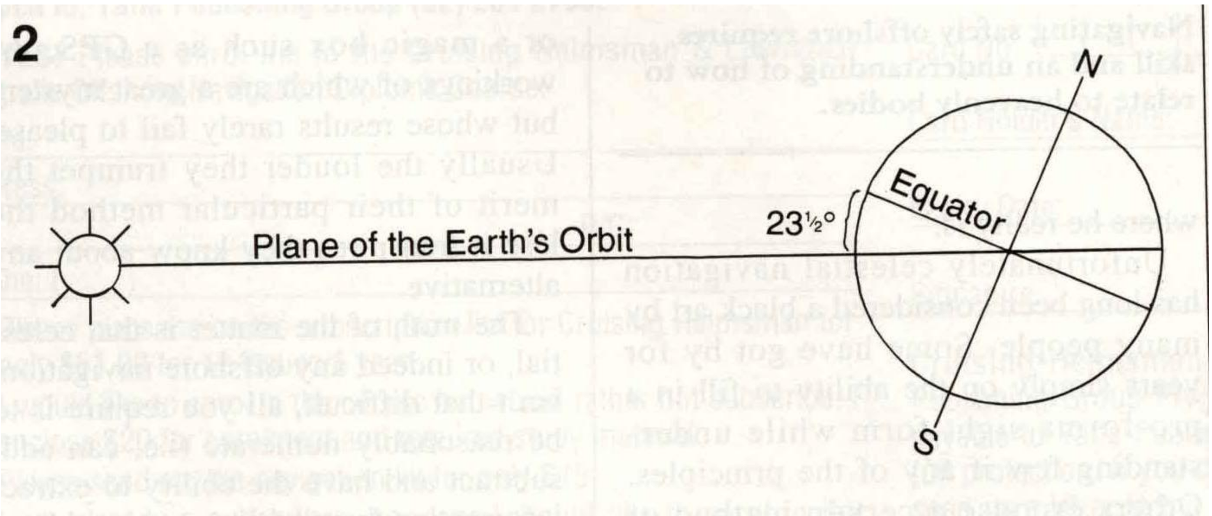
The more of this equipment you have the better but to do this course you will only require a 2B pencil and a roller ,or parallel, ruler although a calculator which gives trig ratios will also come in handy.

1.1 The true motion of the sun and the earth



For most of the time while we are navigating we shall be dealing with the apparent movement of the sun and the stars and we will assume that our planet is at the centre of the universe. This month, however, we shall begin by looking at the true motion of the earth, the sun, and the stars.

The stars are such a great distance from us that it is safe to assume that they form a backdrop on what is called the celestial sphere, a sphere of very nearly infinite size which has planet earth at its centre. Near the centre of this sphere is our sun around which the earth orbits once every 365 days. As it orbits the sun the earth is also rotating about its axis once every 24 hours and the plane of this axis is offset by about 23 $^{1}/_{2}$ ° from the plane of the earth's orbit around the sun. As a result the latitude on the earth's surface in which the sun passes directly overhead gradually shifts from 23 1/2° North latitude, in late June, through to 23 1/2° South Latitude, in late December, and back again over a period of 12 months. It is this change in the sun's latitude which gives us our season's.

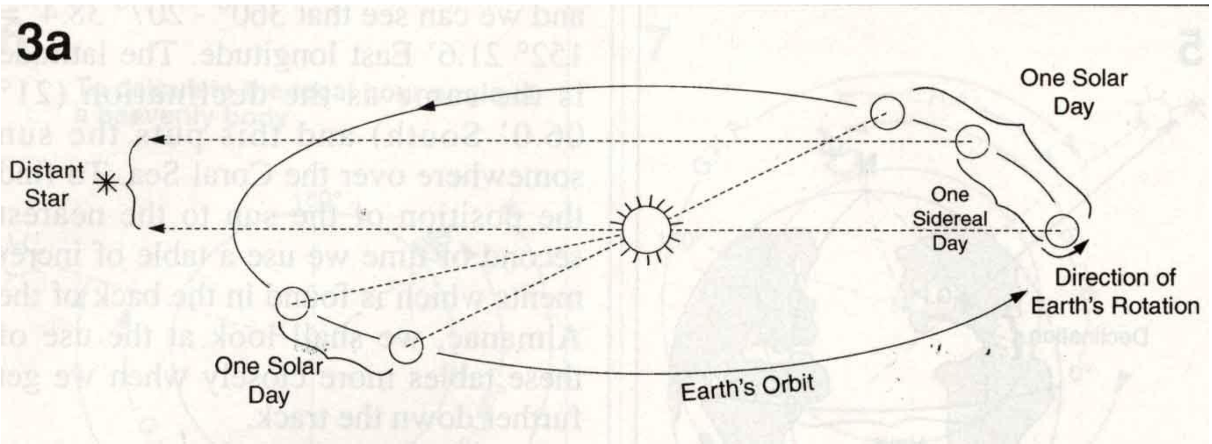


The earth doesn't orbit the sun in a pure circle but in an ellipse with our distance from the sun varying from 91 to 93 million miles. This affects the mariner in two ways. The simplest effect is that the size of the sun as observed from the earth varies throughout the year, this change in the sun's apparent diameter has to taken into consideration when correcting sextant altitudes of the sun.

The fact that the earth is following an ellipse also affects the speed at which it is moving along its path as a body describing an ellipse moves more quickly when closer to the centre of that ellipse and slower when further away. As we shall see this has a small but important effect on the length of our days.

1.2 Time

At the very heart of all successful celestial navigation is an accurate knowledge of the correct time. Without this knowledge we are reduced to navigating by the rudimentary methods of 500 years ago. So how exactly is 'time' measured?
A day is defined as the length of time that elapses between two successive transits of a particular meridian by a heavenly body. The best timekeepers in the heavens, because of their very great distance from the earth, are the stars. Unfortunately if we were to base our time keeping on the stars we would soon be in trouble as the sun would rise 4 minutes later each day. So we base our day of twenty four hours on two successive transits of the sun over a given meridian instead.



This would be all well and good but, as mentioned before, the earth's orbit of the sun is an ellipse and thus the speed of the earth varies throughout the year. As a result the actual time that elapses between two meridian passages of the true sun varies slightly between 23h59m30s and 24h00m30s. So to get around this problem we base our day on an imaginary or 'mean' sun. This mean sun is on the **Greenwich or Prime meridian** every day of every year at 1200 GMT(UT) while the time of the true, or apparent, sun's meridian passage varies gradually over the course of a year and occurs between 1146 GMT and 1214 GMT. The difference between apparent noon and 1200 is called the Equation of Time.The actual time of meridian passage (of the true sun) is listed in the daily pages of the almanac and this time is used by us when we are working out that most basic of sights, the Latitude by Meridian Altitude.

SUN **3b**

Day	Eqn. of time 00 h		Eqn. of time 12 h		Mer. Pass.	
	m	s	m	s	h	m
16	09	24	09	35	12	10
17	09	45	09	55	12	10
18	10	05	10	15	12	10

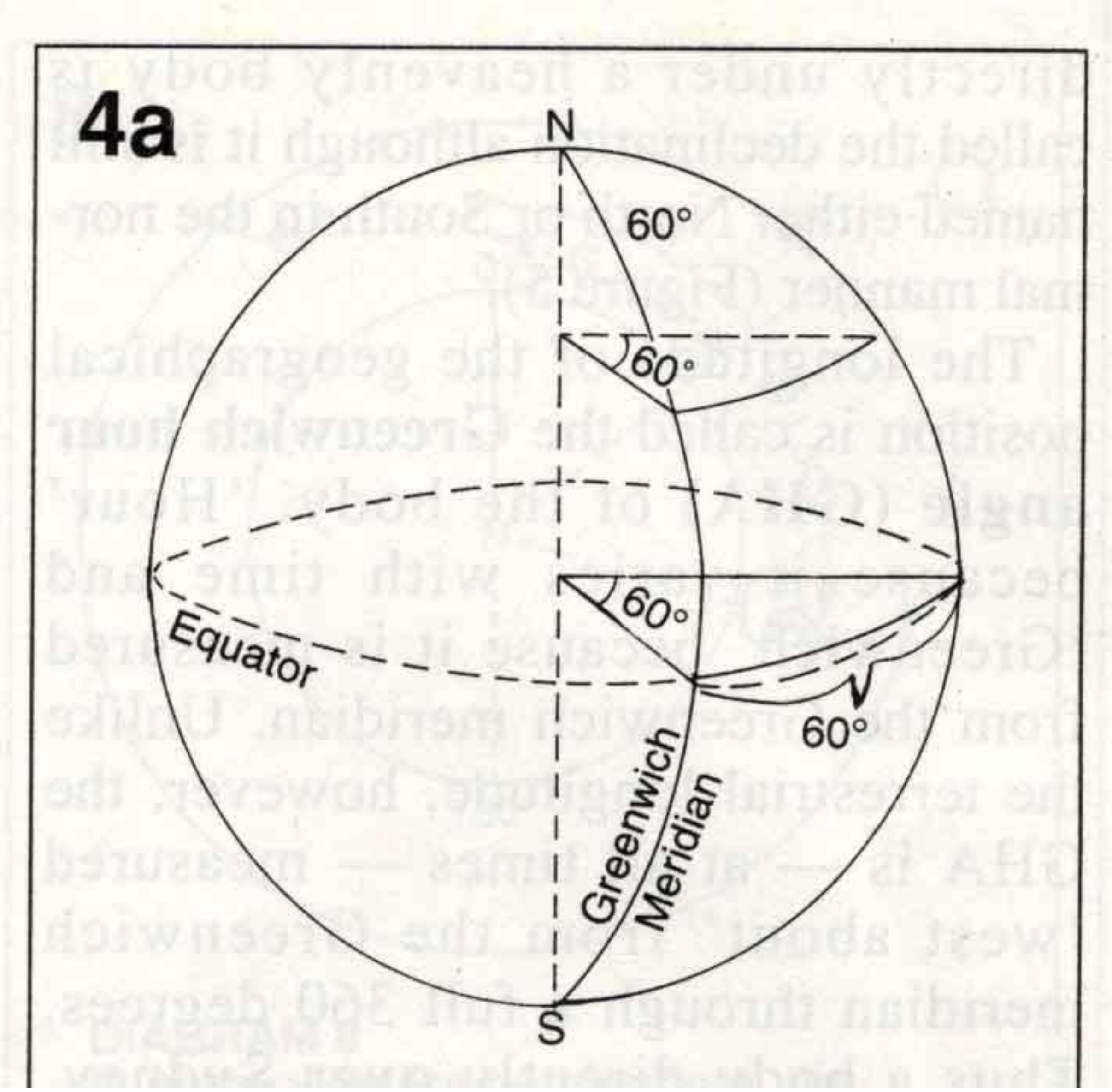
On all other occasions we are only interested in the apparent sun - that is the one that we can see - and its apparent motion.

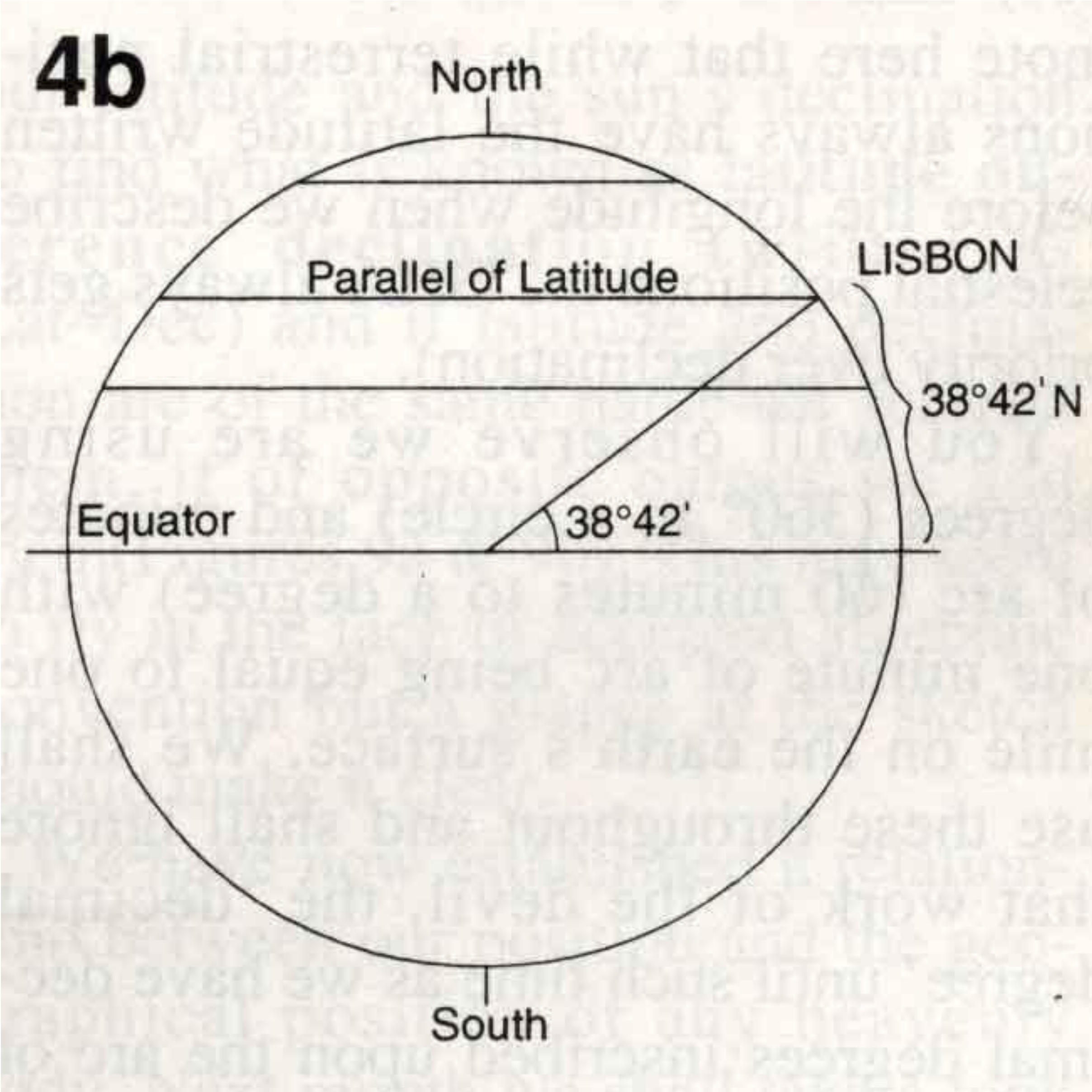
The sun's apparent motion as viewed from the earth is influenced by two things: the change in its hour angle — which is due to the rotation of the earth about its axis — and the change in its declination which is due to the movement of the earth along its orbit around the sun over a 12-month period. Both the Greenwich hour angle and the declination are listed in the daily pages of the Nautical Almanac.

UT (GMT)		SUN			3c
		G.H.A.		Dec	
d	h	°	'	°	'
16	00	177	38.8	S21	06.9
	01	192	38.6		06.4
	02	207	38.4		06.0
	03	222	38.1	...	05.5
	04	237	37.9		05.0
	05	252	37.7		04.6
	06	267	37.5	S21	04.1

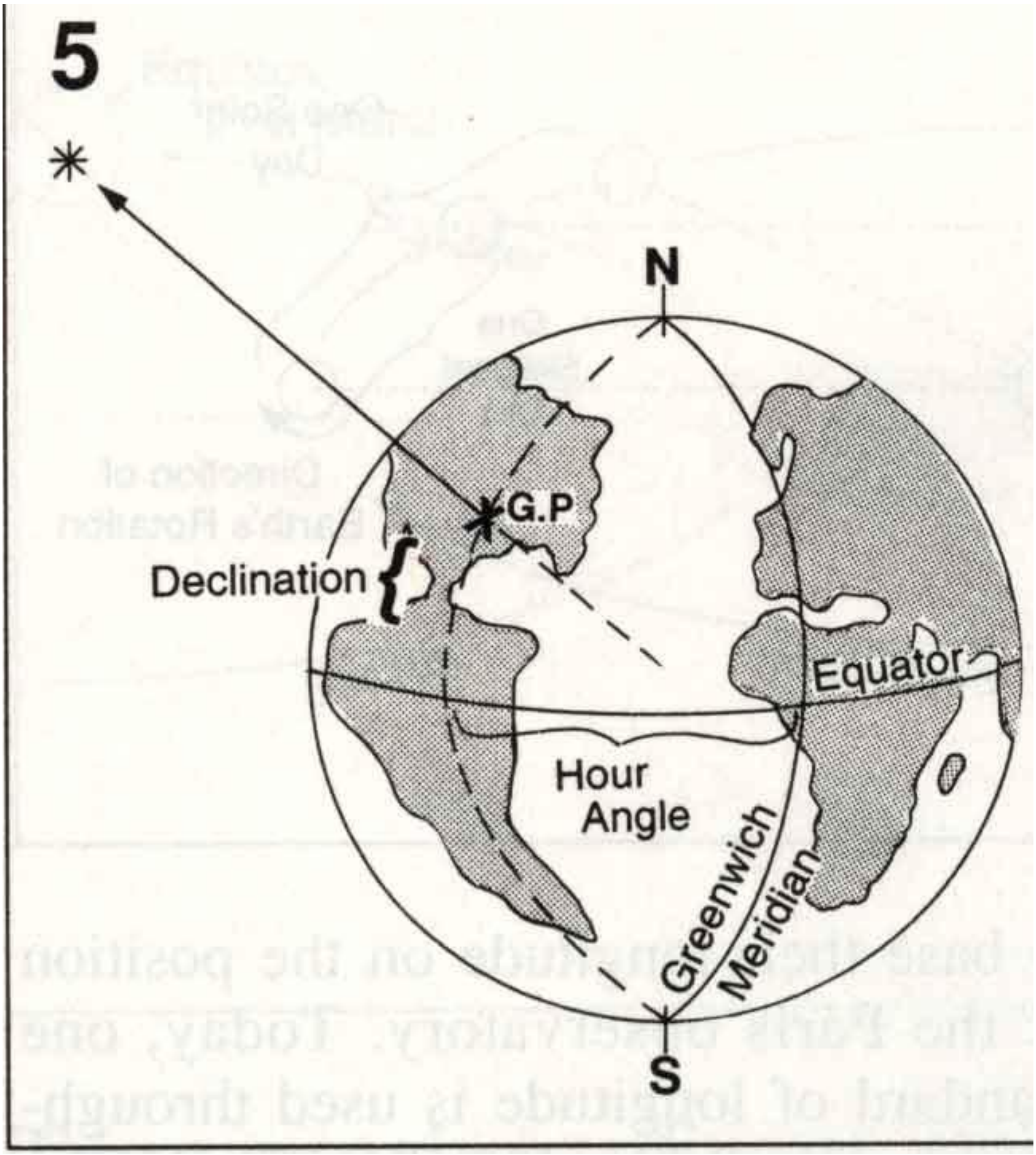
1.3 The Hour Angle and the Geographical Position

I assume that we are all familiar with the manner in which our position upon the earth's surface can be described but, for the benefit of those who aren't, a brief refresher. The simplest method of describing our position is to just say that we are in such and such a direction and distance from a known point but it is far more useful to use **latitude**- to define our distance north or south of the equator- and **longitude** - to describe our position either east or west of a known meridian. Early navigators measured their longitude east or west from their point of departure, typically Land's End or Teneriffe and for many years various national bodies adopted their own standards, the French, for instance, choosing to base their longitude on the position of the Paris observatory. Today one standard of longitude is used throughout the world, that based on the meridian which passes through the Greenwich Observatory just to the east of London. This meridian is known as either the Greenwich or Prime meridian and the longitude of all places on the earth's surface is measured either east or west from here to a meridian 180 degrees away . The longitude of all places lying to the east of Greenwich is named east and vice versa with places to the west. Thus Darwin, for instance, is in latitude 12° 28' South and longitude 130° 51' East. Both latitude and longitude can be measured in two ways, either as an angle measured at the earth's centre between the place in question and either the equator or the Greenwich meridian or as an arc on the earth's surface, this latter method is how it shown on charts. Make a good note of that because, as we progress, you will see that we tend to skip between one method and the other quite often and the ability to be able to see these angles in your mind's eye is quite important.


4a
N
60°
60°
60°
Equator
60°
Greenwich
Meridian
S



Now in the same way that we can describe the position of a place on the surface of the earth so can we describe the position of the sun, stars or planets. At any given time a heavenly body is directly over some point on the earth's surface. This is not a fixed point as, due to the earths rotation about its axis,every body in the heavens appears to move west at a rate of approximately 15 degrees per hour. Now this position, known as the **Geographical Position (G.P.)**, could be described in terms of latitude and longitude in exactly the same way as a position on the earth's surface can be described. However to avoid confusion the latitude of a point directly under a heavenly body is called the **declination** although it is still named either North or South in the normal manner. The longitude of the geographical position is called the **Greenwich hour angle (GHA)** of the body. 'Hour' because it varies with time and 'Greenwich' because it is measured from the Greenwich meridian. Unlike the terrestrial longitude, however, the GHA is - at all times - measured "west about" from the Greenwich meridian through a full 360 °. Thus a body directly over Sydney, Nova Scotia, (latitude 46 ° 09' North, longitude 60° 12' West) would have a Greenwich hour angle of 60° 12' and a declination of 46° 09' North while one over Sydney, N.S.W. (lat. 33° 51' South, long. 151° 12' East) would have a GHA of 208 ° 48' (360° - 151° 12' E = 208° 48') and a declination of 33° 51'S. (Note here that while terrestrial positions always have the latitude written before the longitude when we describe celestial positions the GHA always gets priority over Dec.)



You will observe that we are using degrees (360° to a circle) and minutes of arc (60 minutes to a degree) with one minute of arc being equal to one mile on the earth's surface. We shall use these throughout and shall ignore that work of the devil, the "decimal degree" until such time as we have decimal degrees inscribed upon the arc of our sextants . Seconds of arc (60 to a minute of arc) are, however, no longer used in practical navigation if indeed they ever were.

Some people experience a degree of difficulty when they try to subtract degrees and minutes. To get around this problem convert the last degree to minutes so that if , for instance, subtracting 189° 45 from 360° it becomes:-

359° 60’

- 189° 45

170° 15’____

The geographical position of the sun, moon, and stars and planets of navigational significance can be extracted directly from the almanac for any given date and time. Thus at 0200 GMT on the 16th of February 1992 , see diagram Number (?) the sun can be seen to have a GHA of 207° 38.4’ and a declination of 21° 06.0’ South. Out of interest we can convert this into latitude and longitude and we can see that 360° - 207° 38.4’ = 152° 21.6’ East longitude. The latitude is the same as the declination (21° 06.0 South) and this puts the sun directly over the Coral Sea.
To find the position of the sun to the nearest second of time we use a table of increments which is found in the back of the Almanac, we shall look at the use of these tables more closely when we get further down the track.

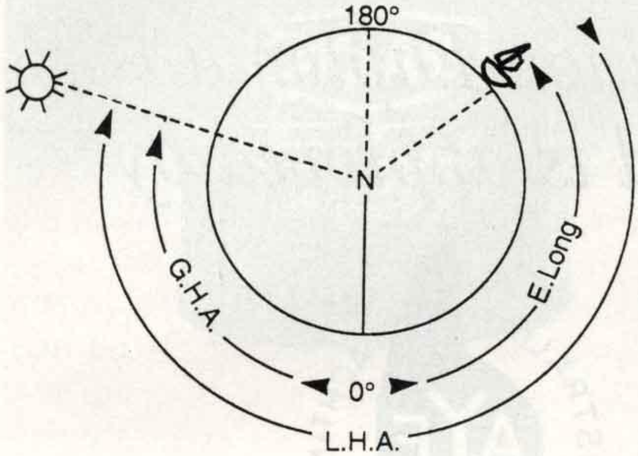
As you can see, for any given moment of time we can work out the geographical position of the sun to a high degree of accuracy, typically 1/10th of a nautical mile. We also have a fair idea of our own position. Now, for these to positions to be of any real use to us we must be able to to establish some relationship between the two of them.

The Greenwich hour angle of the sun at any given moment is, as we have seen, measured west about from the Greenwich meridian. Our longitude however is measured either east or west from this same meridian. By combining these two - the sun’s GHA and our longitude- we produce what is known as the **local hour**

angle of the sun. This is the angular distance which the sun lies to the west of us. In Australia, and in fact any place having an easterly longitude, it is simply a matter of adding our longitude to the GHA. {GHA + E long = LHA). For people sailing in the western hemisphere life is not so easy, they have to subtract their longitude from the GHA {GHA - W long = LHA}. There are times when you will find that the result of combining these two values results in a either an LHA greater than 360° or with a negative value. The first occurs with the sun's LHA in the eastern hemisphere during the afternoon and to get a usable figure one simply subtracts 360° from the LHA that has been calculated.{{Sketch and Example}} The latter is found in the western hemisphere in the morning and in this, the most complicated case, the simplest way of resolving it is to add 360° to the GHA before subtracting the westerly longitude.

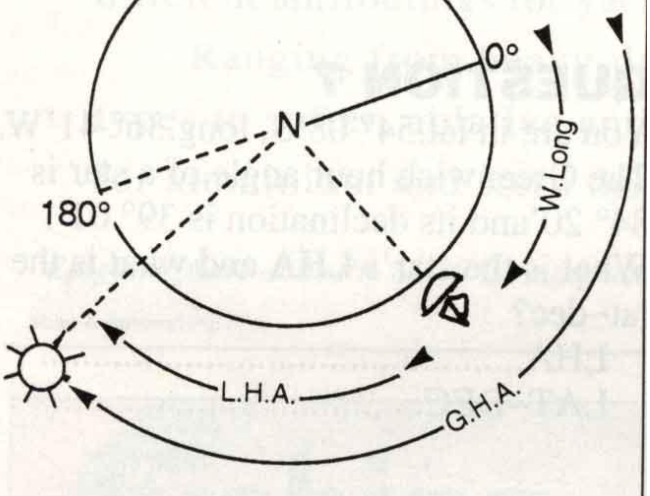
6

To calculate the local hour angle of a heavenly body



LHA = GHA + E. Long

$$\begin{aligned} \text{eg., GHA} &= 120^\circ\ 15' \\ \text{E.Long} &= \underline{127^\circ\ 57'}\ (+) \\ \text{LHA} &= 248^\circ\ 12' \end{aligned}$$



LHA = GHA - W.Long

$$\begin{aligned} \text{eg., GHA} &= 160^\circ\ 19' \\ \text{W.Long} &= \underline{49^\circ 31'}\ (-) \\ \text{LHA} &= 110^\circ\ 48' \end{aligned}$$

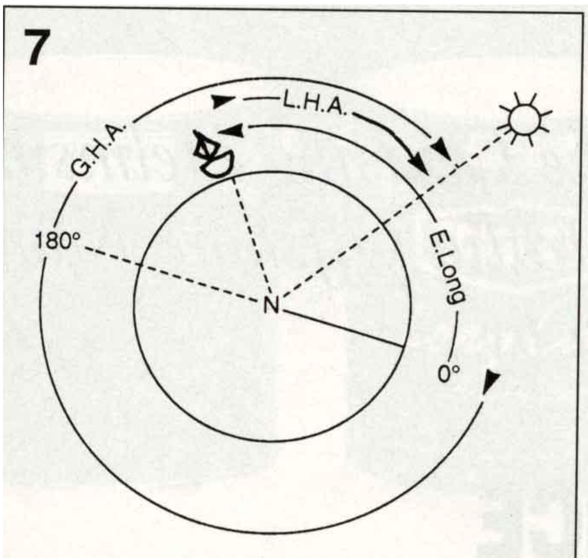


DIAGRAM 7
If, in the eastern hemisphere, your calculations give a GHA of greater than 360° simply subtract the 360°

GHA =	310° 13'	
E.Long =	112° 27'	(+)
LHA	422° 40'	
	360° 00'	(–)
LHA	62° 40'	

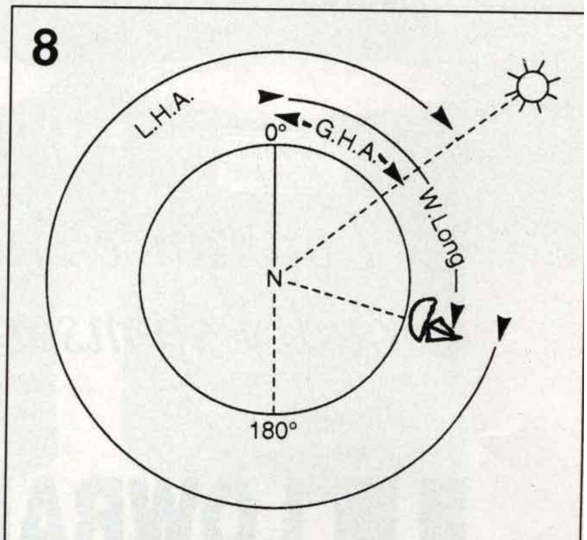


DIAGRAM 8
If, in the western hemisphere, the GHA is smaller than the longitude, add 360° to the GHA and then subtract the longitude.

GHA	= 20° 11'	
+	360° 00'	
	380° 11'	
W. Long	95° 22'	(–)
LHA	= 284° 49'	

In a similar manner we can combine our latitude and the sun's declination to find what is known as **"latitude difference declination"** (written as **Lat.~Dec.**) and here if lat. and dec. are of the same name we subtract them, if of opposite names we add them. This may seem to fly in the face of accepted algebraic convention but a glance at the sketch should make it clear

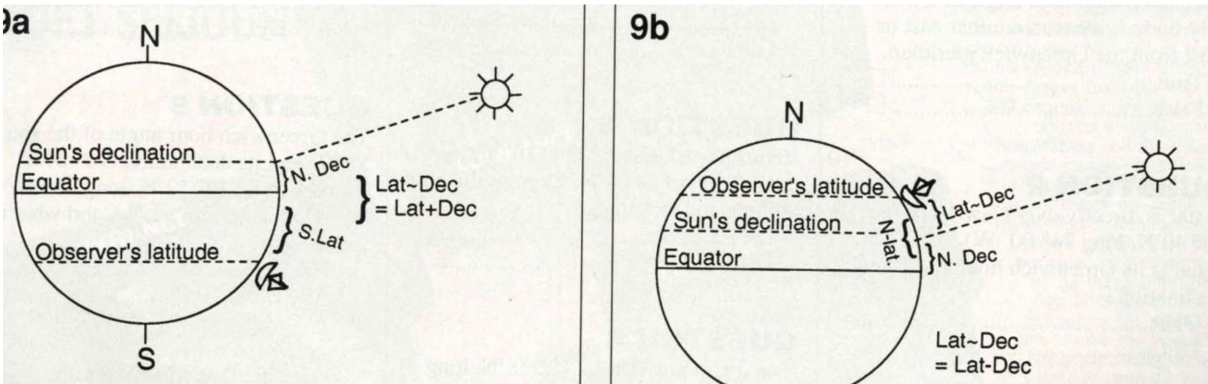
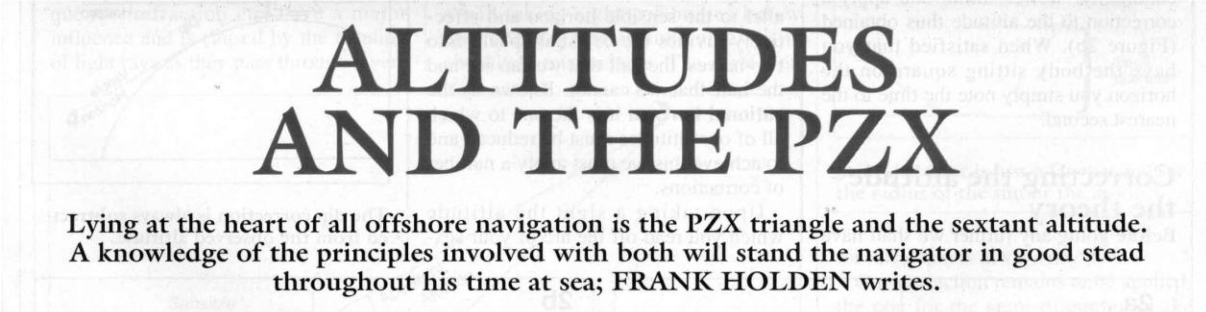


DIAGRAM 9
To find the Lat~Dec we add if they are of opposite names and (9b) subtract if they are of the same names.

We have now established a relationship between our position and the geographical position of the sun. Next month we shall take a look at sextant altitudes and see where they fit into the scheme of things.


ALTITUDES
AND THE PZX

Lying at the heart of all offshore navigation is the PZX triangle and the sextant altitude. A knowledge of the principles involved with both will stand the navigator in good stead throughout his time at sea; FRANK HOLDEN writes.

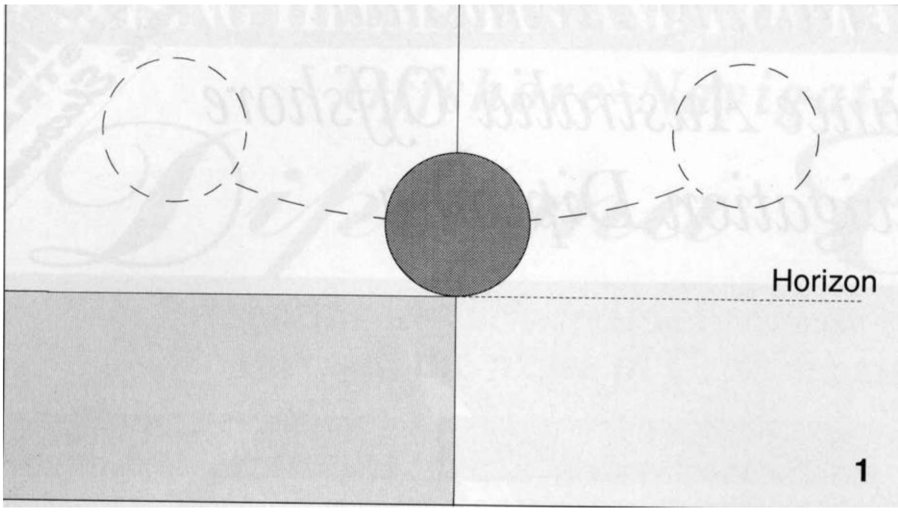
2 Sextant Altitudes and the PZX Triangle

Last month we had a look at how our position is defined on the face of the earth by latitude and longitude and the way in which, at any given instant, the position of a heavenly body can be defined by its Greenwich hour angle and declination. We also looked at how it is possible to establish a relationship between these two positions using the local hour angle and the latitude difference declination. This month we shall take a look at another essential part of position fixing at sea - the altitude.

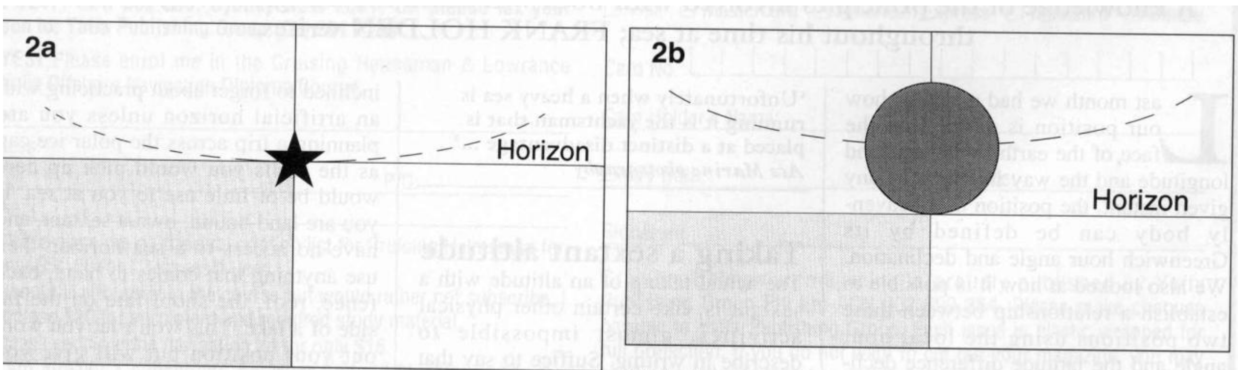
2.1 Taking a Sextant Altitude

The actual taking of an altitude with a sextant is, like certain other physical activities, almost impossible to describe in writing. Suffice to say that when you actually come to do it you will find that it comes naturally and that practice makes perfect. I would be inclined to forget about practising with an artificial horizon unless you are planning a trip across the polar ice cap as the skills you would pick up here would be of little use to you at sea. If you are land bound, own a sextant, and have no access to a sea horizon then use anything that comes to hand, back fence, roof, the shore line on the far side of a lake. This won't let you work out your position but will give you practice in actually using the instrument.

Having brought the body down to the horizon you must gently rock the sextant from side to side through about three or four degrees either way. This enables you to find the point on the horizon directly below the body .



With a star or a planet you are dealing with a point source of light which you simply sit astride the horizon. With the sun or the moon it is impossible to pick the centre of the object with sufficient accuracy and so you must use either its upper or - more commonly - lower ‘limb’ and apply a correction to the altitude thus obtained. When satisfied that you have the body sitting square on the horizon you simply note the time to the nearest second.



Vith a star or planet you simply sit it astride the horizon.

With the sun or the moon either the upper or the lower limb must just kiss the horizon.

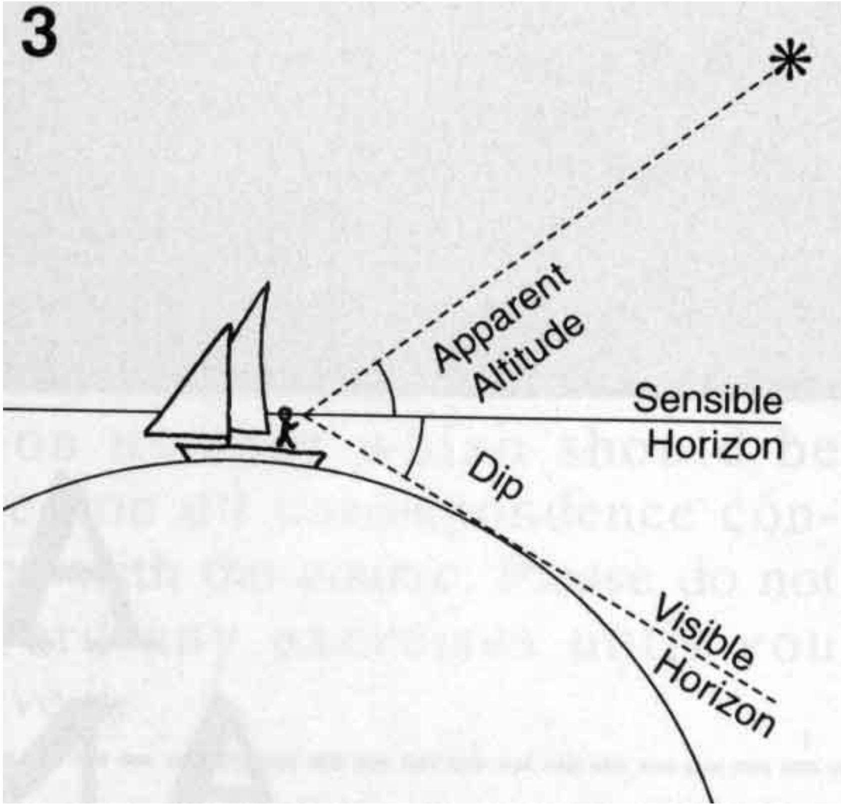
2.2 Correcting the Altitude - the Theory

Before going any further we shall have to look at a few definitions. Our **zenith** is a point in the heavens directly overhead, that is where a line drawn from the centre of the earth through our position would touch the celestial sphere, that sphere of almost infinite size which has the earth at its centre. The **visible horizon** is that which bounds our view at sea on a clear day, more simply put it is the one that we can see. The **sensible horizon** , on the other hand, is an imaginary horizon whose plane passes through the eye of the observer at right angles to the vertical.

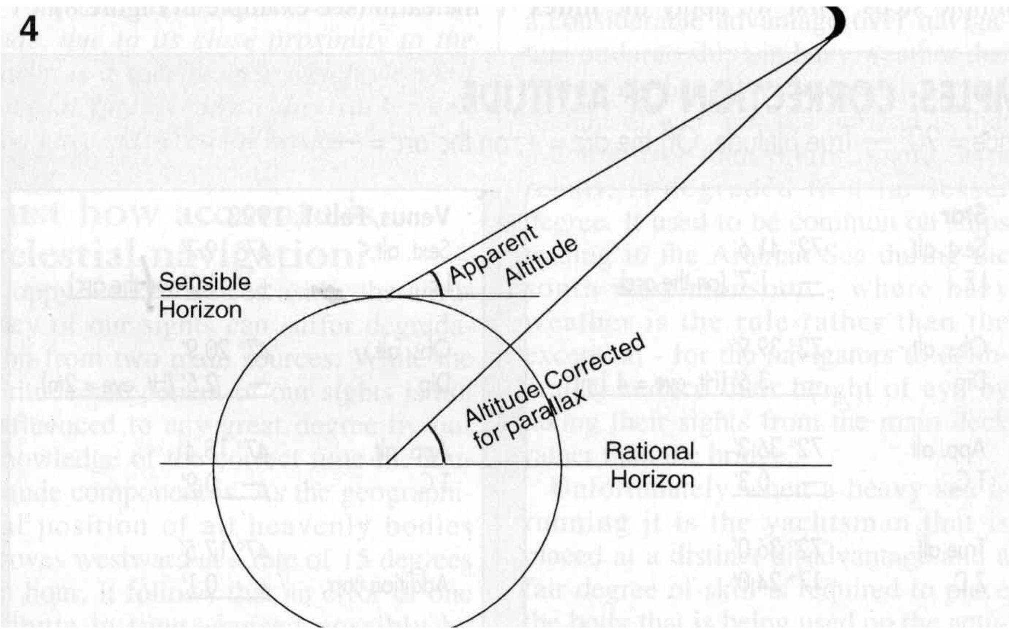
The horizon that we must use in our navigation is, however, one that lies through the centre of the earth. It is parallel to the sensible horizon and effectively divides the celestial sphere into two halves, the half that we can see and the half that we cannot. Known as the **rational horizon** it is the one to which all of our altitudes must be reduced and to achieve this we must apply a number of corrections.

Upon taking a sight the altitude which you read off the arc of your sextant can best be described as a "raw" altitude. The first correction that we must apply -**index error** - is simply a correction for any small error which may exist in the sextant itself due to a slight misalignment of the mirrors and is named either **'on the arc'** or **'off the arc'**. <u>If the index error is 'on the arc' the correction is subtracted from the sextant altitude, if it is 'off the arc' it is added to the sextant altitude.</u> We shall look at the cause and correction of index error in greater detail in a future article. Having applied this correction we now have an **observed altitude** which is the angle between the visible horizon and the body.

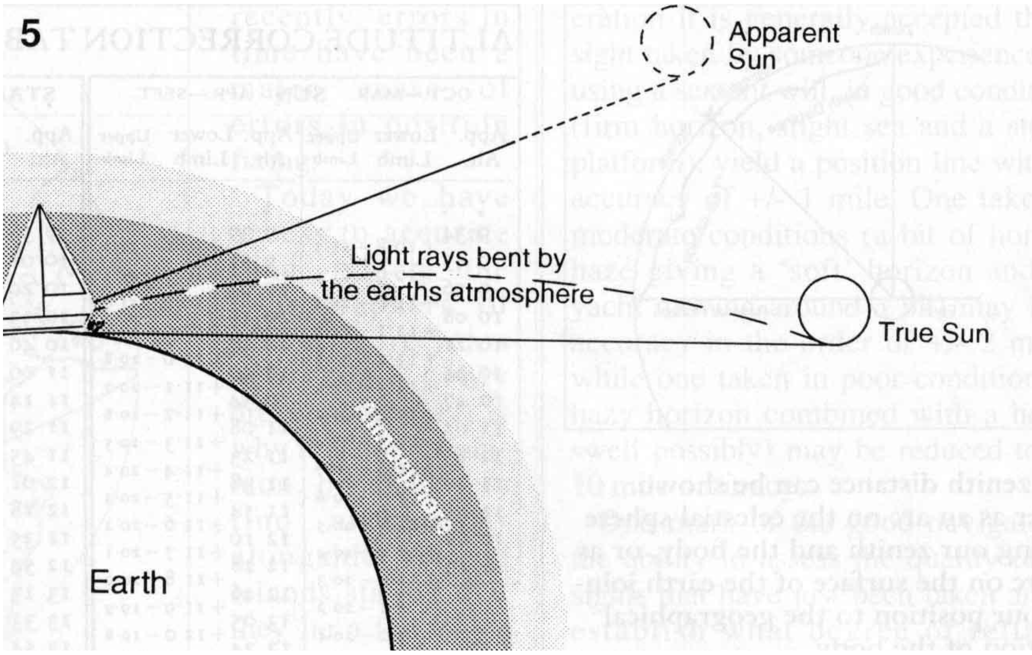
We must now apply a correction for **'dip'** of the visible horizon. This may be defined as the angle of depression of the visible below the sensible horizon. Inspection of the sketch will show that it is is <u>always subtracted</u> and that the greater the observer's 'height of eye' above the surface of the sea the greater will be the correction. We now have what is known as the **apparent altitude.**



Several corrections remain to be applied before we have a true altitude suitable for use in navigation. One of these is called **parallax** and is due to the fact that we are observing the body from the surface rather than the centre of the earth. The stars are such a great distance from the earth that there is no parallax at all, with the sun it never exceeds .15’ of arc while with the planets it is also a very small amount which varies very slightly as their distance from the earth varies throughout the year.
The moon, however, is so close in celestial terms to the earth that the parallax can be as much as one degree of arc and a special set of corrections must be applied if we are not to be considerably in error. This is one reason that when working with either longhand methods or sight reduction tables the moon is very rarely used by navigators.
Referring to the sketch you can see that parallax is at a maximum when a body is at 0° altitude and decreases to zero at 90° altitude and that the correction is always positive.

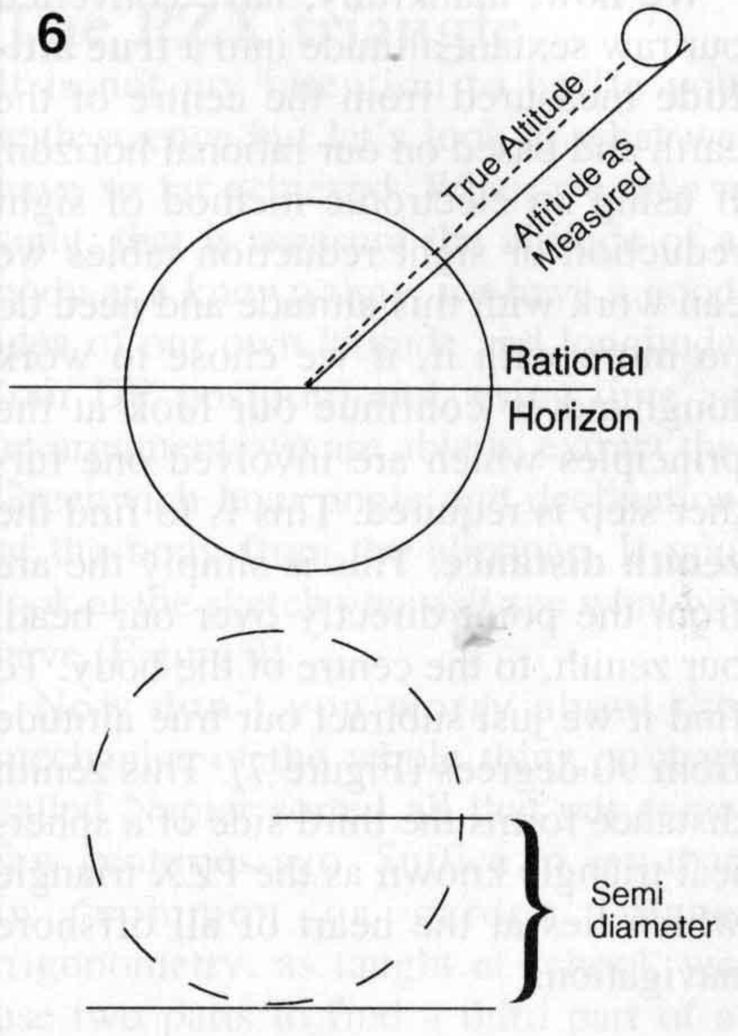


The only correction common to all bodies that remains for us to consider is **refraction**. While parallax, except with the moon, is of little consequence refraction can have a major influence and is caused by the bending of lights rays as they pass through layers of the earth's atmosphere of varying density in the same way that light rays passing from water to air are bent. Once again the error so caused is greatest when a body is on the horizon and decreases to zero at 90°. If the body is below 20° in altitude the refraction is influenced to an increasing degree by the air temperature and atmospheric pressure, both of which affect the density of the air. As a result we tend to avoid taking sights of bodies below about 15° altitude unless it is absolutely unavoidable. The correction for refraction is always negative.



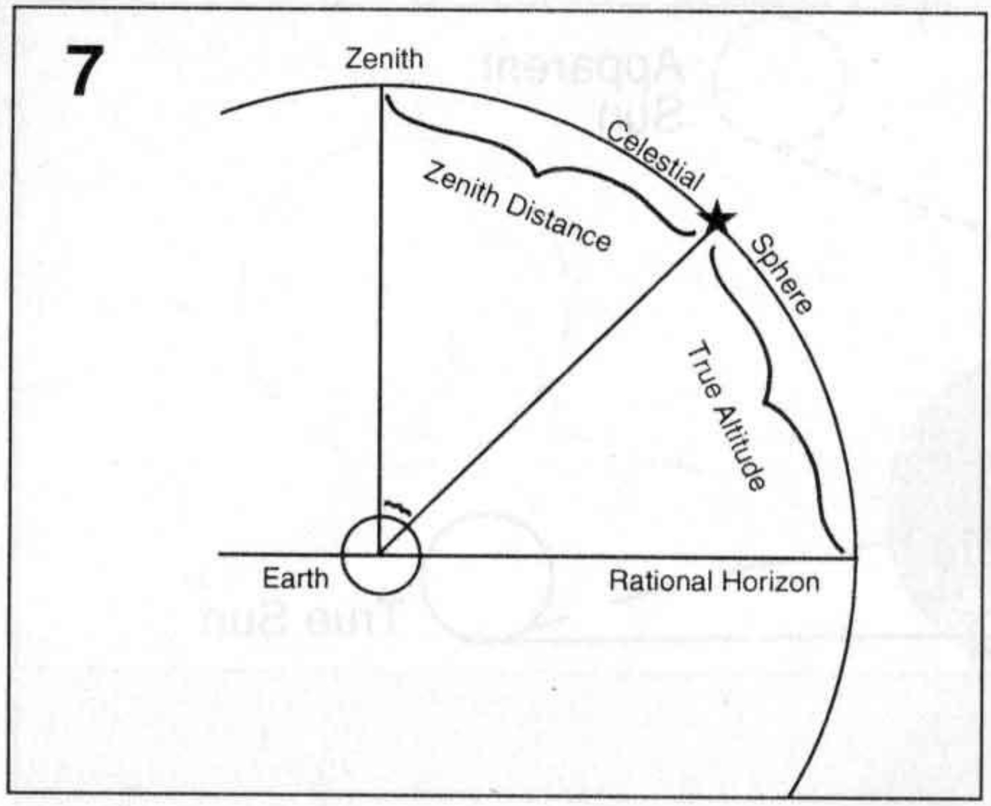
One correction remains to be applied and that is that for the **semi-diameter** of the sun and the moon. As we measured the altitude of either the lower or upper 'limb', or edge, of the body we must apply another major correction. The semi-diameter of the sun is in fact just a fancy name for its radius. This, as we saw last month, varies slightly throughout the year as the distance of the sun from the earth varies. If, as is usual, you have taken an altitude of the lower limb, this correction is additive, if for some reason you have taken the upper limb it is subtracted.

6



We now, thankfully, have converted our raw sextant altitude into a **true altitude** measured from the centre of the earth and based on our rational horizon. If using an electronic method of sight reduction or sight reduction tables we can work with this altitude and need do no more with it, if we chose to work longhand or continue our look at the principles which are involved one further step is required. This is to find the **zenith distance.** This is simply the arc from the point directly over our head, our zenith, to the centre of the body. To find it we just subtract our true altitude from 90°

This zenith distance forms the third side of a spherical triangle known as the PZX triangle which lies at the heart of all offshore navigation.



The zenith distance can be shown either as an arc on the celestial sphere joining our zenith and the body, or as an arc on the surface of the earth joining our position to the geographical position of the body.

2.3 Correction of Sextant Altitudes in Practice

If we are doing our navigating with a pocket computer we simply need to enter our sextant altitude and our index error. The computer, having been told whether it is dealing with sun, star, moon or planet will do the rest for us as all of these corrections can be calculated mathematically. If we are using sight reduction tables or are working out our sights longhand things are not as bad as they first may appear. In the front of the almanac and also on the book mark is a table of total corrections for all bodies but the moon. Correction of an altitude is thus reduced to three simple steps.

First we apply the **index error** by either adding or subtracting it depending upon whether it is ‘on’ or ‘off’ the arc. Then, having established our height of eye in either feet or metres above sea level we lift the **dip** or **height of eye correction** from the table and always subtract it from our observed altitude.

Next, entering the table with apparent altitude as an argument we apply the **total correction** which in the case of a star or planet is simply a correction for refraction. The total correction for stars or planets is always negative. In the case of Venus and Mars there is also a small auxiliary correction for parallax which must be applied to compensate for their varying distance from the earth.

ALTITUDE CORRECTION TABLES 10°-90°—SUN, STARS, PLANETS

SUN

OCT.—MAR. App. Alt.	Lower Limb	Upper Limb	APR.—SEPT. App. Alt.	Lower Limb	Upper Limb
° ′	′	′	° ′	′	′
9 34			9 39		
	+10·8	−21·5		+10·6	−21·2
9 45			9 51		
	+10·9	−21·4		+10·7	−21·1
9 56			10 03		
	+11·0	−21·3		+10·8	−21·0
10 08			10 15		
	+11·1	−21·2		+10·9	−20·9
10 21			10 27		
	+11·2	−21·1		+11·0	−20·8
10 34			10 40		
	+11·3	−21·0		+11·1	−20·7
10 47			10 54		
	+11·4	−20·9		+11·2	−20·6
11 01			11 08		
	+11·5	−20·8		+11·3	−20·5
11 15			11 23		
	+11·6	−20·7		+11·4	−20·4
11 30			11 38		
	+11·7	−20·6		+11·5	−20·3
11 46			11 54		
	+11·8	−20·5		+11·6	−20·2
12 02			12 10		
	+11·9	−20·4		+11·7	−20·1
12 19			12 28		
	+12·0	−20·3		+11·8	−20·0
			12 46		
	2·1	−20·2		+11·9	−19·9
			13 05		
	2·2	−20·1		+12·0	−19·8
			13 24		
	2·3	−20·0		+12·1	−19·7
			13 45		
	2·4	−19·9		+12·2	−19·6

8

STARS AND PLANETS

App. Alt.	Corrⁿ
° ′	′
9 56	
	−5·3
10 08	
	−5·2
10 20	
	−5·1
10 33	
	−5·0
10 46	
	−4·9
11 00	
	−4·8
11 14	
	−4·7
11 29	
	−4·6
11 45	
	−4·5
12 01	
	−4·4
12 18	
	−4·3
12 35	
	−4·2
12 54	
	−4·1
13 13	
	−4·0
13 33	
	−3·9
13 54	
	−3·8
14 16	
	−3·7

App. Alt.	Additional Corrⁿ
1993 VENUS	
Jan. 1–Feb. 2, May 28–July 15	
°	′
0	
	+0·2
41	
	+0·1
76	
Feb. 3–Feb. 26, May 5–May 27	
°	′
0	
	+0·3
34	
	+0·2
60	
	+0·1
80	
Feb. 27–Mar. 14, Apr. 19–May 4	
°	′
0	

DIP

Ht. of Eye	Corrⁿ	Ht. of Eye
m		ft.
2·4		8·0
	−2·8	
2·6		8·6
	−2·9	
2·8		9·2
	−3·0	
3·0		9·8
	−3·1	
3·2		10·5
	−3·2	
3·4		11·2
	−3·3	
3·6		11·9
	−3·4	
3·8		12·6
	−3·5	
4·0		13·3
	−3·6	
4·3		14·1
	−3·7	
4·5		14·9
	−3·8	
4·7		15·7
	−3·9	
5·0		16·5
	−4·0	
5·2		17·4
	−4·1	
5·5		18·3
	−4·2	
5·8		19·1
	−4·3	
6·1		20·1
	−4·4	

Ht. of Eye	Corrⁿ
m	
1·0	−1·8
1·5	−2·2
2·0	−2·5
2·5	−2·8
3·0	−3·0
See table ←	
m	′
20	−7·9
22	−8·3
24	−8·6
26	−9·0
28	−9·3
30	−9·6
32	−10·0
34	−10·3

A separate total correction table is used for the sun which includes not only a refraction component but also an allowance for parallax and, largest of the three, semi-diameter. If, as is normal we are using the lower limb the total correction for the sun is always additive. You will notice that this table is in two parts, this takes into account the small seasonal change in the observed diameter of the sun.

Full correction of the moon's altitude, due to its close proximity to the earth , is a special case which we shall look at further down the track when you have mastered the basics.

EXAMPLES: CORRECTION OF ALTITUDE

Note: Zenith distance = 90° — True altitude. Off the arc = +; on the arc = —

Sun, lower limb	
Sextant alt.	37° 28.0′
Index error	+ 1.0′ (off the arc)
Observed alt.	37° 29.0′
Dip	— 2.9′ (Ht. eye = 2.7m)
Apparent alt.	37° 26.1′
Total corr.	+ 15.0′
True alt.	37° 41.1′
Zenith dist.	52° 18.9′

Star	
Sext. alt.	72° 41.6′
I.E.	— 1.7′ (on the arc)
Obs. alt.	72° 39.9′
Dip	— 3.6′ (Ht. eye = 4.1m)
App. alt	72° 36.3′
T.C.	— 0.3′
True alt.	72° 36.0′
Z.D.	17° 24.0′

Venus, Feb 1, 1993	
Sext. alt.	47° 19.7′
I.E.	+ 1.2′ (on the arc)
Obs. alt.	47° 20.9′
Dip	— 2.5′ (Ht. eye = 2m)
App. alt.	47° 18.4′
T.C.	— 0.9′
	47° 17.5′
Addition corr.	+ 0.1′
True alt.	47° 17.6′
Z.D.	42° 42.4′

2.4 Just how accurate is celestial navigation ?

Sloppy work practices aside the accuracy of our sights can suffer degradation from two main sources.
While the latitude component of our sights is not influenced to any great degree by our knowledge of the correct time the longitude component is. As the geographical position of all heavenly bodies moves westward at a rate of 15° per hour it follows that an error of one minute in time - caused possibly by careless reading of our watch - will introduce an error in our position of 15’ of longitude and up until recently errors in time have been a major cause of errors in position fixing.
Today we have access to accurate time which the hydrographers of one hundred or more years ago could only dream about. This is why it is not uncommon, on charts, to find annotations alongside remote islands stating that they lie a few miles either east or west of their charted position.
Good work practices coupled with radio time signals and quartz watches should reduce errors from this cause to a minimum. I find the best sort of watch to use at sea is one with both an analogue and a digital display, leave the analogue display on local time and keep the digital display of both time and date on Greenwich Mean Time (GMT). This also removes the risk, especially when navigating in the central Pacific, of using the wrong date when extracting information from the almanac.
Any sight requires a good horizon if it is to be any good and two things can reduce the quality of our horizon, haze and a heavy sea. We yachtsmen enjoy a considerable advantage over navigators on large ships in hazy weather due to the fact that, as we have such a small

‘height of eye’ our sea horizon is that much closer than theirs is and as a result is degraded to a far lesser degree. It used to be not uncommon on ships trading in the Arabian Sea during the south-west monsoon - where hazy weather is the rule rather than the exception- for the navigators to deliberately reduce their height of eye by taking their sights from the main deck rather than the bridge.

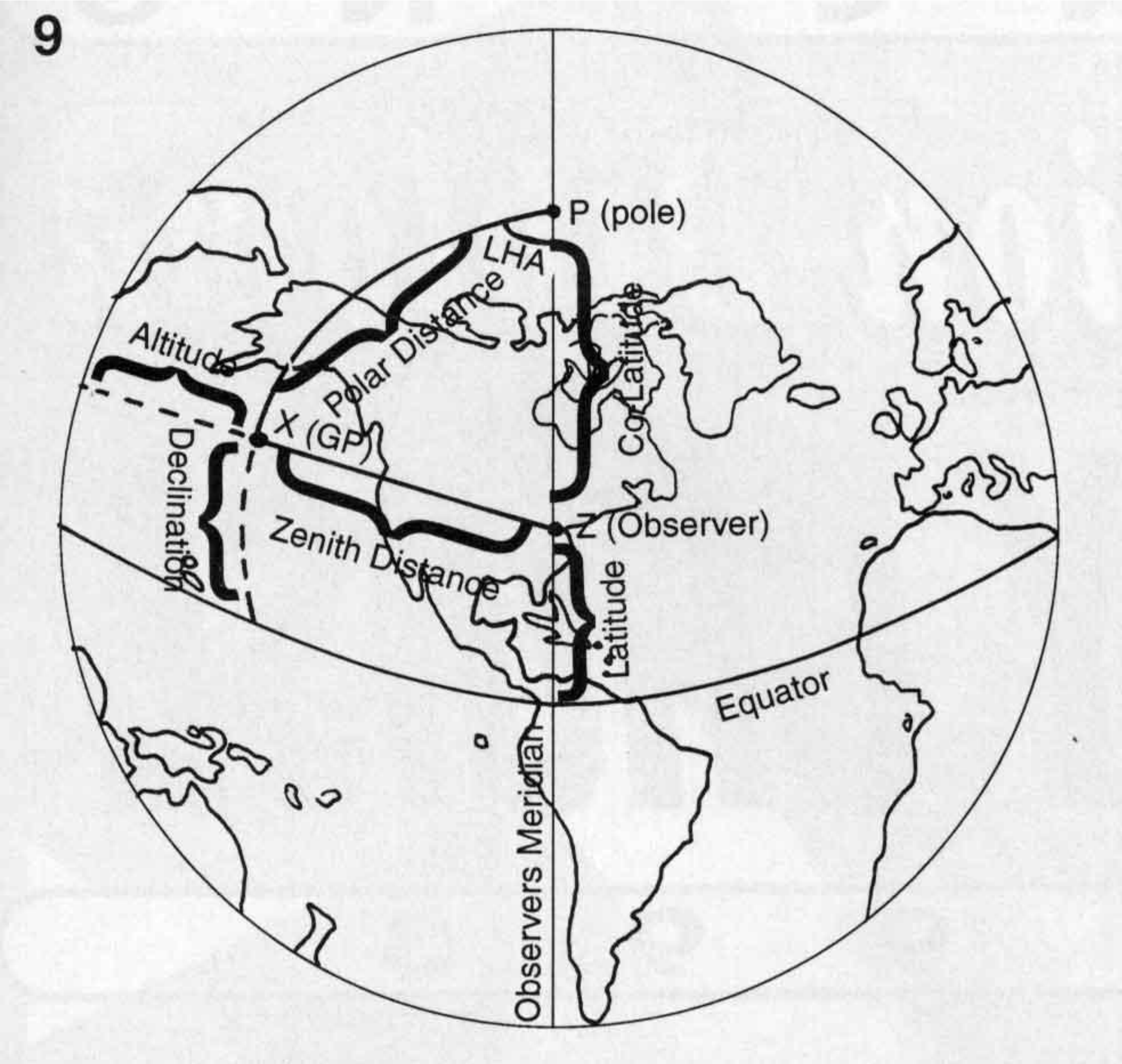
Unfortunately when a heavy sea is running it is the yachtsman that is placed at a distinct disadvantage and a fair degree of skill is required to place the body that is being used on the actual horizon rather than simply atop a wave.

Taking the above factors into consideration it is generally accepted that a sight taken by someone experienced in using a sextant will, in good conditions (firm horizon, slight sea and a steady platform), yield a position line with an accuracy of+/- 1 mile. One taken in moderate conditions (a bit of horizon haze giving a ‘soft’ horizon and the yacht moving around a bit) may have accuracy in the order of +/-2 miles while one taken in poor conditions (a hazy horizon combined with a heavy swell possibly) may be reduced to +/- 10 mile accuracy.

One mark of the good navigator is the ability to assess the quality of the sights that have just been taken and to establish what degree of reliance should be placed in them.

2.5 The PZX Triangle

It is not my intention to baffle you with science but lets look at what we have so far achieved. When we take a sight, that is measure the altitude of a body at a known time, we have a good idea of our own latitude and longitude (our D.R. position) and using time as an argument we are able to extract the Greenwich hour angle and declination of the body from the almanac. If you look at the sketch you will see what we have. Now don't you worry about the mechanics of the whole thing, a chap called Napier sorted all that out some few centuries ago. Suffice to say that in 'common or garden' plane trigonometry as taught at school we use two parts to find a third part of a triangle. In spherical trigonometry we must use three parts to find a fourth. By a bit of mathematical mumbo-jumbo (cosine latitude = sine co-latitude and cosine declination = sine polar distance for instance) we can substitute the latitude for the co-latitude and the declination for the polar distance in any formula based on the PZX triangle. The angle at the pole (angle P) is the local hour angle and thus we now have our three parts which we can use to find out what the zenith distance and therefore the true altitude should be. Next month we shall see how we can use the PZX triangle to establish a position line by comparing what the zenith distance should be with what we have actually measured.


9
P (pole)
LHA
Polar Distance
Altitude
Co-Latitude
X (GP)
Declination
Zenith Distance
Z (Observer)
Latitude
Equator
Observers Meridian

2.6 Part 2. - The Questions

Find the true altitude of the following using the total correction tables:-

1/ The star Regulus has a sextant altitude of 29° 00’, the index error is 4.5’ on the arc and your height of eye is 4.6 metres.

2/ The star Polaris has a sextant altitude of 41° 30’, the index error is 2.1’ off the arc and your height of eye is 2 metres.

3/ The star Sirius has a sextant altitude of 67° 56.8’, the index error is 0.5’ on the arc and your height of eye is 3.3 metres.

4/ The star Canopus has a sextant altitude of 21° 13.6’, the index error is 1.2 ’ on the arc and your height of eye is 2.7 metres.

5/ On the 10th of March, 1993, the planet Venus has a sextant altitude of 81° 27.5’, the index error is 1.5’ off the arc and your height of eye is 3.9 metres.

6/ In late June, 1992, the planet Mars has a sextant altitude of 33° 59.5’ the index error is nil while the height of eye is 5.7 metres.

7/ In early February the sextant altitude of the sun’s lower limb is 21°51.3’, the index error is 2.1’ off the arc and the height of eye is 4.1 metres.

8/ In late December the sextant altitude of the sun’s upper limb is 87° 58’, the height of eye is 3.1 metres and the index error is 1.9’ off the arc.

9/ In mid July the sextant altitude of the sun’s lower limb is 41° 29.1’ while the index error is 2.0’ on the arc and the height of eye is 3.9 metres.

2.7 Part 1 - TheAnswers

1/ {False}

2/ gha = 74° 00’, dec = 40° 40’ N.

3/ gha = 213° 54’, dec = 9° 26’S

4/ lat 19° 21’S long 84° 21’ W

5/ lat 7° 05’ N long 122° 41’E

6/ local hour angle = 62° 35’ lat ~ dec = 15° 49’

Typo Alert N/S was missing from the next two questions so you could have one of two answers, sorry........

7/ local hour angle = 47° 39’ lat ~dec = 15° 07’ or 93 09’.

8/ local hour angle = 37° 40’ lat ~dec = 12° 20’ or 18 38’.

9/ local hour angle = 289° 41’ lat ~dec = 21° 51’

fin

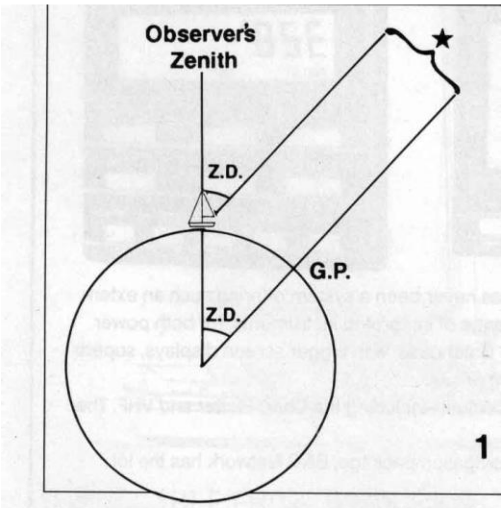
WHERE ON EARTH!

In part three of the series FRANK HOLDEN looks at sight reduction, position lines and we do a bit of lateral thinking.

3 Lateral thinking, part one

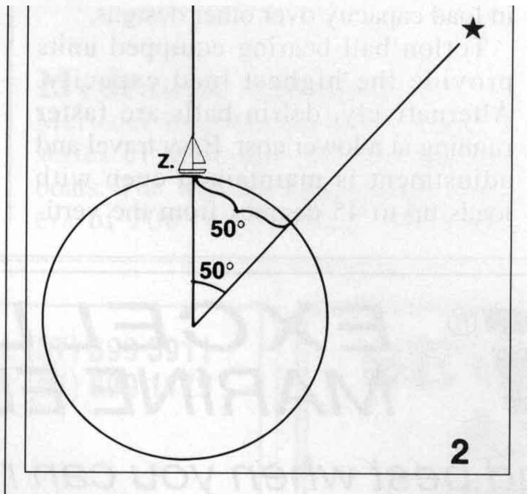
Last month we saw how the sextant altitude of a heavenly body, the local hour angle, the body's declination and the observer's latitude all formed part of a triangle on the earth's surface which is known as the PZX triangle. This month we shall see how, with a little bit of lateral thinking, we can use this information to find where on earth we are.

We have seen how the altitude as read off the sextant can be reduced to a **zenith distance** as measured at the centre of the earth. Now we must see how this zenith distance can, quite literally, be brought down to earth. Looking at the sketch 1 you can see that the zenith distance as measured by the observer on the surface of the earth is the same as the zenith distance as measured at the centre – sketch 2 -due to the very great distance from the earth of all the heavenly bodies except the moon.



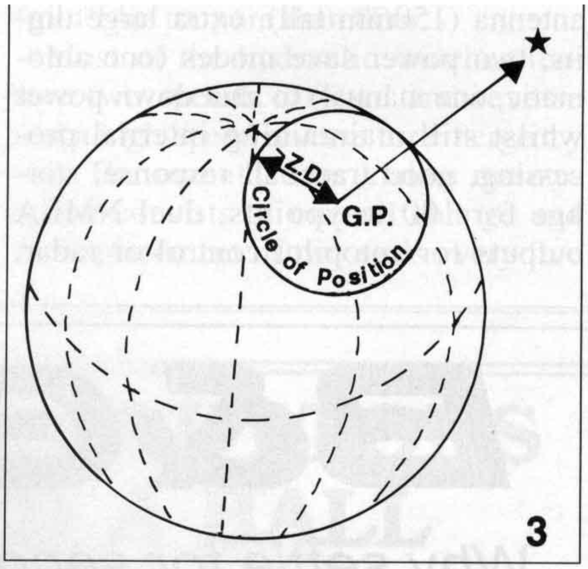
As heavenly bodies are an almost infinite distance away, the zenith distance measured at the surface of the earth is the same as the zenith distance measured at the centre of the earth.

10



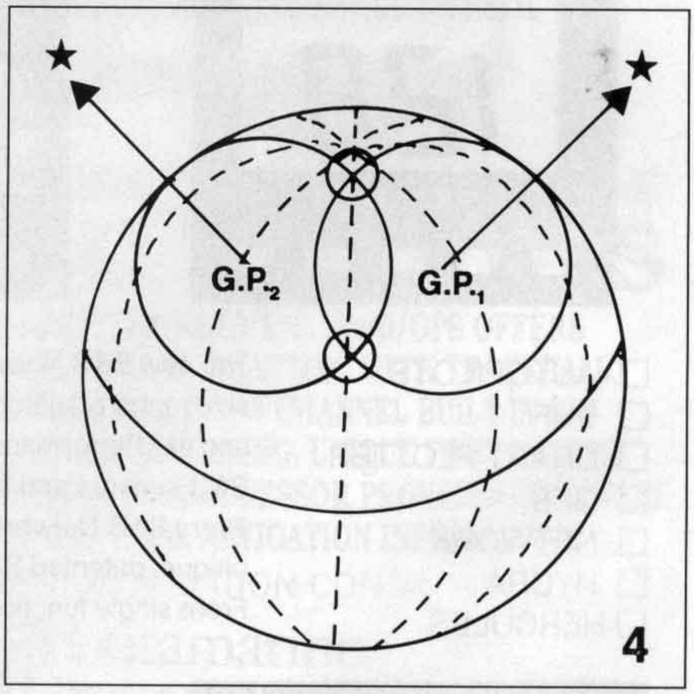
The zenith distance measured at the centre of the earth is the same as the zenith distance expressed as degrees of arc on the earth's surface.

You may also remember that an angle (in this case the zenith distance) measured at the centre of the earth can also be described as an arc on the earth's surface where -by definition - one degree equals 60 nautical miles and 1 minute of arc equals I nautical mile. Thus if our zenith distance as observed is 10°00' then we are 600 miles from the geographical position of the body.



The observer lies somewhere on the circumference of a circle, the radius of which is equal in miles to the zenith distance expressed in minutes of arc, ie., ZD = 20° x 60 = 1200′ ... therefore radius of position circle equals 1200 miles.

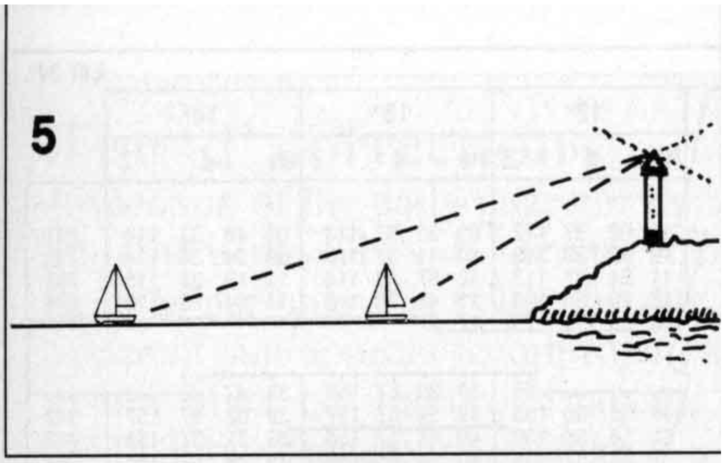
Theoretically if we were to take two simultaneous star sights we could draw two **circles of position** centred on the geographical positions of the two stars by using their zenith distances as radii. We would then be at one of the two points where these circles intersect. In practice however this would not work due to the large distances involved.



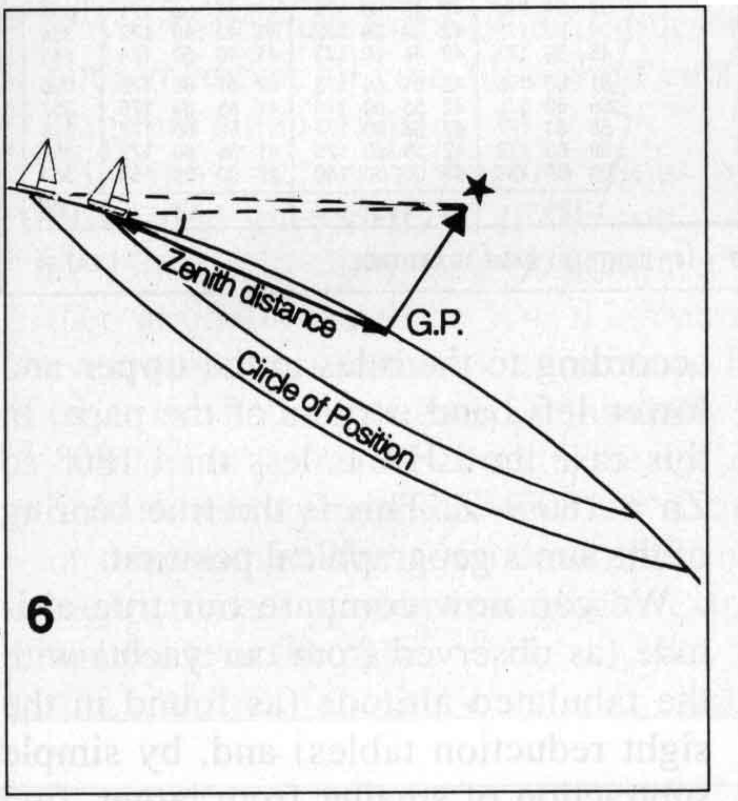
If we can establish our zenith distance from two bodies simultaneously then we are at one of the two positions where the position circles intersect.

This is where you have to start using a bit of that lateral thinking.

At any given moment of time we know the geographical position of the body we are using and we have a rough idea of where we are, that is we know our D.R. position. By using this information in the PZX triangle we can work out what the zenith distance should be, this is known as the calculated zenith distance (CZD). By comparing this with the true zenith distance (TZD) as derived from our sextant altitude we can establish whether we are either closer or further away from the geographical position.

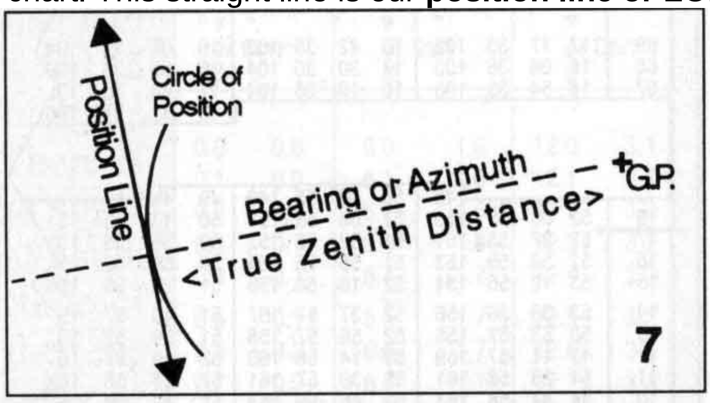


If we take a vertical sextant angle of a lighthouse, the greater the angle the closer we are to the lighthouse.

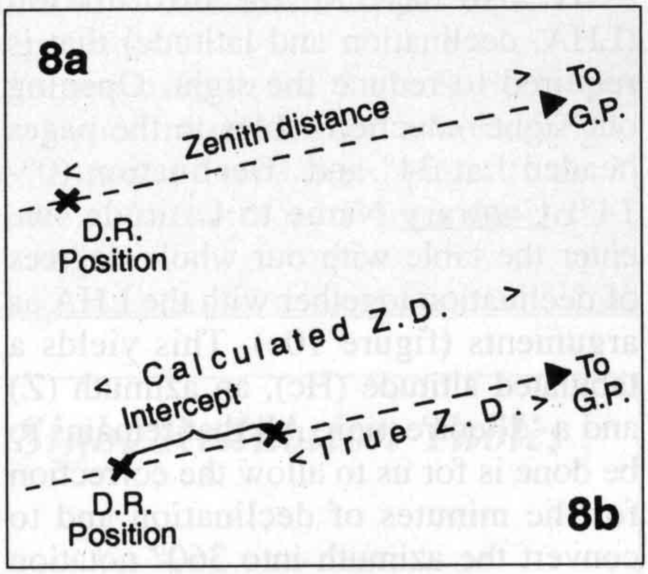


In similar fashion, the higher the altitude of a body (and thus the smaller the zenith distance) the closer the observer is to the geographical position.

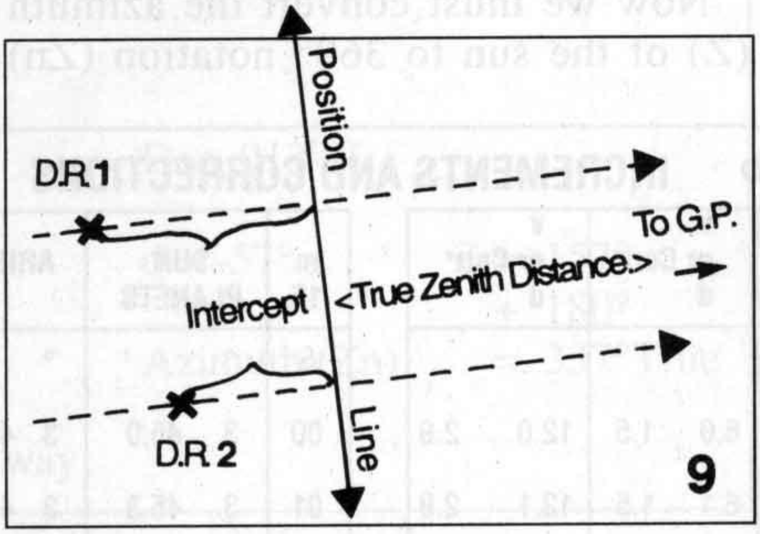
If the star is higher in the sky than our DR would suggest then we are , in fact , closer to the G.P. than we thought. If it is lower in the sky then we are further away with each 1' of arc on our sextant equalling one mile. Thus our circle of position will be either larger or small than anticipated. If we now accept that we are only dealing with a very small segment of the circle we can safely portray it as a straight line on our chart. This straight line is our **position line or LOP.**



The radius of the position circle is normally so great (600′+) that the observer can be assumed to lie somewhere on a straight line drawn tangental to the position circle, ie., at right angles to the bearing or azimuth of the body. This line is called a position line.



8a: Having established an approximate position known as a DR position, we work out a PZX triangle to find what the zenith distance would be if we were at that position.
8b: By comparing the true zenith distance - obtained with our sextant - with the zenith distance obtained by calculation, we can see if we are towards or away from the geographical position. This difference is called the intercept.



Within reason, no matter what DR position we use, the position line established shall be the same. Note: An accurate DR is not critical and will not affect our position line but is required if we are to accurately calculate our set and drift.

3.1 Sight Reduction in Practice

There are several ways in which we can calculate or 'reduce' our sights and thus establish a position line. The method that we shall explore in greatest detail and which we shall use throughout this series is that one based on the 'Sight Reduction Tables for Air Navigation'.

These tables were first published in 1947 and , as the name suggests, were designed to enable aviators to rapidly reduce their sights. The accuracy of these tables is, however, more than sufficient to allow them to be used for all practical offshore navigation. They are based on the premise that our latitude - together with the body's local hour angle and declination - are all in integral degrees, in other words they are whole numbers. This can be accomplished with the former two by adjusting our D.R. position while the later is corrected by using a small auxiliary table.

These tables have been compiled in such a way that we can use the sun's true altitude rather than converting it to a true zenith distance.The other information that we require before we can use them is our own approximate position (also known as our D.R. position) together with the body's hour angle and declination at the time of sight.

Let us assume that a sun sight was taken on the 25th April 1993 at 03h15m03s GMT when we were in the vicinity of latitude 34° 15' S, longitude 148° 45' E. The first step is to simply open the Nautical Almanac to the 25th April and note the sun's GHA and declination at 03h GMT.

UT (GMT)		SUN			10a
		G.H.A.		Dec.	
d	h	°	′	°	′
25	00	180	29.7	N13	07.3
	01	195	29.8		08.1
	02	210	29.9		09.0
	03	225	30.0		09.8
	04	240	30.1		10.6
	05	255	30.2		11.4
	06	270	30.3	N13	12.2
	22	150	36.8		03.5
	23	165	36.9		04.3
		S.D.	15.9	*d*	0.8

Note the GHA and declination at 03h. Note also the 'd' correction of 0.8′ at the bottom of the column. The 'd' correction is the factor to be applied over the hour. In our example the time of sight is 03h15m03s, therefore the correction of declination for the extra 15m03s is applies as follows: 15min is 1/4 of an hour, consequently 1/4 of 0.8′ is 0.2′ and because the declination is increasing as time passes we add the correction factor (see example).

The increment for 15m 03s is then obtained from the 'Increments and Corrections' pages towards the back of the almanac and is <u>always added.</u> The correction for declination can either be mentally interpolated or ascertained by using these pages.

14m — 10b INCREMENTS AND CORRECTIONS

m 14	SUN PLANETS	ARIES	MOON	v or d	Corr	v or d	Corr	v or d	Corr
S	° ′	° ′	° ′	′	′	′	′	′	′
00	3 30.0	3 30.6	3 20.4	0.0	0.0	6.0	1.5	12.0	2.9
01	3 30.3	3 30.8	3 20.7	0.1	0.0	6.1	1.5	12.1	2.9
02	3 30.5	3 31.1	3 20.9	0.2	0.0	6.2	1.5	12.2	2.9
03	3 30.8	3 31.3	3 21.1	0.3	0.1	6.3	1.5	12.3	3.0
04	3 31.0	3 31.6	3 21.4	0.4	0.1	6.4	1.5	12.4	3.0

15m

m 15	SUN PLANETS	ARIES	MOON	v or d	Corr	v or d	Corr	v or d	Corr
S	° ′	° ′	° ′	′	′	′	′	′	′
00	3 45.0	3 45.6	3 34.8	0.0	0.0	6.0	1.6	12.0	3.1
01	3 45.3	3 45.9	3 35.0	0.1	0.0	6.1	1.6	12.1	3.1
02	3 45.5	3 46.1	3 35.2	0.2	0.1	6.2	1.6	12.2	3.2
03	3 45.8	3 46.4	3 35.5	0.3	0.1	6.3	1.6	12.3	3.2
04	3 46.0	3 46.6	3 35.7	0.4	0.1	6.4	1.7	12.4	3.2

Note that you may have to either add or subtract this correction for declination and that no sign is given on the daily pages.

3.2 The 'd' correction

10d					15^m
v or d	Corr^n	v or d	Corr^n	v or d	Corr^n
′	′	′	′	′	′
0.0	0.0	6.0	1.6	12.0	3.1
0.1	0.0	6.1	1.6	12.1	3.1
0.2	0.1	6.2	1.6	12.2	3.2
0.3	0.1	6.3	1.6	12.3	3.2
0.4	0.1	6.4	1.7	12.4	3.2
0.5	0.1	6.5	1.7	12.5	3.2
0.6	0.2	6.6	1.7	12.6	3.3
0.7	0.2	6.7	1.7	12.7	3.3
0.8	0.2	6.8	1.8	12.8	3.3
0.9	0.2	6.9	1.8	12.9	3.3
1.0	0.3	7.0	1.8	13.0	3.4
1.1	0.3	7.1	1.8	13.1	3.4

The hourly change in declination is found in the daily pages, while the actual correction is found on the 'increments and corrections' page.

Inspection of the daily pages of the almanac will show that the GHA of the sun increases by 15 degrees per hour this being the rate at which the sun orbits the earth.

There is also a small but important change in the sun's declination. This hourly change is at a maximum at the equinoxes and is negligible at the time of the solstices.

If you ignore it then the maximum error produced will be in the order of one mile in latitude, if you apply it the wrong way a maximum error of two miles may result but remember - all your little short cuts and omissions are cumulative.
On most occasions you can allow for it simply by mental interpolation. If the sun's declination at 0500 is 5° 40.6' and at 0600 it is 5° 41.6' then at 0430 it will be 5° 41.1'. You may, however, prefer to use the 'd' correction. This is listed at the bottom of each of the daily pages and should not be confused with the 'd' correction used in the Sight Reduction Tables. Simply note the value of 'd' and whether the declination is increasing or decreasing. When you enter the 'Increments and Corrections' pages to get the increment of your hour angle extract the correction for 'd' from the right hand side of the page.

Now, to make the tables work we must use what is known as a **chosen position** rather than our D.R. position. This simply involves selecting a latitude that is the nearest whole number of degrees to our D.R. latitude. In this example we shall use 34° South. We must also obtain an LHA which is a whole number. In the example our GHA for 03h15m03s is 229° 15.8' and our D.R. longitude is 148° 45' East. If we choose a longitude of 148° 44.2' East we will achieve our objective. (229°15.8' [GHA] + 148°44.2' [E.Long] = 018°00' [LHA]). We now have enough information to let us plot our chosen position on our plotting sheet.
We also have all the information (LHA, Declination and Latitude) that is required to reduce the sight. Opening our sight reduction tables to the pages headed Lat 34° and 'Declination (0°-14°) <u>Contrary</u> Name to Latitude' we enter the table with our whole degrees of declination together with the LHA as arguments.

10c	0°			1°			2°			12°			13°			14°			LAT 34°
	Hc	d	Z	Hc	d	Z	Hc	d	H	Hc	d	Z	Hc	d	Z	Hc	d	Z	
	°	′	′	°	°	′	′	°	°	′	′	°	°	′	′	°	°	′	′ °
69	17 17	35	102	16 42	36	103	16 06	35	104	10 02	37	112	09 25	37	113	08 48	37	114	291
68	18 06	36	103	17 30	35	104	16 55	36	104	10 49	38	113	10 11	37	113	09 34	38	114	292
67	18 54	35	103	18 19	36	104	17 43	36	10	11 34	37	113	10 57	38	114	10 19	38	115	293
							18 31	37	106	12 20	38	114	11 42	38	115	11 04	38	115	294
										13 05	-38	115	12 2						
			148	50 43	55	149	49 4					55	39 39	57	156	38 42			
18	52 03	55	150	51 08	55	151	50 13	55	151	40 55	56	156	39 59	57	157	39 02	57	157	342
17	52 27	55	151	51 32	56	152	50 36	55	153	41 14	56	158	40 18	57	158	39 21	57	159	343
16	52 50	55	153	51 55	56	154	50 59	56	15	1 33	57	159	40 36	58	159	39 38	57	160	344
15	53 12	-56	154	52 16	-56	155	51 20	-56	156	50	-57	160	40 53	-58	161	39 55	-57	161	345
14	53 33	56	156	52 37	57	157	51 40	57	15	07	58	161	41 09	58	162	40 11	58	162	346
13	53 53	57	158	52 56	57	158	51 59	57	15	42 22	58	163	41 24	58	163	40 26	58	163	347
12	43 11	57	159	53 14	58	160	52 16	57	16	2 36	58	164	41 38	58	164	40 40	59	165	348
11	54 28	58	161	53 30	57	161	52 33	58	162	50	59	165	41 51	59	166	40 52	58	166	349
10	54 44	-58	163	53 46	-59	163	52 47	-58	163	02	-59	167	42 03	-59	167	41 04	-59	167	350
9	54 58	58	164	54 00	59	165	53 01	59	165	13	59	168	42 14	59	168	41 15	60	168	351
8	55 11	59	166	54 12	59	166	53 13	59	167	23	60	169	42 23	59	169	41 24	59	170	352
7	55 22	59	168	54 23	59	168	53 24	59	168	31	59	171	42 32	60	171	41 32	59	171	353
6	55 32	59	169	54 33	59	170	53 34	60	170	39	60	172	42 39	59	172	41 40	60	172	354
5	55 41	-60	171	54 41	-59	171	53 42	-60	172	45	-59	173	42 46	-60	173	41 46	-60	174	355
4	55 48	60	173	54 48	60	173	53 48	59	17	51	60	175	42 51	60	175	41 51	60	175	356
3	55 53	60	175	54 53	60	175	53 53	59	175	55	60	176	42 55	60	176	41 55	60	176	357
2	55 57	60	176	54 57	60	177	53 57	60	177	58	60	177	42 58	60	177	41 58	60	177	358
1	55 59	60	178	54 59	60	178	53 59	60	178	59	60	179	42 59	60	179	41 59	60	179	359
0	56 00	-60	180	55 00	-60	180	54 00	-60	180	00	-60	180	43 00	-60	180	42 00	-60	180	360
LHA	0°			1°			2°			12°			13°			14°			LHA

S. Lat. { LHA greater than 180° ....Zn=180-Z
LHA less than 180°.................Zn=180+Z

DECLINATION (0° – 14°) CONTRARY NAME TO LATITUDE

LAT 34°

This yields a tabulated altitude (Hc), an azimuth (Z) and a ‘d’ correction. All that remains to be done is for us to allow the correction for the minutes of declination and to convert the azimuth into 360° notation (Zn).

For the former we use the Table 5 - Correction to Tabulated Altitude - card. Simply enter it with the odd minutes of declination in the left hand column and the ‘d’ correction. Now lift the correction from the table and apply it to the tabulated altitude <u>taking care that you apply the sign correctly.</u>

Now we must convert the azimuth (Z) of the sun to 360° notation (Zn) according to the rules in the upper and lower left hand corners of the page. In this case the LHA is less than 180° so Zn=180 + Z. This is the true bearing of the sun’s geographical position.

We can now compare our true altitude (as observed from our yacht) with the tabulated altitude (as found in the sight reduction tables) and, by simple subtraction, find the intercept which is named either **<u>T</u>**owards or **<u>A</u>**way from the geographical

position. The rule we use is “**tabulated (altitude) tiny towards**”, that is the higher the sun is in the sky the closer we are to the geographical position.
If we now pencil in the sun’s azimuth through our chosen position we can step of our intercept and draw a position line (a small segment of our position circle) at right angles to this azimuth line.

If we have done everything correctly it is reasonable to assume that we were somewhere either on or close to this position line at the time of taking our sight.

Sight Reduction using the *Sight Reduction Tables for Air Navigation*

See figure 11

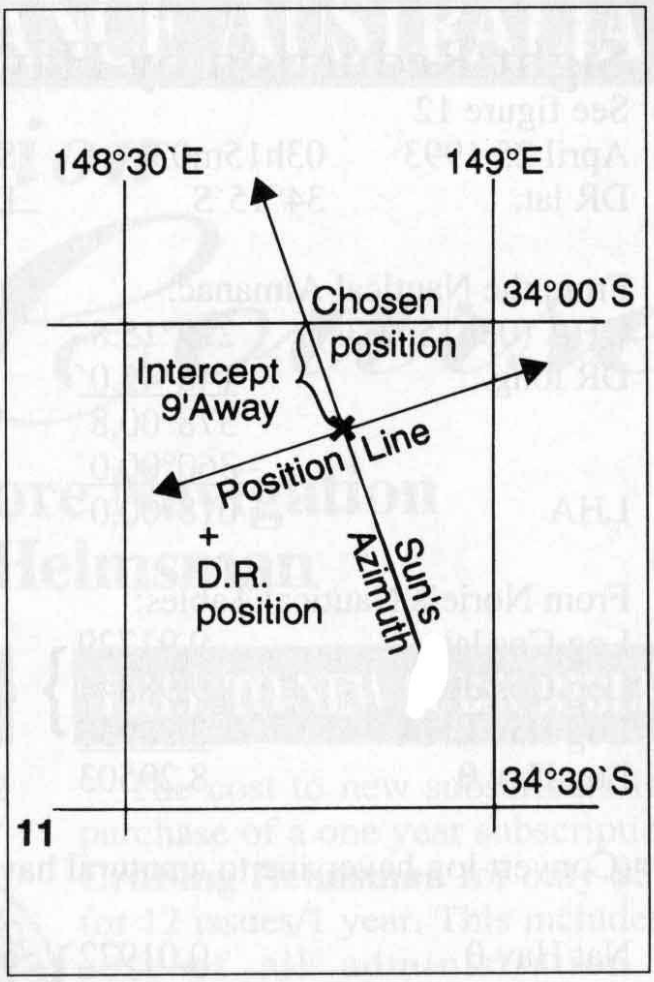
April 25 1993 03h15m03s — Sun's true alt. 39°41´
DR lat. 34°15´S — DR long. 148°45´E
Chosen lat. 34°00´S

From the Nautical Almanac:

GHA 03h		225°30.0´	Dec.	13°09.8´N
Increment	15m03s	3°45.8´	d = 0.8´	+ 0.2´
GHA	03h15m03s	229°15.8´	Dec.	13°10.0´N
Chosen long.		148°44.2´		
		378°00.0´		
		-360°00.0´		
Local hour angle		018°00.0´		

From the Sight Reduction Tables:
Chosen lat. 34°S — LHA 018° — Dec. 013°N

Tabulated alt.	39°59´	d = -57°	Z = 157°
Corr. for 10´ of dec.	- 10´		+ 180°
Tabulated alt. (Hc)	39°49´	Azimuth (Zn)	= 337°True
True alt. (Ho)	39°41´		
Intercept	9´ Away		



To plot the position line first mark in both your DR position and your chosen position. Then draw in the sun's azimuth through the chosen position. Finally step off the intercept either Towards or Away and draw the position line at right angles to the azimuth.

3.3 The Haversine Method

Few people these days bother to work out sights by what is also known as the “longhand” method. It still has its place in the scheme of things and is the most cost effective method of all as all that is required is a nautical almanac and a set of nautical tables, such as Nories, which contains haversines. For the mathematically inclined a haversine is an artificially produced ratio where Haversine A = 1/2(1 - Cos A). Unlike all other trigonometric ratios the value of the haversine is positive (+) from 0 degrees to 360 degrees and this fact lets us produce a formula where all that is required is a bit of simple addition.

All preparation is identical to that required for working with the Air Tables and you just arm yourself with a DR latitude, declination, local hour angle and a true zenith distance.

The calculated zenith distance = (cosine lat. x cosine dec. x haversine lha) +
(haversine lat. diff. dec.).

This may seem fairly daunting but by using the Log Hav tables in our nautical tables which - when entered with degrees and minutes - yield the logarithm of the haversine it is reduced to simple addition. Let us consider again the sun sight that we have previously reduced with the aid of the tables.

Sight Reduction by Haversine Formula

See figure 12

April 25 1993	03h15m03s	Sun's true alt.	39°41´
DR lat.	34°15´S	DR long.	48°45´E

From the Nautical Almanac:

GHA (03h15m03s)	229°15.8´	Declination	13°10.0´N
DR long.	148°45.0´	DR lat.	+ 34°15.0´S
	378°00.8´	Lat. diff dec.	47°25.0´
	- 360°00.0´		
LHA	018°00.0´	True Zenith dist.	= 90° - True alt.
			= 50°19.0´

From Norie's Nautical Tables:

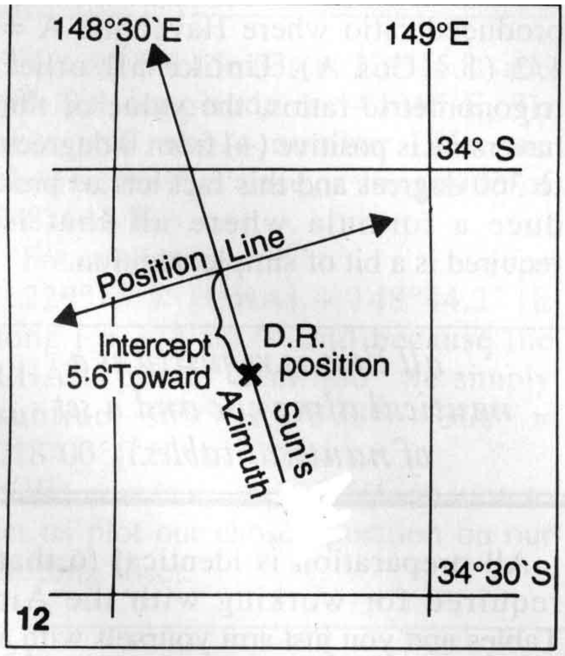
Log Cos lat.	9.91729	add
Log Cos dec.	9.98844	
Log Hav LHA	8.38930	
Log Hav θ	8.29503	

(Convert log haversine to a natural haversine)

Nat Hav θ	0.01972	add
Nat Hav L-D	0.16163	
Nat Hav CZD	0.18135	

(Convert from haversine to degrees and minutes)

As, with this method, we are comparing zenith distances rather than altitudes to find the intercept the rule for naming the intercept is the opposite to that used with the sight reduction tables. Here we use 'True (zenith distance) Tiny Towards'. That is the higher in the sky the object the closer to geographical position will be our position line. Now simply lay your intercept off along the azimuth line either away or towards the G.P. from your D.R. position.



With the Haversine method of sight reduction, the intercept is plotted from the DR position.

That's it folks - the dreaded longhand in ten lines. Slightly slower than the air tables and not suited for star sights unless you are extremely patient but it does have the small benefit that you can work directly from your D.R. position and don't need to convert to a chosen position.

3.4 Why is a Nautical Mile?

The basic unit of measurement that we use offshore is the minute of arc (') and you have already seen the relationship between a minute of arc in a body's altitude and a minute of arc on the earth's surface.

One minute of latitude is, by definition, one minute of arc and is known by us as a **nautical mile**. The reason that it is called a mile is that, some centuries ago, it was found to be roughly the same as a land - or statute - mile. Those who prefer metrics may like to consider that this statute mile was itself based on the Roman measure of one thousand paces and even today the nautical mile can be divided up into cables, there being ten cables to a nautical mile.

Now the the earth is not a pure sphere but is what is known as an oblate spheroid and is slightly flattened at the poles. This means that the length of one minute of arc measured on the earth's surface varies by some 19 metres between the equator and the poles.
But for most of our purposes that is largely academic - as far as we are concerned one nautical mile equals one minute of arc.

3.5 Publications required by the Offshore Navigator

Regardless of whether you choose to use the sight reduction tables or prefer the haversine formula you will require a **nautical almanac**. This is an annual publication and, amongst other information, contains all that is required to let you establish the GHA and Declination of the sun and the moon as well as the planets and stars of navigational significance.

A copy of **Norie's Nautical Tables** will be required if you choose to use the haversine method of sight reduction. These tables, which cost $38.95, contain the necessary log. haversine and log. cosine tables. Amongst the many other tables which are included the most useful is possibly the Traverse table, the use of which we shall discuss next month.

The **Sight Reduction Tables for Air Navigation** come in 3 volumes, Volume 1 is for use with selected stars. A new edition is produced every 5 years, the present edition being for epoch 1990 is due for replacement at the end of next year. Volumes 2 (latitude 0° to 39°) and 3 (latitude 40° to 89°) are designed for use with sun, moon or planet sights and do not need replacement. These tables are published in both Britain (A.P. 3270) and the U.S. (Pub 249). While they are identical in content the American ones are most commonly used at sea as they are cheaper.

Try your hand at this one.
You are in D.R. Position Latitude 12° 18’ South, Longitude 072° 21’ East. At $05^h15^m00^s$ on the 2nd of September, 1993, you obtain a true altitude of the sun of 54° 21’. What is the intercept and what is the azimuth?

ANSWER

Sept 2 ‘93 05h15m00s Sun’s true alt. 54°21´
DR lat. 12°18´S DR long. 072°21´E

Chosen lat. 12°00´S

From the Nautical Almanac:

GHA 05hr	255°04.0´	Dec.	07°54.9´N
Increment 15min 00sec	3°45.0´	d=0.9´	- 0.2´
GHA 05h15m00s	258°49.0´	Dec.	07°54.7´N
Chosen long.	072°11.0´ E		
Local hour angle	330°00.0´		

From the Sight Reduction Tables:
Chosen lat. 12°S LHA 330° Declination 07°N

Tabulated Alt.	54°38´	d= -33´	Z= 121°
Correction for 55´ of Dec	- 30´	Az= 180° - Z	
Tabulated alt. (Hc)	54°08´	Azimuth (Zn)= 059°True	
True alt. (Ho)	54°21´		
Intercept	13´ **Away**		

3.6 Part 3 – The Questions

Q1a The sextant altitude of the sun's lower limb, in mid April, is 32° 51'. The index error is 2' on the arc and the height of eye is 4.4 metres. What is the true altitude of the sun?

Q2 A star has a sextant altitude of 71° 11.2'. Index error is 2' off the arc and the height of eye is 5.1 metres. What is the true altitude?

Q3 What is the Greenwich hour angle and declination of the sun at 2100 GMT on the 2nd September, 1993?

Q4 At $07^h15^m02^s$ GMT on the 15th March, 1993, what is the sun's gha and declination?

Q4b If you are in Longitude 48° 11'West what is the local hour angle?

Q5a At 0900 GMT on the 16th March, 1993, the sun's Greenwich hour angle is 312° 50.1' . Your D.R. position is 25° 07' South, 012° 11' East. Select a chosen position.

Q5b What local hour angle will you enter the "Air Tables" with?

Q6 At 0600 GMT on the 2nd September, 1993, the sun's Greenwich hour angle is 270° 04.2'. Your D.R. position is 20° 11' North, 05° 58' West. Select a chosen position.

Q6b What local hour angle would you enter the "Air Tables" with?

Q7 The sun's declination at the time of taking your sight was 18° 21' South. The "d" correction in the Air Tables is +32. What correction should you apply to your tabulated altitude?

Q8 Your sun sight yielded a true altitude of 63° 11’. From the Air tables you have obtained a tabulated altitude of 63° 23’. What is the intercept and is it towards or away?

Q9 It is early January,the tabulated altitude was 27° 59’, the sextant altitude of the sun’s lower limb was 28° 05’. Height of Eye = 3.3 Metres, Index Error Nil. What is the intercept and is it away or towards?

Q10 The sun’s local hour angle is 315°, you are in south latitude, the sun’s declination is northerly. From the air tables Z = 130°. What is the sun’s azimuth.

Q11 On the 2nd of September, 1993, the sun’s local hour angle is 047°. You are in the northern hemisphere. From the air tables Z = 118°, what is the sun’s azimuth.

Q12 Your chosen latitude is 12° South, the sun’s local hour angle is 327° and the declination is 7° 00’ North. What is the tabulated altitude and what is the azimuth?

Q 13 Your chosen latitude is 34° North, the sun’s local hour angle is 047° and the declination is 5° 15’ North. What is the tabulated altitude and what is the azimuth.

3.7 Part 2 - The Answers

1/ A. 28°49.9’

2/ A. 4128.5’

3/ A 67°52.7’

4/ A 21°07’

5/ A. 81°25.5’

6/ A. 33°54’

7/ A 22°03.7’

8/ A 87°40.6’

9/ A 41°38.5’

Fin

PLANE SAILING

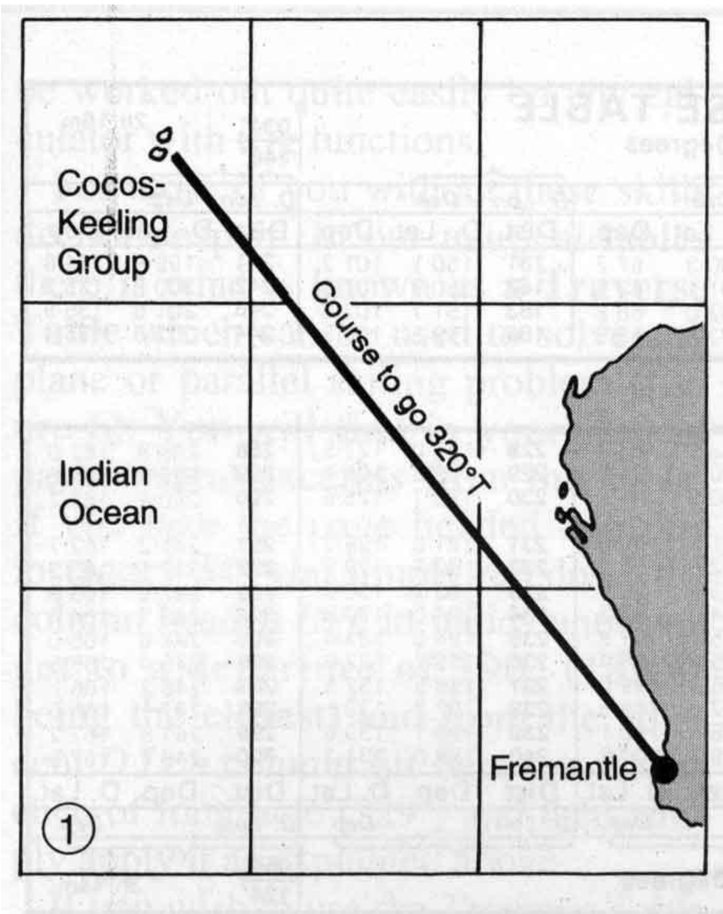
FRANK HOLDEN looks at ways of establishing the course and distance to sail for an ocean passage. Part Four in the series.

4 Plane sailing

It’s all plane sailing
or
How far - which way?

Last month we dealt with the most abstract and difficult part of offshore navigation, the actual sight reduction. With a bit of luck you now understand the concept of position lines and why an intercept is named either towards or away. While we still have a fair way to go in sight reduction and have yet to use it with the planets, stars or moon let alone to find our position when out of sight of land , maybe the time is right for us to get our yacht underway on a voyage to foreign parts.

Having selected a destination and chosen a suitable time of year for our venture the next thing is to work out how far we have to go and in which direction we should point our boat. If we have a chart that shows both our port of departure and our destination the course to steer can be found quite simply by laying off the track on the chart and reading the course directly. For runs such as Fremantle to the Cocos Keeling Group and Sydney to Lord Howe Island or New Caledonia this is quite acceptable.



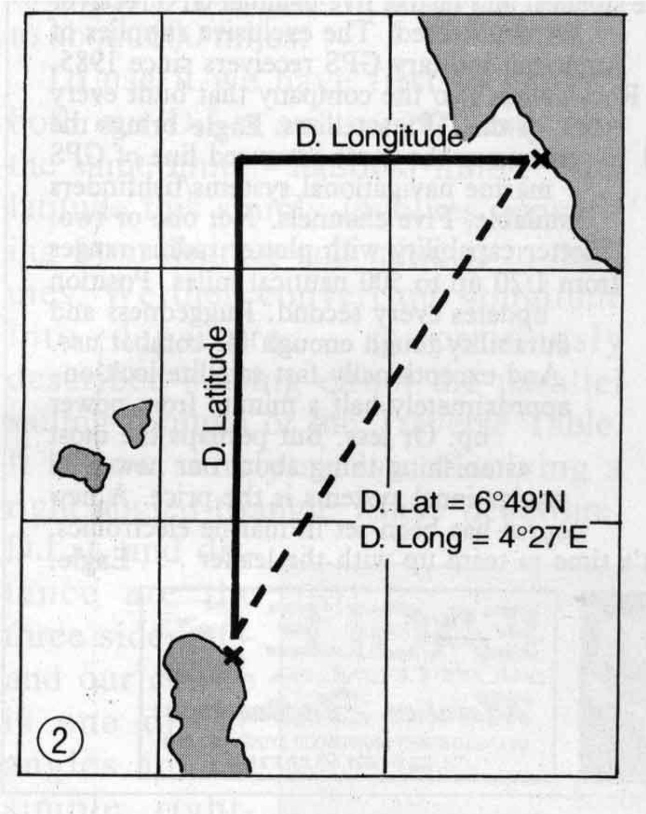
On most passages we can lift the course to go directly from the chart.

Finding the distance to go is not quite so simple as the scale of the chart is invariably unsuitable for this purpose. So to work out those distances that we can't read of the chart because of the scale we must use one of the **sailings**. There are three of these, two of which - *mercator sailings* and *great circle sailings* - can be considered strategic, and are used for long ocean passages. The third one -*plane sailing* - is of a more tactical nature and is the one that we shall look at this month.

4.1 Calculating D.Lat and D. Long.

Before we can work out the course and distance to go we must know the latitude and longitude of both our departure point and our destination.

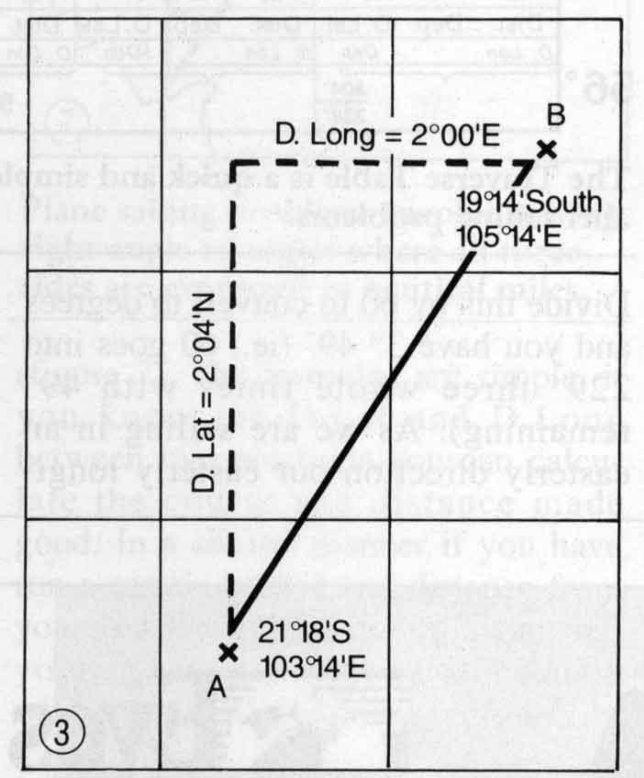
The next step is to calculate the **difference in latitude** and the **difference in longitude** between these two points.



Before we can find the distance, we must ascertain our difference of latitude and our difference of longitude.

This is a simple arithmetic operation, if they are of the same name subtract larger from smaller, but note whether you are heading east or west, north or south. Conversely if you are crossing either the Equator or the Greenwich meridian you simply add them.

Lets say that you are going from Latitude 21° 18´ South, Longitude 103° 14´ East to Latitude 19° 14´ South ,Longitude 105° 14´ East. By inspection you can see the difference of latitude - d. lat - is 2° 04´ North while the difference of longitude - d. long - is 2° 00´ East and you shall be heading in a north-easterly direction.



D.Lat and D.Long are established arithmetically.

4.2 Parallel sailing

Now let us assume that we want to get to a destination directly to the north or south of our present position and that the d. lat. is 3° 00´ . We already know that one minute of latitude equals one nautical mile so the answer is simple. The distance to go is 3 x 60´ = 180 miles.

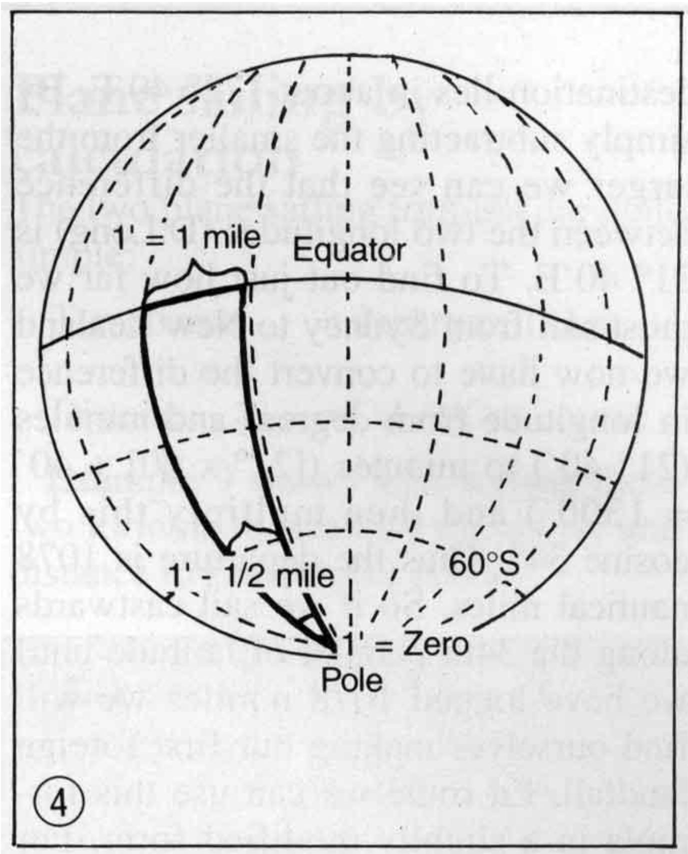
If our destination lies either due east or due west things start to get a little more complicated. What if we wish to sail either east or west to a destination, say, 12° of longitude away? To resolve this problem we use **parallel sailing** so named because it is assumed that we are sailing along a parallel of latitude.

One minute of longitude measured at the earth's surface varies in length depending upon the latitude in which it is measured. At the equator it is equal to one nautical mile but as you go from there towards the poles it gradually decreases in length as the meridians converge. (You may find a globe or a good atlas comes in handy at this stage in helping to envisage some of these simple concepts.)

As a result it can be shown (i.e. take my word for it) that *a minute of longitude measured at the surface of the earth varies in length as the cosine of the latitude, it varies in length from 1 nautical mile in Latitude 0° (the Equator) to zero in Latitude 90° (the Poles).*

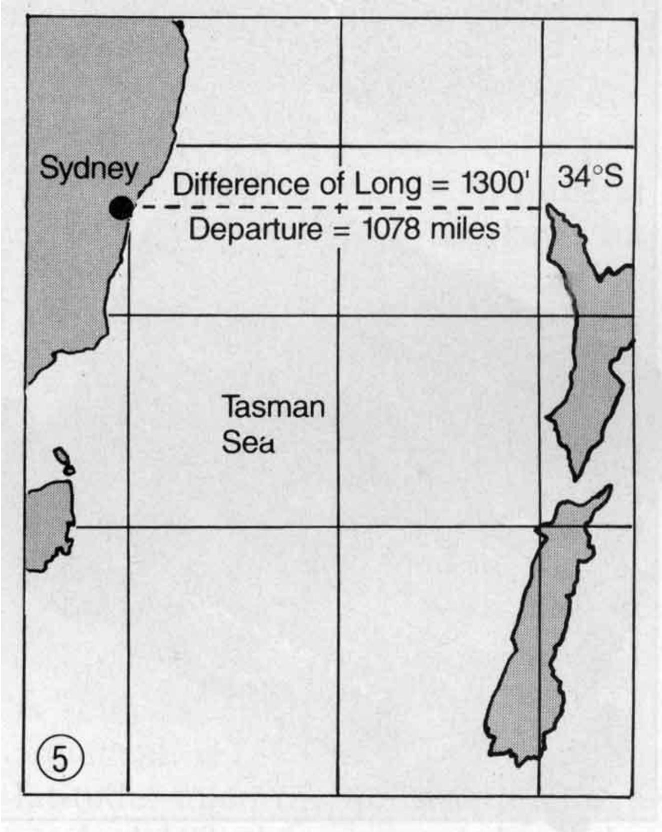
Thus to find out how many nautical miles away our destination lies to either the east or west we simply multiply the difference in longitude (in minutes) by the cosine of the latitude. This linear distance (in nautical miles) between any two meridians of longitude when measured in a given latitude is called the **departure.** We now have a handy little formula for our notebook:-

D.Long x Cosine Latitude = Departure



A minute of longitude varies in length from 1 mile at the equator to zero at the poles.

To see the practical utility of this formula let us make our first voyage from Sydney to the northern-most tip of New Zealand, both of which lie in about latitude 34° South. The longitude of Sydney is 151° East while our destination lies in about 172° 40' East. By simply subtracting the smaller from the larger we can see that the difference between the two longitudes (*d.long*) is 21° 40´ East . To find out just how far we must sail from Sydney to New Zealand we now have to convert the difference in longitude from degrees and minutes (21° 40´) to minutes ({21° x 60} + 40´ =1300´) and then multiply this by Cosine 34°. Thus the departure is 1078 nautical miles. So if we sail eastwards along the 34th parallel of latitude until we have logged 1078 miles we will find ourselves making our first foreign landfall.



In any given latitude the departure equals the D.Long multiplied by the cosine of the latitude.

En route we can use this formula in a slightly modified form. Lets say that after a day and a half of sailing without being able to get any sights we have logged 190 miles. By shifting the formula around so that :-

D.long = Departure / Cosine latitude

= 190´ / Cosine 34°

= 229´

we can see that we have made an *easting* of 229 minutes of longitude. Divide this by 60 to convert to degrees and you have 3° 49´. As we are sailing in an easterly direction our easterly longitude has increased and our D.R. Longitude is now :-

151°E + 3° 49´ E = 154° 49´ East.

For those that can handle simple trigonometry those two problems can be worked out quite easily on any calculator that has trig functions.

For those of you that don't have those skills do not despair. In our nautical tables there is what is known as a **Traverse Table** which can be used to solve any plane or parallel sailing problem. If you take the page headed - in this instance - 34° you simply run down the column headed *Dep.* in italics until you get to a departure of

190´ (189.8´ being the closest) and from the adjacent *D. Long* column lift out your difference of longitude (229´) and then simply apply it as explained above.
If you wish to use the Traverse table to work out the distance to New Zealand you will find that it can only be used with a d.long of up to 600´. To resolve this we shift the decimal point one place to the left and run down the *D.Long* column until we reach 130´, from the *Dep.* column we can now lift out a departure of 107.8´, shift the decimal point back to its rightful place and we have a departure (i.e. distance) of 1078 miles.

TRAVERSE TABLE

34 Degrees

34° | 326° / 214° | 034° / 146° | 2h 16m

D. Lon	Dep.		D. Lon	Dep.		D. Lon	Dep.		D. Lon	Dep.		D. Lon	Dep.	
Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.
1	00·8	00·6	61	50·6	34·1	121	100·3	67·7	181	150·1	101·2	241	199·8	134·8
2	01·7	01·1	62	51·4	34·7	122	101·1	68·2	182	150·9	101·8	242	200·6	135·3
3	02·5	01·7	63	52·2	35·2	123	102·0	68·8	183	151·7	102·3	243	201·5	135·9
4	03·3	02·2	64	53·1	35·8	124	102·8	69·3	184	152·5	102·9	244	202·3	136·4
48	39·8	26·8	108	89·5	60·4	168	[illegible]	93·9	228	189·0	127·5	288	238·8	161·0
49	40·6	27·4	109	90·4	61·0	169	140·1	94·5	229	189·8	128·1	289	239·6	161·6
50	41·5	28·0	110	91·2	61·5	170	140·9	95·1	230	190·7	128·6	290	240·4	162·2
51	42·3	28·5	111	92·0	62·1	171	141·8	95·6	231	191·5	129·2	291	241·2	162·7
52	43·1	29·1	112	92·9	62·6	172	142·6	96·2	232	192·3	129·7	292	242·1	163·3
53	43·9	29·6	113	93·7	63·2	173	143·4	96·7	233	193·2	130·3	293	242·9	163·8
54	44·8	30·2	114	94·5	63·7	174	144·3	97·3	234	194·0	130·9	294	243·7	164·4
55	45·6	30·8	115	95·3	64·3	175	145·1	97·9	235	194·8	131·4	295	244·6	165·0
56	46·4	31·3	116	96·2	64·9	176	145·9	98·4	236	195·7	132·0	296	245·4	165·5
57	47·3	31·9	117	97·0	65·4	177	146·7	99·0	237	196·5	132·5	297	246·2	166·1
58	48·1	32·4	118	97·8	66·0	178	147·6	99·5	238	197·3	133·1	298	247·1	166·6
59	48·9	33·0	119	98·7	66·5	179	148·4	100·1	239	198·1	133·6	299	247·9	167·2
60	49·7	33·6	120	99·5	67·1	180	149·2	100·7	240	199·0	134·2	300	248·7	167·8
Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.
D. Lon		Dep.	D. Lon		Dep.	D. Lon		Dep.	D. Lon		Dep.	D. Lon		Dep.

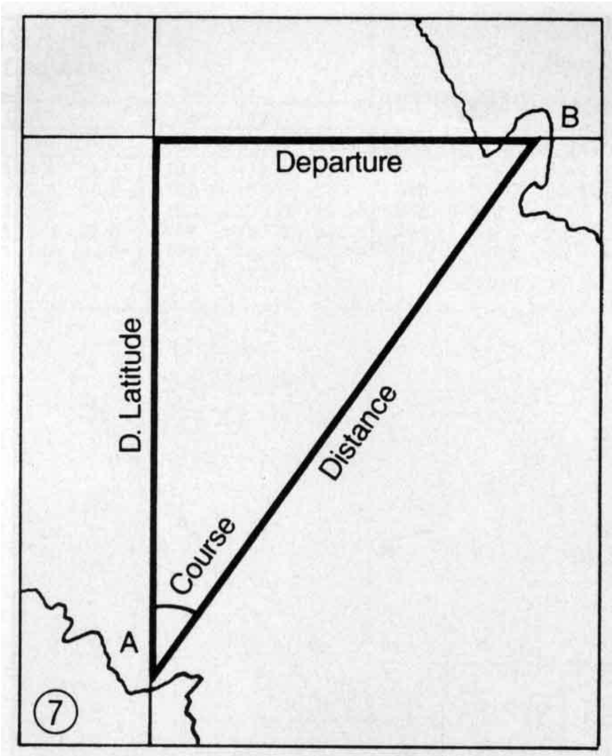
56° | 304° / 236° | 56 Degrees | 056° / 124° | 3h 44m

6

The Traverse Table is a quick and simple method of working out plane and parallel sailing problems.

4.3 The Plane Sailing Formula

Most voyages don’t take us so obligingly on east / west courses so we will have to find a way of getting about that has slightly more utility. The simplest way of doing this is to use the **plane sailing formula**. This method assumes that we are sailing on a flat, or *plane* surface, and is accurate for distances of up to about 600 miles.
To use it we have first to convert both our d. lat. and our d. long. into the same units - nautical miles. With latitude this simply involves converting from degrees and minutes to minutes. We then convert our longitude into departure - as previously described - using either the parallel sailing formula or the Traverse Table. It is now simply a case of solving a right angled triangle where departure, d. lat, and distance are the three sides of - and our course is one of the angles in - a simple right angled triangle.



Plane sailing problems involve solving right angle triangles where all three sides are expressed in nautical miles.

The formulae are simple, if you know the d.lat and d.long between two positions you can calculate the course and distance made good. In a similar manner If you have run a certain course and distance from your last known position you can find your d. lat and d. long and thus a work out a ded' reckoning position.

The Mean Latitude

As with the parallel sailing formula you may use either a calculator or the Traverse Table.

In either case a **mean latitude** , i.e. the arithmetic mean of our initial and our final latitudes, is used when working out the departure. So if we have left 14° North and arrived at 18° North we use a mean latitude of 16° in our calculations.

So, having safely returned from New Zealand, let us consider a run from Sydney (Lat 33° 52´South, Long 151° 13´East) to Lord Howe Island (Lat 31° 30´South, Long 159° 30´ East). First we must establish a d.lat, a d. long, and a mean latitude for use in our calculations.

Posn "A"	Lat 33° 52´South	Long 151° 13´East
Posn "B"	Lat 31° 30' South	Long 159° 30´East
	2° 22´North	8° 17´East
	D. Lat = 142´ North	D. Long = 497´East

Mean Latitude = 32° 41'

Plane Sailing By Calculation:-

The two Plane Sailing formula are quite simple,

Tan Course = Departure/ D. Lat

and

Distance = D. Lat/ Cos Course.

Example 9 shows how we use these two formula to establish the course and distance to Lord Howe Island.

Departure	= D.long x Cos Mean Latitude
	= 497´ x Cos 32° 41´
	= 497´ x .84167
Departure	= 418.4 nautical miles.
Tan Course	= Departure/DLat
	= 418.4 / 142
	= 2.94648
Course	= $71^{1}/_{4}°$
Distance	= DLat/Cos Co.
	= 142 / Cos $71^{1}/_{4}°$
	= 142 / 0.32144
Distance	= 441.7 nautical miles

4.4 Using the Plane Sailing Formula to find a D.R. position

Once we are on passage we can use the plane sailing formula to work out D.R. positions. So let us assume that we have sailed from Sydney and have run 120 miles by log on a course of 060° True. Our D.R. position can be found by calculation in three steps as shown in example 10.

Departure Position :- Sydney.

Lat	33°52´ South	Course steered	060° True
Long	151° 13´East	Distance by log	120 Miles

D. Lat = Cos Course x Distance
= Cos 060° x 120
= 0.5 x 120
D. Lat = 60´ = 1° North

Final Latitude 32° 52´ S
Mean Latitude 33° 22´ S

Departure = Sin Course x Distance.
= 0.86603 x 120´
Departure = 104´

D. Long = Departure / Cos Latitude
= 104 / Cos 33° 22’
= 104 / .83517
D. Long = 124.5´ = 2° 04.5´ East

Departure Latitude	33° 52´ South	Longitude	151° 13´ East
D.Lat	1° 00´ North	D.Long	2° 04.5´ East
D.R. Lat	32° 52´South	D.R. Long	153° 17.5´ East

4.5 The Traverse Table

The Traverse Tables are an integral part of all nautical tables and have, for many years, given the navigator a simple way of resolving plane sailing problems. Simple as they are, you will find that a certain amount of practice is required if you aim to be proficient.

They have two applications, to convert difference of longitude to departure and also to work out the plane sailing problem itself.

In the first instance the correct page is selected using the latitude as an argument, i.e. if you are in 19° mean latitude open the table to the page marked 19°, then proceed down the column marked *D. long* (in italics) until you find the requisite number of minutes and lift the *Departure* out of the adjacent column.

Right angled triangles of greater than 45° are mirror images of those less than 45° so for degrees greater than 45° we simply use the degrees and column headings from the bottom of the Traverse Table pages. Care must always be taken when doing this to ensure that you don't go in at the bottom of the page and come out the top!

12° 348° / 192° **TRAVERSE TABLE** 12 Degrees 012° / 168° 0h 48m

D. Lon		*Dep.*	*D. Lon*		*Dep.*	*D. Lon*		*Dep.*	*D. Lon*		*Dep.*	*D. Lon*		*Dep.*
Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.
1	01·0	00·2	**61**	59·7	12·7	**121**	118·4	25·2	**181**	177·0	37·6	**241**	235·7	50·1
2	02·0	00·4	**62**	60·6	12·9	**122**	119·3	25·4	**182**	178·0	37·8	**242**	236·7	50·3
3	02·9	00·6	**63**	61·6	13·1	**123**	120·3	25·6	**183**	179·0	38·0	**243**	237·7	50·5
57	55·8	11·9	**117**	114·4	24·3	**177**	[illegible]	36·8	**237**	231·8	49·3	**297**	290·5	61·7
58	56·7	12·1	**118**	115·4	24·5	**178**	174·1	37·0	**238**	232·8	49·5	**298**	291·5	62·0
59	57·7	12·3	**119**	116·4	24·7	**179**	175·1	37·2	**239**	233·8	49·7	**299**	292·5	62·2
60	58·7	12·5	**120**	117·4	24·9	**180**	176·1	37·4	**240**	234·8	49·9	**300**	293·4	62·4
Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.
D. Lon		*Dep.*	*D. Lon*		*Dep.*	*D. Lon*		*Dep.*	*D. Lon*		*Dep.*	*D. Lon*		*Dep.*

78° 282° / 258° 78 Degrees 078° / 102° 5h 12m

11

Take care when using the Traverse Tables and remember to do all your working from either the top or bottom of the page.

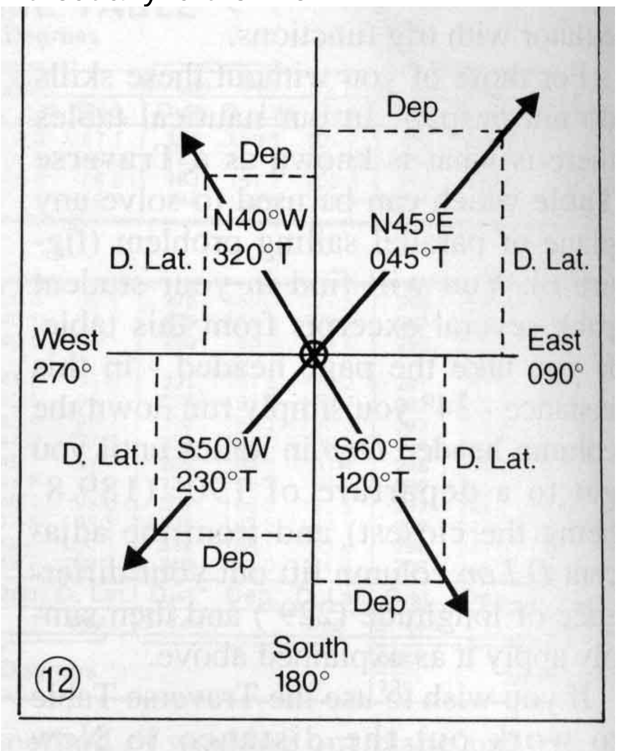
To calculate a D.R. position when you know the course steered and distance sailed you use the course steered as the page heading and then, proceeding down the distance column until the log distance is reached, extract the d.lat and departure from the adjacent columns. Use the Traverse to convert departure to d. long and then proceed in the same manner as you would if using a calculator.

The establishment of a course and distance between two known points is not so easy. Once again you establish the d. lat and departure in the normal way. Then you must work through the pages of the table until you find a match for your D.Lat and Departure. Then you extract the distance from the adjacent column and the course from either the top or bottom of the page depending from which end you are working.

Quite often you will not get an exact match but it will be more than accurate enough for practical navigation.

4.6 Naming the Course

The course that we have found may be in any one of the four quadrants and it is now up to us to establish exactly which one. Most of you will be familiar with the old system of compass points, half points and quarter points to which ships were steered until the demise of commercial sail, I hope that you are all familiar with the 360° notation that is in use today. There is a third system which was a sort of half way house in the early years of the 20th century, this is the **quadrantal system** and with it the course is named from either North or South towards either East or West, i.e. N30°E or S56° W. The course which we obtain from the Traverse Table is just such a number and it is up to us to name it. This is done by applying the name of our d.lat and d. long which we ascertained earlier. Let us say, for instance, that we are proceeding from the west coast of Australia towards India, our course would be in a general north westerly direction. If by Traverse Table or calculation the course was found to be 40° then this would be written by us as N40°W. Subtracting 40° from 360° gives us a true course of 320°. In the corner of each page of the TraverseTable there is a small aide memoire which lets you extract the course in 360° Notation without any further work.



Assuming the centre of the diagram is the point of departure, the courses are converted to 360° notation as shown.

4.7 The D.R. Position

Commonly written as it is pronounced the dead reckoning position is found simply by applying the course steered and distance run to the last known position.

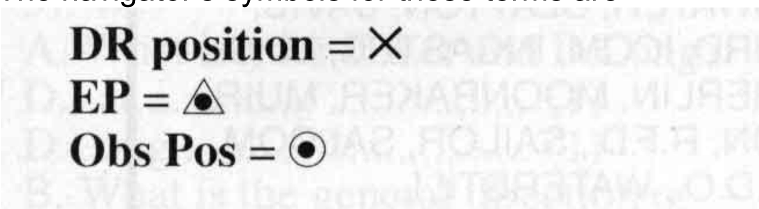
The term itself is actually a corruption of the expression ‘deduced reckoning’, as in “having used my powers of deduction I reckon we are about here”, and is more correctly written ded’ reckoning. This **ded’ reckoning (D.R.)** position is the one that we normally use when seeking a position from which to work out our sights.

The **estimated position (E.P.)** on the other hand incorporates an allowance for set and drift and leeway. It is commonly used in coastal navigation where we can keep a check on tidal streams and currents. Offshore we tend to compare our D.R. with our observed position (Obs Posn) and work out the set and drift after the event.

The **Chosen or Assumed Position** is, as we saw last month, the position used in reducing our sight when we use the Sight Reduction Tables.

The **Observed Position (Obs Posn)** or ‘Fix’ is, when used with sun sights just a running fix. Only when used with a number of simultaneous sights, Sun / Moon or several stars for instance, is it a ‘fix” in the way we understand it in coastal navigation.

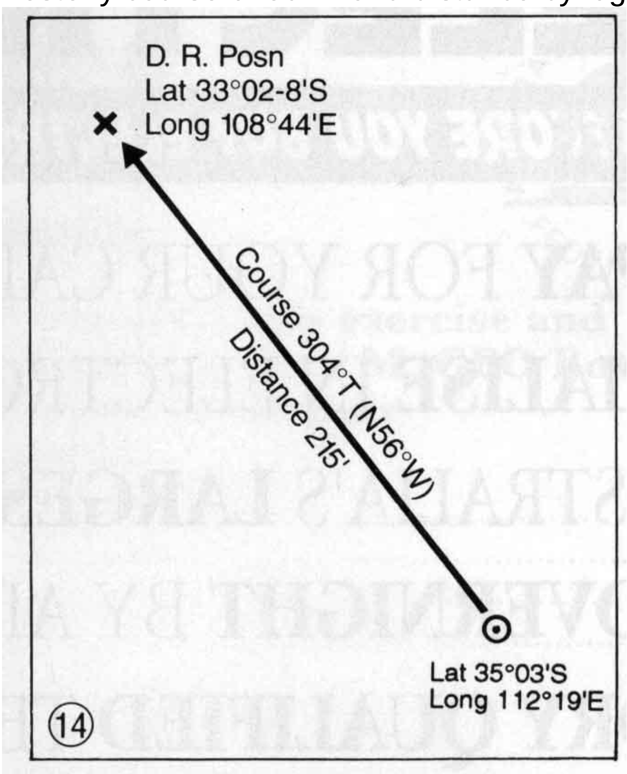
The navigator’s symbols for these terms are



4.8 Some practice

Two examples for you to try before you start this month's questions.

1/ You leave Latitude 35° 17´ South, Longitude 112° 19´ East and steer a north westerly course of 304° for a distance by log of 215 miles. What is you D.R. position?



Departure position:-

Lat.	35° 03´South	Course	=304° or N 56° W
Long	112°19´East	Distance	= 215 miles

a/ Open the traverse Table to 56° (bottom of page), enter with 215´ in distance column and extract departure of 178.2´ and d.lat of 120.2´.

b/ Work out D.R. latitude. 35° 03´South - D.Lat of 2° 00.2´ North = 33° 02.8´South.

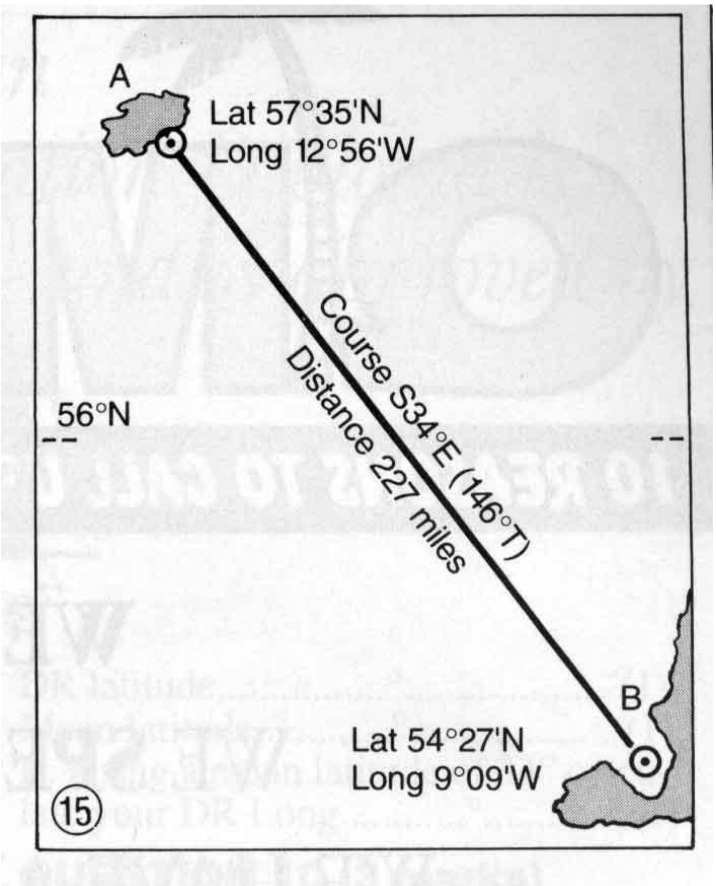
c/ Work out Mean Latitude, by inspection it is 34°.

d/ Enter Traverse Table with 34° at the top of the page and locate *Departure* of 178.2´. Extract *D. Long* of 215´.

e/ Convert D. Long to Degrees and Minutes and apply to your initial longitude according to its name. In this case it is 112° 19´East minus 3° 35´West which gives us 108° 44´East.

Our D.R. position after sailing 304° True for 215 miles is , therefore Latitude 33° 02.8´S, Longitude 108° 44´East.

2/ What is the course and distance from an island in Latitude 57° 35´North, Longitude 12° 56´West to port in Latitude 54° 27´North, Longitude 9° 09´West.



a/ Calculate the D. lat and d. long.

"A"	Lat	57°35´North	Long	12° 56´West
"B"	Lat	54° 27´North	Long	9° 09´West
	D.Lat	3° 08´South	D. Long	3° 47´East
		188´ South		227´East

b/ Mean Latitude by inspection is 56°

c/ Enter table at 56° with *D. Longitude* of 227´and extract *Departure* of 126.9´.

d/ Scan through table until a match of 126.9 (Dep) and 188 (d. Lat) is found in the Dep/D.Lat columns.

e/ Lift out the Distance(227), from the adjacent column and the course from either the top or bottom of the page (34°) as required.

f/ Convert the course to 360° notation. S 34° E = 180° - 34° = 146° True

4.9 Part 4 – The Questions

1/. You are in latitude 14° 27´ South, longitude 109° 15´East and your destination lies in latitude 15° 39´South, longitude 113° 18´East.

a) What is the D.Lat and D. Long?

D.Lat?

D.Long?

b) In what general direction does your destination lie? (i.e. North East, South West). ....

2/ You are in latitude 47° 58´North, 11° 09´West and your destination is in 49° 05´North, 13° 57´West.

a) What is your D. Lat and D. Long?

D.Lat ?

D. Long ?

b) What is the general direction of your destination? ....

3/. You are in 01° 15´ South, 5° 17´East. Your Destination lies in 6° 42´South, 3° 11´East.

a) What is the D.Lat and D.Long?

D.Lat ?

D.Long?

b) In what general direction does your destination lie? ....

4/ You sail due north from a position in latitude 27° 12´South to a position in latitude 19° 48´South. How many miles have you sailed? ....

5/ You are in 56° 00´North, 120° 05´East and your destination lies in 56° 00´, 115° 15´East.

a) What is the D.Long (expressed in minutes) between these two positions? ....

b) What is the course and distance to your destination?..........

6/ a)What is the D. long between a port in Lat 34° 00´South, 3° 21´West and a port in 34° South, Long 1° 11´East? ....

b)What is the course(in three figure notation) and distance between the first and second ports?

Course?
Distance?

7 a/ Express 060° in quadrantal notation ....
b/ Express 210° in quadrantal notation ....

8 a) Express S40°W in 360° notation ....°
b) Express N52°W in 360° notation ....°

9/ a)From a position in Latitude 34° 25´ North, Longitude 172° 05´East you steer 168° True for 72 miles. What is your DR latitude and what is your mean latitude?
DR Latitude?
Mean Latitude?
b)Using a mean latitude of 34° calculate your D.R. longitude.

D.R. Long ?

10/ a)You steer 034° from a position Latitude 12° 30´South Longitude 11° 05´East for 68 miles - what is your D.R latitude and what mean latitude will you enter your Traverse tables with?
DR Lat?
Mean Latitude?
b)Calculate your D.R. longitude.

DRLong?

11/ You intend to sail from an anchorage in 34° 19´South, 51° 05´East to a port in 33° 42´South, 54°35´East.
a)In what general direction will you be sailing?
Direction?
b)What is the D.lat and D.long between these two destinations?
D.Lat?
D.Long?
c) What is the Mean Latitude?
Mean latitude?
d) Rounding your mean latitude to the nearest whole degree use your Traverse Table to establish the course (in 360° notation) and distance.
Course?
Distance?

12/ You intend to sail from 55° 00´North, 7° 10´West to a port in 57° 03.5´North, 9°39´ West.

a)In what general direction will you be sailing?

Direction?

b)What is the D.lat and D.long between these two locations?

D.Lat?

D.Long?

c) What is the Mean Latitude?

Mean latitude?

d) Rounding your mean latitude to the nearest whole degree use your Traverse Table to establish the course (in 360° notation) and distance.

Course?

Distance?

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

4.10Part 3 - The Answers

Q1	A = 32° 59.8’
Q2	A = 71° 08.9’
Q3	A = GHA = 135°07.2’ Dec = N 7° 40.3’
Q4a	A = GHA = 286 31’ Dec = S 2° 05.9’
Q4b	A = 238° 20’
Q5a	A = Lat 25° South. Long = 12° 09.9’ East
Q5b	A = 325°
Q6	A = Lat = 20° North. Long = 6° 04.2’ West or 5° 04.2’ West
Q6b	A = 264°
Q7	A = + 11’
Q8a	A = Intercept 12’
Q8b	A = Towards
Q9a	A = 17.3’
Q9b	A = Towards
Q10	A = 050°
Q11	A = 242°
Q12a	A =Tabulated altitude = 52° 05’
Q12b	A= Azimuth = 062°
Q 13a	A = Tabulated alttitude =37° 54’
Q13b	A = Azimuth = 247°

The Day's Work

FRANK HOLDEN works through the method of plotting a passage. Part Five.

5 The Day's Work

The Day's Work, as far as the navigator is concerned, doesn't involve paint or varnish but is that work involved over a period of twenty four hours in the navigation of his ship. This day is often measured from noon to noon but may be from a.m. stars to a.m. stars or any other period that you may choose. It lets you establish the distance run, the speed made good, the amount of set experienced, and allows you to estimate the number of days left until your next landfall.

Once you get any distance of the coast and are no longer able to plot your position on a coastal chart of a reasonable scale you will have to find an alternative method of presenting your work. You can use a navigation computer or, as we have seen, you may do all your work by calculation using either the traverse tables or a scientific calculator. All of these methods have their place in the scheme of things but they give you little or no visual indication of what is going on and any 'finger trouble' may well go undetected.

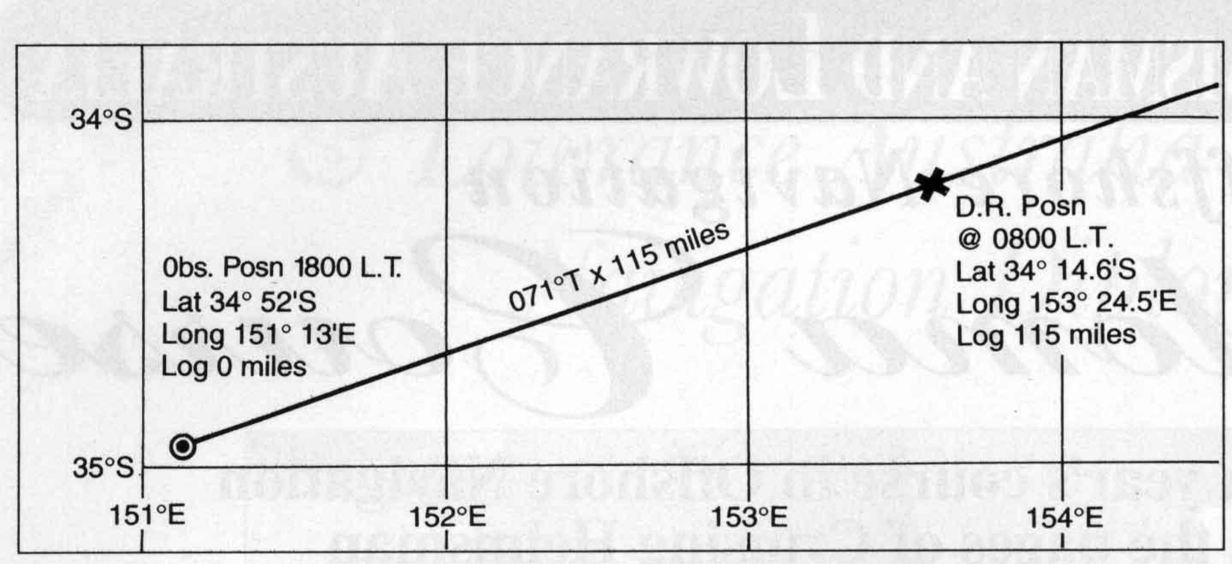
A third method is to use plotting sheets. These are published by the major hydrographic departments and the most popular would appear to be the US ones . The scale of these is adequate for all practical navigation and for most voyages only a few sheets are needed. In fact on many shorter runs both your departure point and destination will fit on the same sheet.

If using a plotting sheet it cannot be stressed too highly that all fixes should be transferred from it to your actual navigation chart as soon as you have finished your work and it is also a good idea to transfer any dangers that lie near your track to the plotting sheet.

Depending on your course from several days to several weeks sailing will fit on the one sheet so a good running record of you progress is before you at all times. Having chosen a sheet covering the latitude that you are sailing in you simply mark in the longitude to suit as the longitude grid is deliberately left blank. The same sheets can be used in either the northern or southern hemispheres simply by inverting the sheet.

5.1 Using the Plotting Sheet

The first and most obvious step is, before departure, to ensure that you have the appropriate plotting sheets on board. We shall make our voyage from a mythical port somewhere south of Sydney (Lat 34° 52´S, Long 151° 13´E.) to an equally mythical island in the middle of the Tasman Sea (Lat 32° 30´S, Long 159° 30´E.). The course is 071° True and the distance is 439 miles. Our plotting sheet isn't quite large enough to let us lay it off in one run so we will simply mark on it our departure position and lay off our course.



The first step is to lay off your course, step off the distance and establish your D.R. position. **Fig 1**

You sailed on a Monday afternoon in mid March and streamed the log upon departure. You have been able to steer the course required overnight and, being an experienced navigator by now, we shall assume that your altitudes have no operator error, your horizon is firm, and your work is error free.

After breakfast on the Tuesday, having laid out your sight book, almanac and sight reduction tables you step out on deck with your sextant and take a sun sight. At the same time you note the exact time in GMT and also read the log. The sextant altitude of the sun's lower limb is 26° 24.6´ and the log reads 115 miles. The galley clock shows 0800 local time while the time/date digital watch that you are using for navigation shows that Greenwich mean time is 16d08h00m00s.

We now have four primary pieces of information; knowledge of the course steered and log distance run will let us establish a good ded' reckoning position while this position - together with the sextant altitude and time - will let us work out a position line.

To work out the ded' reckoning position at the time of sight simply establish your distance run by subtracting the log reading at the time of your last fix from the log reading at the time of sight. If you have steered a good course through the night convert this to degrees true, lay off this course on the plotting sheet and step off the distance run with your dividers, taking care to lift it from the latitude scale adjacent to your track.

5.2 The DR position

If you are using the Air Tables for your sights it is possible to obtain a perfectly satisfactory position line even if your ded' reckoning position is a full 1° or more out in both latitude and longitude. However a good navigator will still calculate the D.R. position at the time of sight as accurately as is possible as this is the only way that it is possible to assess the amount of set and drift experienced since the last fix.

Upon clearing the coast you should have noted your departure position and log reading together with the time. Thereafter it is prudent to mark a D.R. position on the chart every 4 hours or at the end of each watch. Now that you have taken a sight it is a good move for you as skipper to run up a D.R. position from your last fix , this eliminates the risk that a watch keeper may have introduced an error into the system while you slumbered.

Mark your D.R. position on the plotting sheet with a cross and note both the local time and log reading next to it. Lift the latitude and longitude from the margin of your plotting sheet and write it in your sight book. In your sight book you should already have noted the time and date - both in GMT - and have entered your sextant altitude.

We shall assume that you only took one altitude, in practice you will probably have taken three, one immediately after the other.

5.3 Reducing the Sight

You are now ready to reduce your sight and work out a position line.

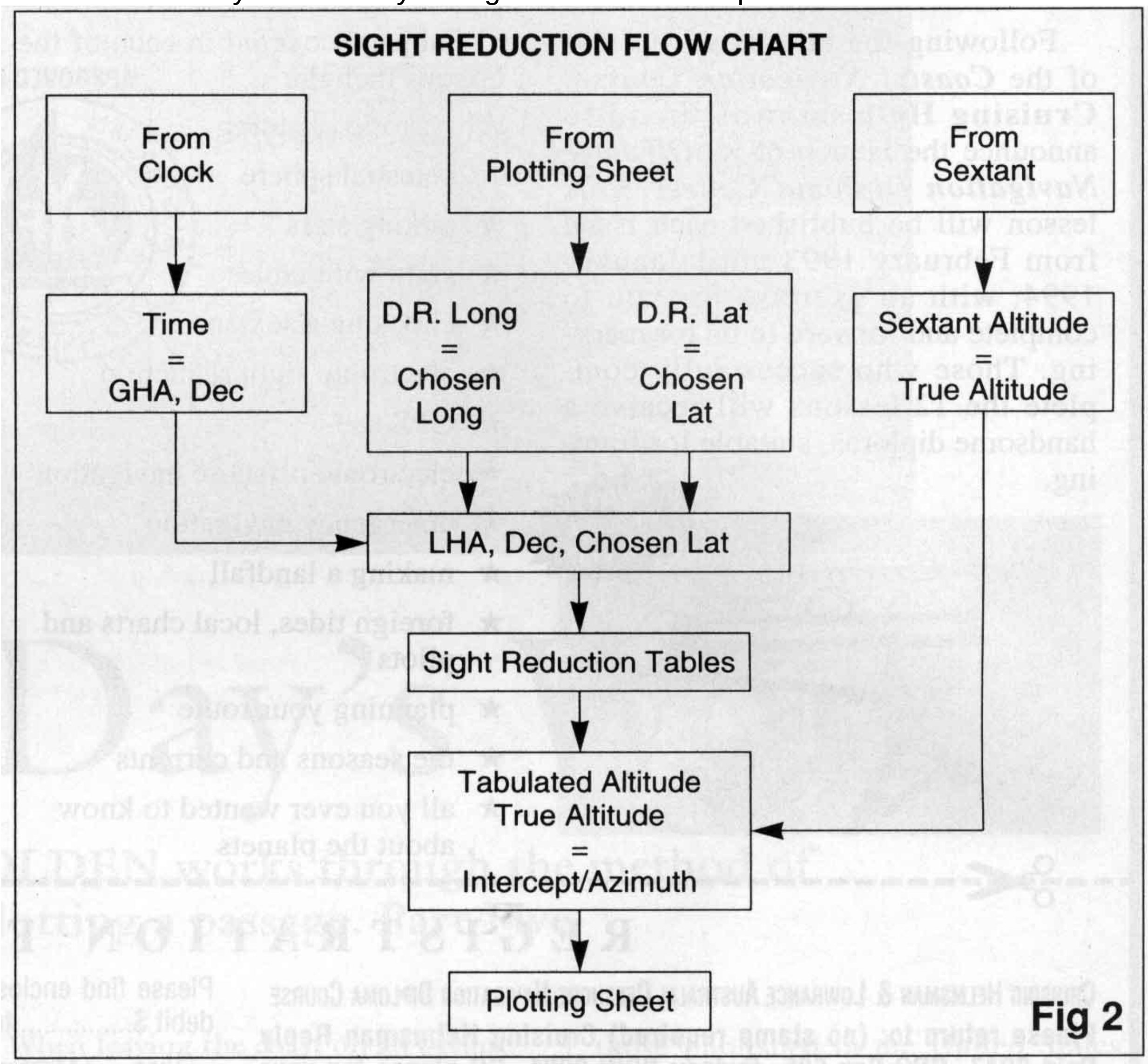
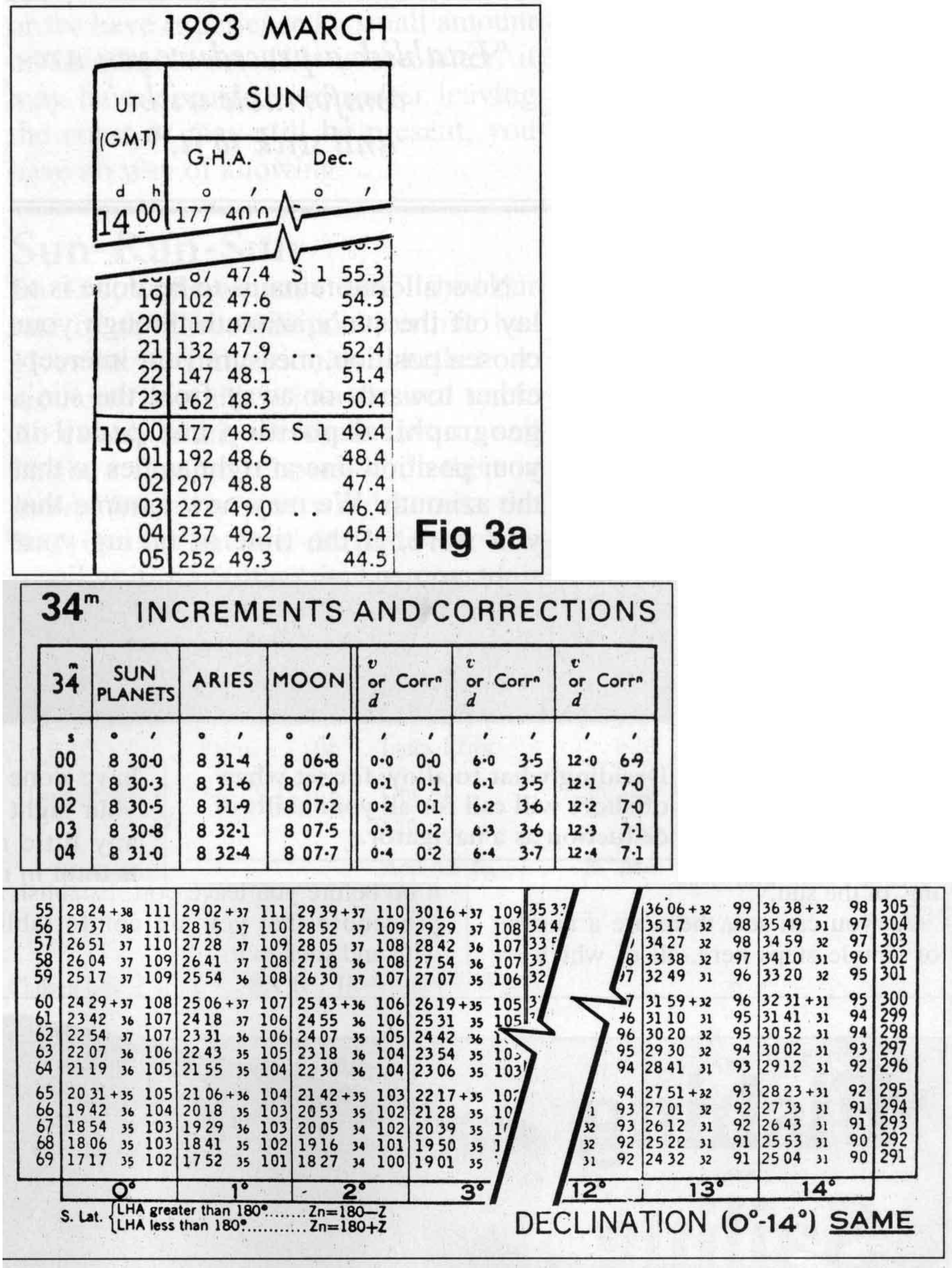


Fig 2

In the first three months of this course, we covered all the steps required to convert this information - sextant altitude, time and D.R. position - into a position line. Now it is simply a matter of establishing a logical sequence of working. Let us proceed.

1/ Correct your sextant altitude of the sun and establish the true altitude.
2/ Using the GMT time and date extract the the Greenwich hour angle and declination of the sun from the almanac.
3/ Using your DR position as a guide establish a chosen or assumed position to use in your sight reduction tables. Apply the chosen longitude to the Greenwich hour angle to get a local hour angle. You now have an LHA, a declination and a chosen latitude - the three items required before we can use our sight reduction tables.

4/ Enter the sight reduction tables with this information and establish a tabulated altitude and azimuth - or bearing - of the sun.



1993 MARCH

UT (GMT) d h	SUN G.H.A. ° ′	SUN Dec. ° ′
14 00	177 40.0	
18	87 47.4	S 1 55.3
19	102 47.6	54.3
20	117 47.7	53.3
21	132 47.9	. . 52.4
22	147 48.1	51.4
23	162 48.3	50.4
16 00	177 48.5	S 1 49.4
01	192 48.6	48.4
02	207 48.8	47.4
03	222 49.0	. . 46.4
04	237 49.2	45.4
05	252 49.3	44.5

Fig 3a

34^m INCREMENTS AND CORRECTIONS

34^m s	SUN PLANETS ° ′	ARIES ° ′	MOON ° ′	v or d ′	Corr^n ′	v or d ′	Corr^n ′	v or d ′	Corr^n ′
00	8 30·0	8 31·4	8 06·8	0·0	0·0	6·0	3·5	12·0	6·9
01	8 30·3	8 31·6	8 07·0	0·1	0·1	6·1	3·5	12·1	7·0
02	8 30·5	8 31·9	8 07·2	0·2	0·1	6·2	3·6	12·2	7·0
03	8 30·8	8 32·1	8 07·5	0·3	0·2	6·3	3·6	12·3	7·1
04	8 31·0	8 32·4	8 07·7	0·4	0·2	6·4	3·7	12·4	7·1

	0°	1°	2°	3°	12°	13°	14°	
55	28 24 +38 111	29 02 +37 111	29 39 +37 110	30 16 +37 109		36 06 +32 99	36 38 +32 98	305
56	27 37 38 111	28 15 37 110	28 52 37 109	29 29 37 108		35 17 32 98	35 49 31 97	304
57	26 51 37 110	27 28 37 109	28 05 37 108	28 42 36 107		34 27 32 98	34 59 32 97	303
58	26 04 37 109	26 41 37 108	27 18 36 108	27 54 36 107		33 38 32 97	34 10 31 96	302
59	25 17 37 109	25 54 36 108	26 30 37 107	27 07 35 106		32 49 31 96	33 20 32 95	301
60	24 29 +37 108	25 06 +37 107	25 43 +36 106	26 19 +35 105		31 59 +32 96	32 31 +31 95	300
61	23 42 36 107	24 18 37 106	24 55 36 106	25 31 35 105		31 10 31 95	31 41 31 94	299
62	22 54 37 107	23 31 36 106	24 07 35 105	24 42 36	96	30 20 32 95	30 52 31 94	298
63	22 07 36 106	22 43 35 105	23 18 36 104	23 54 35	95	29 30 32 94	30 02 31 93	297
64	21 19 36 105	21 55 35 104	22 30 36 104	23 06 35 103	94	28 41 31 93	29 12 31 92	296
65	20 31 +35 105	21 06 +36 104	21 42 +35 103	22 17 +35	94	27 51 +32 93	28 23 +31 92	295
66	19 42 36 104	20 18 35 103	20 53 35 102	21 28 35	93	27 01 32 92	27 33 31 91	294
67	18 54 35 103	19 29 36 103	20 05 34 102	20 39 35	32 93	26 12 31 92	26 43 31 91	293
68	18 06 35 103	18 41 35 102	19 16 34 101	19 50 35	32 92	25 22 31 91	25 53 31 90	292
69	17 17 35 102	17 52 35 101	18 27 34 100	19 01 35	31 92	24 32 32 91	25 04 31 90	291

S. Lat. {LHA greater than 180°.......Zn=180—Z; LHA less than 180°...........Zn=180+Z}

DECLINATION (0°-14°) SAME

As you can see there are a number of simple steps here all of which we have done before. It pays to write up your sight book before you start with any little reminders that you feel may be helpful in the margin. Better still write it up before you leave port, establish a procedure that you are comfortable with and stick to it.

Now all that remains to be done is to lay off the sun's azimuth through your chosen position, measure your intercept either towards or away from the sun's geographical position and pencil in your position line at right angles to that position. We may now assume that you were, at the time of taking your sight, somewhere on that position line.

You will notice that at the time of taking this sight the sun's azimuth was 072° - that is it was almost directly ahead of your boat. This means , not surprisingly, that the position line itself lies athwart your track and does in fact cut your track some 5 miles ahead of your D.R. position.

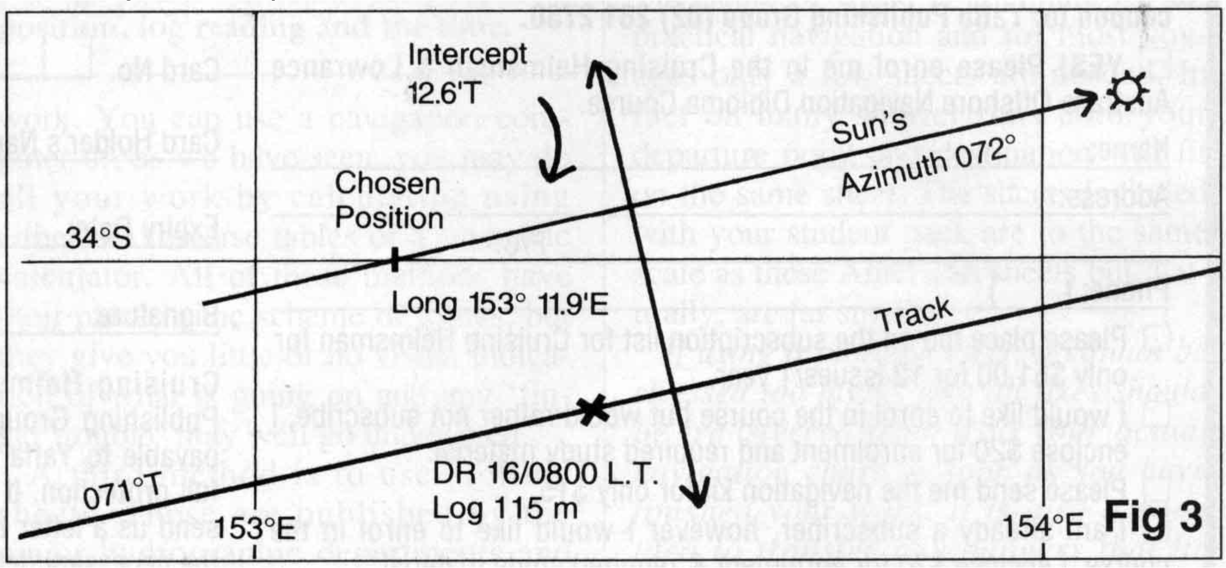


Fig 3

This would appear to indicate that we are some 5 miles ahead of our ded' reckoning position. This may be due to the fact that there is some small error in the log or that we have experienced a small amount of favourable set. If it is the latter it may have occurred soon after leaving the coast or may still be present, you have no way of knowing.

Sight Book – Yacht 'Ferret' – 16/3/93

Local Time 16/0800		D.R. Lat	34° 14.6'S	D.R. Long	153° 24.5'E
GMT 15/2200	Log 115	Index Error 2' off arc		Height of eye 3.3 metres	

GHA 15^d22^h	147° 48.1'	Declination	S 1° 51.4'	Sext Alt	26° 24.6'
GHA 00^m00^s	0°00.0'	d = 1.0' Corrn	−0.5'	Index Error	+2.0'
GHA $15^d22^h00^m00^s$	147° 48.1'	Declination	S 1° 49.9'	Obs Alt	26° 26.6'
Chosen Long	153° 11.9'			Dip	-3.2'
LHA	301° 00.0'			App Alt	26° 23.4'
				Total Corrn	+14.2'
				True Alt	26° 37.6

Chosen Latitude 34°S, LHA 301°, Declination 1° 49.9'S.

Tabulated Alt (Hc)	25° 54.0'	d = +36'	Z	=	108°
"d" Correction	+ 31.0'		Az	=	180° -Z
Tabulated Altitude	26° 25.0'		Azimuth	=	072° True
True Altitude (Ho)	26° 37.6'				
Intercept	12.6' Towards				

Fig 4

5.4 Sun-Run-Sun

So now, while we have established our rate of advance, this position line has given us no indication of whether we are north or south of our desired track. To establish this we shall have to sail on for a few more hours while the sun moves steadily westward across the heavens. What we shall do on this occasion is wait until it is on our port beam (this is easily established by just watching the shadow cast by the mast) and then we shall take an afternoon sight.

We now simply repeat the morning routine; taking the altitude, noting the time and reading the log.

Correct the altitude,

Work out log distance run

Transfer the morning position line (see fig 5)

Establish a new ded' reckoning position

Work out the GHA, Chosen position, and LHA.

Reduce the sight, establish the Intercept.

Lay off the position line on the plotting sheet, where it cuts the transferred position line from the morning sight is our observed position (see fig 8).

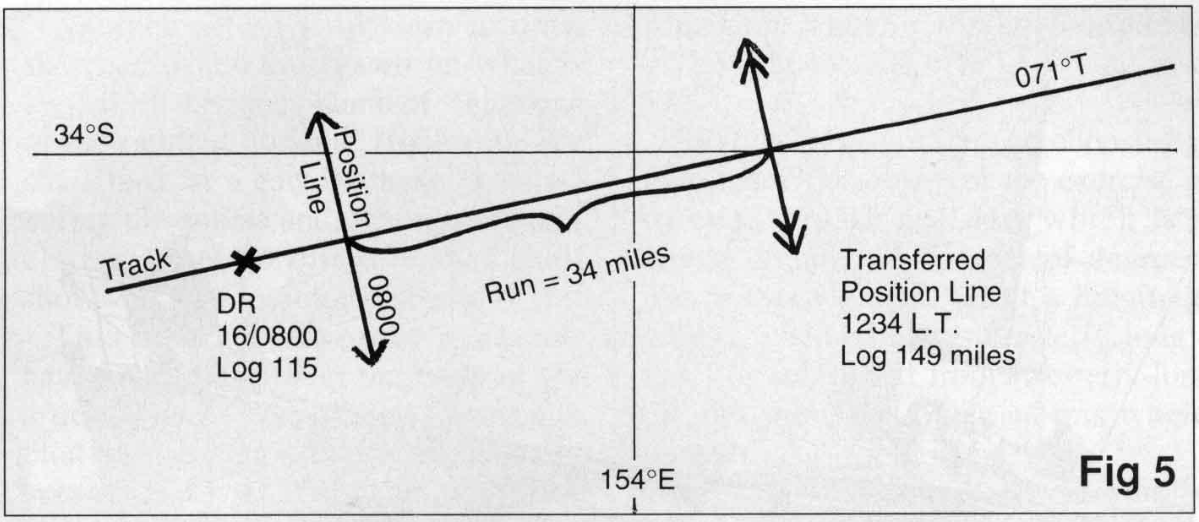


Fig 5

Sight Book – Yacht 'Ferret' – 16/3/93

Local Time 16/1234		D.R. Lat	34° 01.5'S	D.R. Long	154° 10.2'E
GMT 16/0234	Log 149	Index Error 2' off arc		Height of eye 3.3 metres	

GHA 16d02h	207°48.8'	Declination	S 1° 47.4'	Sext Alt	55° 59.6"
GHA 34m00s	8°30.0'	d = 1.0'	Corrn -0.6'	Index Error	+2.0'
GHA 16d02h34m00s	216° 18.8'	Declination	S 1° 46.8'	Obs Alt	56° 01.6'
Chosen Long	154° 41.2'			Dip	-3.2'
LHA	11° 00.0'			App Alt	55° 58.4'
				Total Corrn	+15.6'
				True Alt	56° 14.0'

Chosen Latitude 34°S, LHA 11°, Declination 1° 46.9'S.

Tabulated Alt (Hc)	55° 26.0'	d = +58'	Z	= 108°
"d" Correction	+ 45.0'		Az	= 180° -Z
Tabulated Altitude	56° 11.0'		Azimuth	= 072° True
True Altitude (Ho)	56° 14.0'			
Intercept	3.0' Towards			

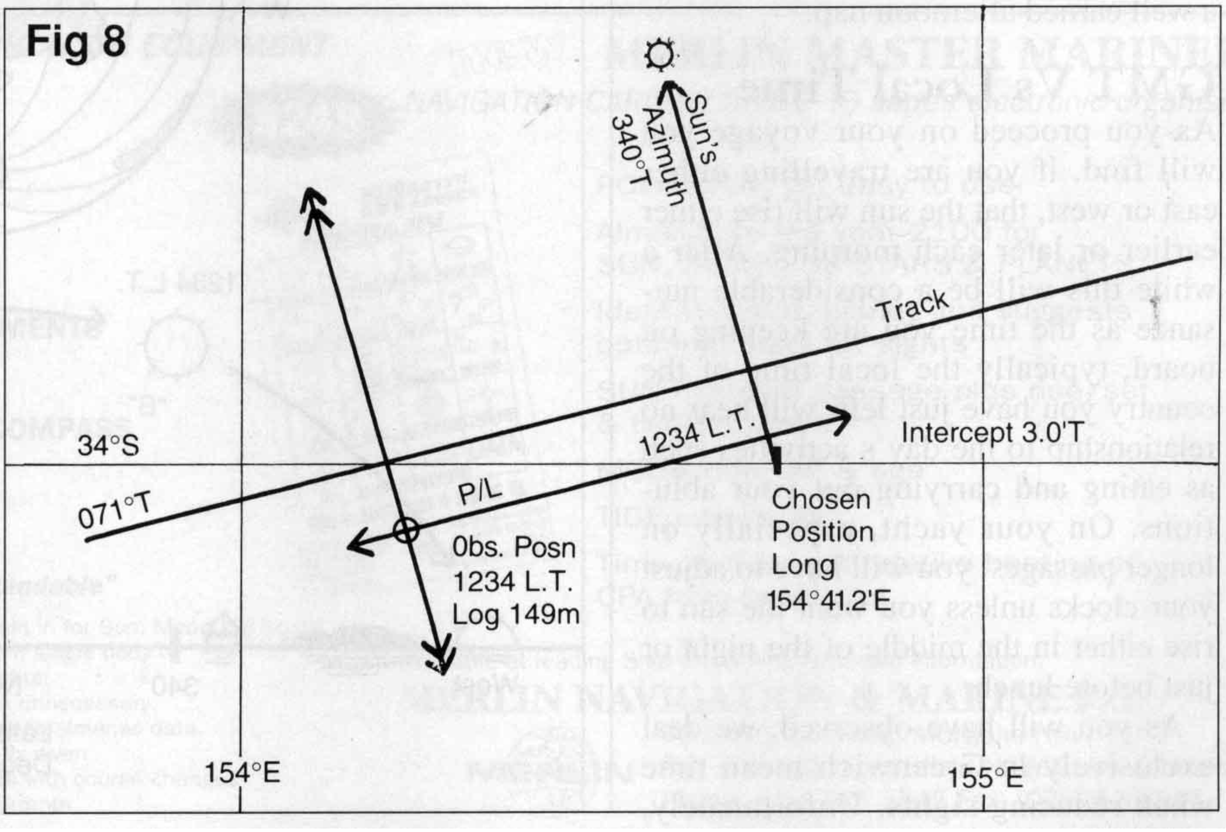
Observed Position @ 1234 Local Time (L.T.): **Lat 34° 06' South**
Long 154° 12' East

Fig 6

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

LHA	0° Hc	d	Z	1° Hc	d	Z	2° Hc	d	Z
	° ′	′	°	° ′	′	°	° ′	′	°
0	56 00	+60	180	57 00	+60	180	58 00	+60	180
1	55 59	60	178	56 59	60	178	57 59	60	178
2	55 57	60	176	56 57	60	176	57 57	60	176
3	55 53	60	175	56 53	60	175	57 53	59	174
4	55 48	59	173	56 47	60	173	57 47	60	173
5	55 41	+59	171	56 40	+60	171	57 40	+59	171
6	55 32	60	169	56 32	59	169	57 31	59	169
7	55 22	59	168	56 21	59	167	57 20	59	167
8	55 11	59	166	56 10	58	166	57 08	59	165
9	54 58	59	164	55 57	58	164	56 55	58	163
10	54 44	+58	163	55 42	+58	162	56 40	+58	162
11	54 28	58	161	55 26	57	160	56 23	58	160
12	54 11	57	159	55 08	58	159	56 06	57	158
13	53 53	57	158	54 50	56	157	55 46	57	156
14	53 33	57	156	54 30	56	155	55 26	56	155

Fig 8



5.5 Some points to note

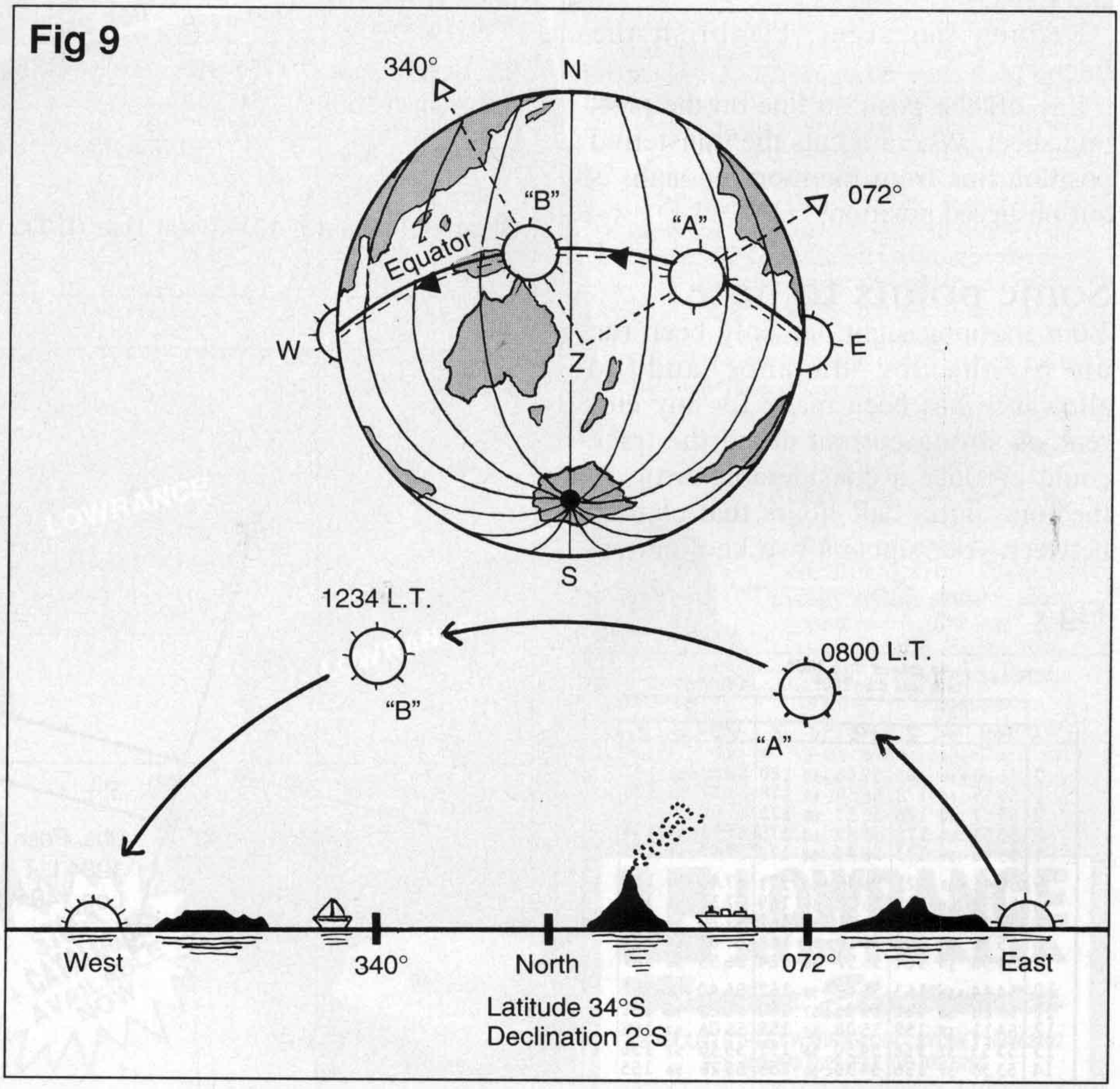
Your morning sight has only been run up by the log distance and no allowance has been made for any current. A strong current along the track could produce a considerable error, in the four and a half hours that elapsed between your sights a 2 knot current could have put you either 9 miles ahead or astern. You are, however , now sure of your offset north or south of the track at the time of the second sight.

Deciding what to allow for set when offshore will call on all your skills of deduction as a navigator and you will never learn it out of a book.

You can, however, now establish the speed made good since departure and, using either the traverse tables, direct measurement or 'subtraction to go' work out the distance to go and a revised ETA (estimated time of arrival.).

Having successfully fixed the position of your ship and, if required, given the watch a new course to steer the skipper may now retire below and take a well earned afternoon nap.

Fig 9



5.6 GMT v. Local Time

As you proceed on your voyage you will find, if you are travelling either east or west, that the sun will rise either earlier or later each morning. After a while this will be a considerable nuisance as the time that you are keeping on board, typically the local time of the country you have just left, will bear no relationship to the day's activities such as eating and carrying out your ablutions. On your yacht, especially on longer passages, you will have to adjust your clocks unless you want the sun to rise either in the middle of the night or just before lunch.

As you will have observed we deal exclusively in Greenwich mean time when reducing sights. Unfortunately our own internal clocks which are located - so I am led to believe - in the vicinity of our stomachs- prefer to work in some form of local time. The difference between these two times can lead to a degree of confusion being created in the minds of many navigators. Rather than spend your life converting from Greenwich to local and back again with all the attendant prospects of making mistakes it pays to have at least one watch (ideally a digital one which also shows the date) which you keep permanently on GMT and use for all offshore navigation. I have seen it suggested that all times are kept in GMT but most people will find that method more confusing than it is worth. Keep your cabin clock on local time and simply note the approximate local - or ship's - time of sights to the nearest minute, this local time is the one that you will write next to your positions when you plot them. You will find that you will have to alter the time shown on your cabin clock by one hour for every 15° that your longitude changes, advancing the time if you are heading eastwards and retarding it if you are heading westwards.

A list showing what local time is kept in all countries of the world is to be found in the back of the almanac. This list does not show summer times which are a purely political device designed to fade the curtains of Queenslanders. Where summer time is kept it is normally one hour ahead of the standard time kept in the area.

When passing times and positions by radio always ensure that you state whether you are using GMT or local time.

5.7 Set and Drift

In coastal navigation it is possible to compare your DR position with your observed position on an hourly basis and to keep a good check on either tides or currents. In fact in many parts of the world, notably the English Channel, the tidal streams are that well documented that it is possible to allow for them before the event . Offshore it is a different matter. Even in good conditions you may be running for up to ten hours between fixes and in overcast conditions this may be for several days. Unless you are quite confident that you are under the influence of a strong and steady current, the Gulf Stream or Aghulus Current for instance, it is best to run up simply on D.R. positions. After you have obtained a fix you may then compare this with your D.R. and gain some insight into what the current has been doing.

With this in mind it pays to give some thought to the timing of our sights - a single position line can yield far more information than may appear possible at first glance. In the examples in this article we were able, simply by taking sights when the sun was ahead and on the beam, to obtain a lot more information than we would have gleaned from two random sights. Good navigators are very astute observers of their surroundings and - simply by watching how the sun moves across the sky through the day- would have been able to pick good times at which to take these sights. Another option is to learn to draw sketches which are drawn on what is known by the fancy name of ‘the plane of the rational horizon’. We shall look at a few of these sketches during the course and, while space precludes doing so this month, I shall show you how to produce them.

This month the worked examples have been included in the body of the article. Go slowly through them both, plotting them on your plotting sheet as you go and it will all come clear. Use a 2b pencil and keep a sharpener handy.

Fin

5.8 Choosing a position

Some people have informed me that they are having a little trouble working with degrees and minutes of arc and with establishing a chosen position.
With the former just imagine that you are working with hours and minutes, something you have been doing without a second thought since you were very young.
Choosing a latitude is simple enough - if the minutes of your D.R. Latitude are less than 30´ round down to the lower full number of degrees - greater than 30´ round up. Thus if the D.R. latitude is 37° 25´ choose 37°, if it is 37° 48 use 38°.
Slightly more difficult is choosing a longitude.
The object of the exercise is to end up with an LHA which is a whole or integral number of degrees. To do this we must select a longitude which, when added to (Easterly longitude) or subtracted from (Westerly longitude) the GHA gives us this whole number.
With easterly longitude you simply inspect the minutes in the GHA - the difference between those minutes and 60 is the number of minutes to use in your chosen longitude.

e.g. GHA = 197° **27**' D.R. longitude = 142° 11' E
Chosen longitude = 142° 33' E 60' - 27' = 33'
LHA = 340° 00´

You will remember that in the western hemisphere we subtract our longitude from the GHA to obtain the LHA. This means that the minutes of our chosen longitude are simply made to equal the minutes in the GHA in the following fashion.

GHA = 72° 21' D.R. longitude = 42° 45' W
minutes of GHA = minutes of chosen longitude = 21'
Chosen longitude = 42° 21'
GHA (72° 21') - W.Long (42° 21') = LHA (030°)

5.9 Part 5 - The Questions

1/ You have fixed your position by morning star sights as Latitude 112° 15´S, Longitude 153° 19´ East. Several hours later, having steered 060° True for a log distance of 27 miles, you take a morning sun sight. Your digital watch shows that, at Greenwich, it is the 2nd September, 1993 and the time is $23^h34^m02^s$ GMT. The sextant altitude of the sun's lower limb (L/L) is 51° 48´ while your height of eye is 3.3 metres and the index error is 1´on the arc.

a/ What is your ´ded reckoning position at time of sight?

Latitude... Longitude...

b/ What is the sun's true altitude?

T.Alt.....

c/ What is the sun's GHA and declination at the time of the sight?

GHA.... Dec....

d/ Select a chosen position and calculate the LHA.

Chosen Lat... Chosen Long...

LHA........

e/ From the sight reduction tables, what is the tabulated altitude, the intercept and the Azimuth?

Tab Alt... Intercept...

Azimuth....

f/ In what longitude does your position line cut latitude 12° South?

Longitude...

2/ A position line that you obtained from a morning sun sight passed through latitude 34° 29´ South , longitude 102° 11´East . The sun's azimuth at the time was 085° True.

You then steered 342° True for 41 miles by log before taking a second sun sight. This sight, calculated using a chosen position of 34° South, 101° 43´East, yielded an intercept of 15´Towards and an azimuth of 317° True.

What was the observed position at the time of the second sight?

Latitude.... Longitude...

3/ You are in the North Atlantic and a position line obtained from a morning sun sight passes through Latitude 13° 09´North, Longitude 37° 12´ West at which time the sun's azimuth is 120° True. You continue on your course of 263° True until the sun bears 237° True. At this time a sight calculated on a chosen position of Latitude 13° North, Longitude 38° 32´West, gives an intercept of 5´away.

What is the observed position at the time of the second sight?

Latitude... Longitude....

4/ You are in the North Pacific and your DR position is latitude34 09 W. longitude 162 19 W. A morning sight at 21h34m00s GMT on the 15th March 1993 gives a sextant altitude of 48 45 , your height of eye is 2.9 metres and the index error is is 2 off the arc.

A / What is the sun's GHA and declination at this time?

GHA Dec

B / What is the true altitude of the sun?

True Altitude

C / Select a chosen latitude and longitude and calculate a an LHA

Chosen Lat

Chosen Long

LHA

D / From the sight reduction tables establish a tabulated altitude, intercept and azimuth

Tab Alt

Intercept

Az

E In what longitude does this position line cut latitude 34 N?

Long

5 You have established that at 1500 ship's time you were in latitude 34 00 S, Longitude 21 19 W. and that you are making good 8 knots. Your destination is in Latitude 34 South, Longitude 25 41 W.

A/ Using the traverse tables what is your distance to go?

Distance

B/ What is the true course to steer?

Course

C/ If you maintain your present speed how long will it take to reach your destination in days hours and minutes?

Time to go

LATITUDE BY MERIDIAN ALTITUDE

FRANK HOLDEN looks at a method of finding latitude with a minimum of fuss.

6 The Meridian Altitude and Longitude by Equal Altitudes

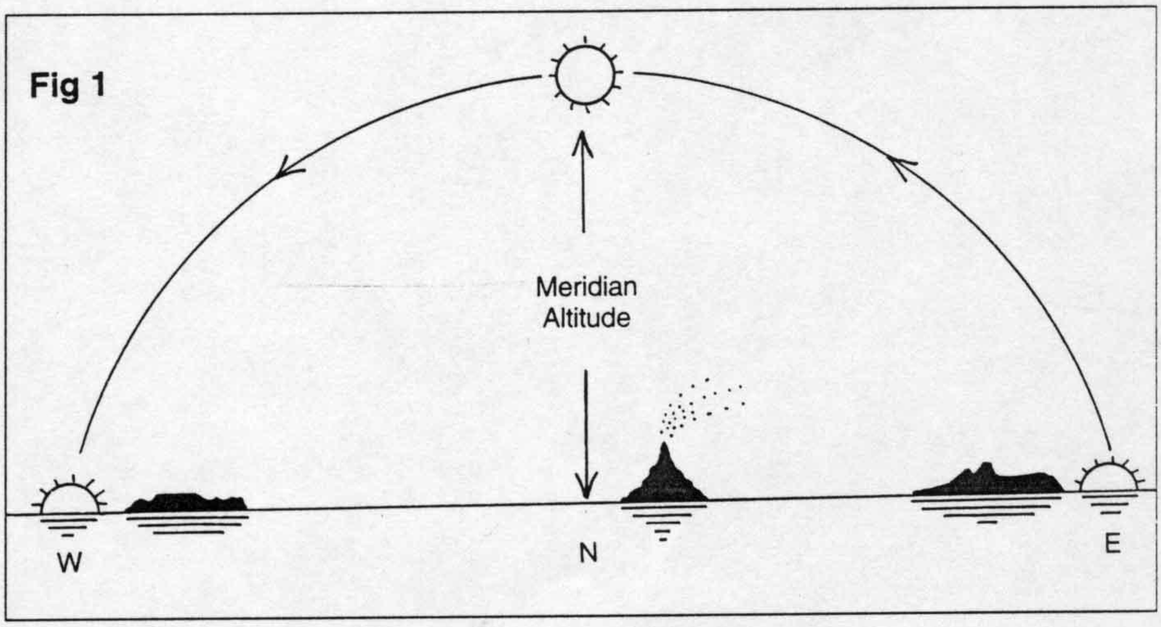
So far in this course all our navigation has been done using what is know as either the intercept method of sight reduction or, in recognition of the man who perfected the method, the Marcq St Hilaire method. This method is available for 100% of the time, all you need is a heavenly body, the details of which are listed in the almanac, a good horizon and an accurate knowledge of the time. This need to know an accurate time is - in fact - the methods only failing.

So - as longitude is time and time is longitude - prior to the invention of the chronometer in the 18th century the only things that the practical navigator had at his disposal were a knowledge of declinations of the sun and the stars and a means of measuring altitudes.

One way of establishing latitude without access to accurate time and which has survived since those days is the procedure known as Latitude by Meridian Altitude. With the meridian altitude all the navigator needs to know is the sun’s declination at the time of taking the sight. Therefore while an accurate knowledge of time is not required an approximate knowledge - to the nearest five minutes or so - is desirable.

This month we shall also look at an alternative method of finding longitude which, while it does rely on an accurate knowledge of time, only requires access to an almanac and a sextant and dispenses with the need to use the sight reduction tables.

6.1 Latitude by Meridian Altitude



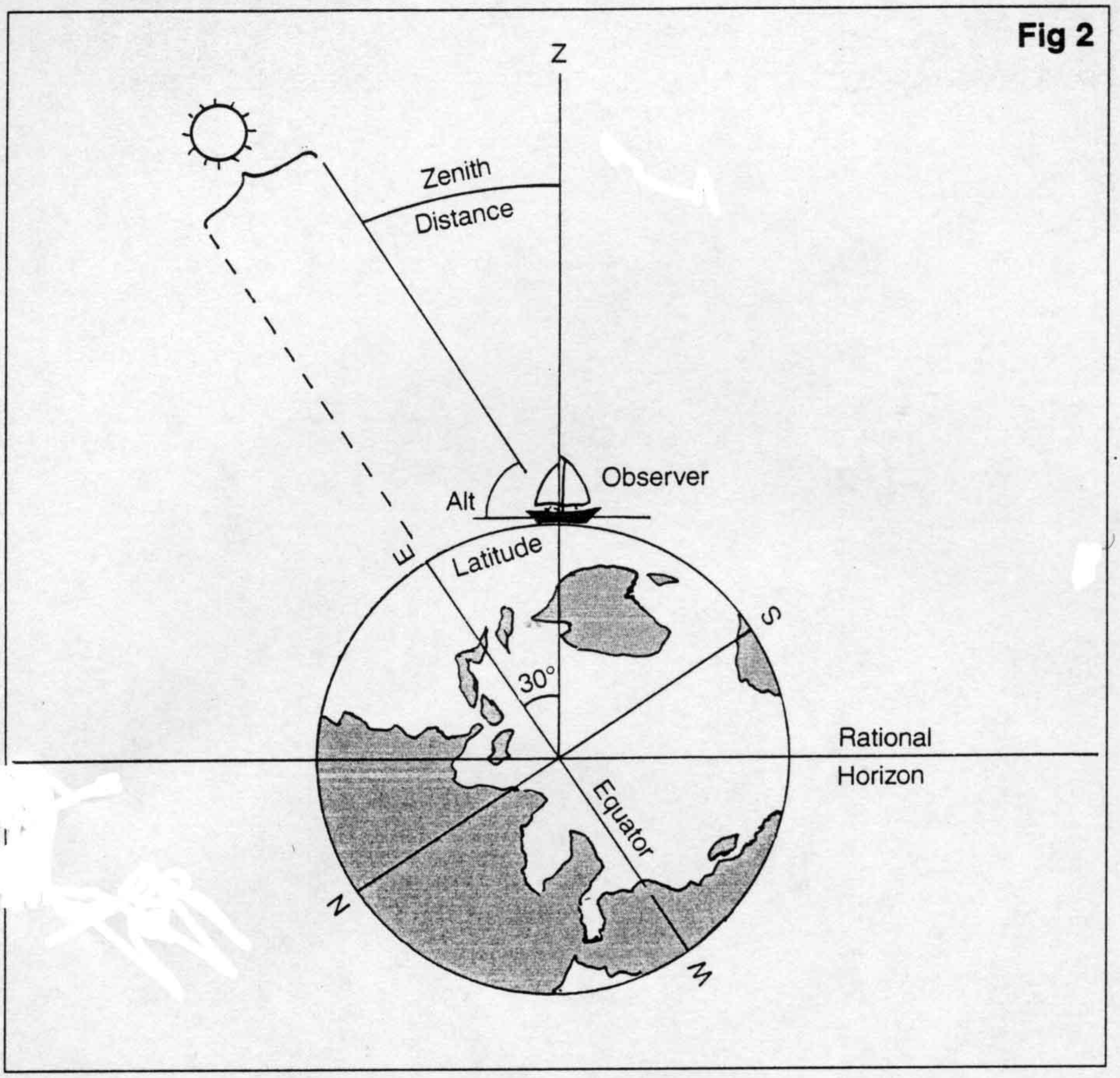
Latitude by Meridian Altitude involves taking a sight when the sun is bearing either due north or due south.

Latitude by Meridian Altitude involves taking a sight when the sun is on the observer’s meridian, that is it is bearing either due north or due south from the observer and is at its maximum altitude for that particular day.

The core formula is simplicity itself.

Latitude = Zenith Distance ~ (difference) Declination.

If the sun were to oblige by staying over the equator for 365 days of the year with zero declination this would mean that zenith distance would equal latitude.



In this sketch, which shows an observer in 30°S it can be seen that zenith distance equals latitude when the sun's declination is 0°.

Unfortunately this is not the case and so we must find the sun's declination at the time of the sight, and then decide which way to apply it to the zenith distance.

You may have noticed the similarity between this little formula and the Latitude ~ Declination calculation as used in the Haversine method of sight reduction. While in that calculation there is one simple rule to remember in the Meridian Altitude problem there are six variations, three for when you are navigating in the southern hemisphere and three for the northern.

The rules for the southern hemisphere can be summarised as follows:-

If you are in South Latitude and the sun has Northerly Declination then

Lat. = ZD - Dec.

If you are in South Latitude and the sun has Southerly Declination while still being the north of you then

Lat. = ZD+Dec.

If you are in South Latitude and the sun has South Declination but is south of you (i.e. you face south when taking the sight) then

Lat. = Dec - ZD.

The rules for the northern hemisphere are a mirror image of these three.

We could name the various parts of the formula ' North' and 'South' as required and establish some convoluted rules for applying them but I doubt if you would ever remember them without a crib sheet so instead we shall see how we can draw some little sketches to help overcome the problem.

You will find in practice that deciding which way to apply the declination is far simpler than it appears here. When actually on passage the rule established on the first day out will hold good until your situation changes, either when you cross the equator or the name of the sun's declination changes for instance. You can also, if all else fails, find the correct answer by trial and error as if you apply the declination the wrong way you will normally get an answer that is quite obviously ridiculous.

6.2 A little bit of technical drawing

Over the last few months a number of little sketches have appeared in these articles which show the earth as seen from a point directly above you, the observer, and which also show the G.P. of the sun. These are known by the rather technical title of drawings 'on the plane of the rational horizon' as the circumference of the circle does - in fact - represent your rational horizon.

The simplest method of all when it comes to establishing which way to apply the declination in meridian altitude problems is to draw one of these little fellows.

You have already seen how zenith distances and geographical positions can be represented on the surface of the earth. These sketches are based on a view of the earth from deepest space with our eye directly above the observer.

First draw a circle with yourself at Z ,the centre. Now draw in your meridian which will pass vertically through your position (Z) and also mark in the east / west points on the circumference. The next step is to draw in the equator so that it passes through these E/W points and then north or south of you- as required- by an amount roughly equal to you latitude, i.e. if your sketched globe has a radius of 9 cms and you are in latitude 15° South pencil in the equator so that it passes about 1.5 centimetres to the north of Z. You may also wish to mark in the elevated pole, in this case the south pole, at an equivalent distance up from the southern margin as shown.

Now mark in the sun’s geographical position when on your meridian - essentially this is just the declination either north or south of the equator -also roughly to scale.
The distance from the sun’s geographical position to the northern horizon is now equal to its altitude at noon while the distance from your zenith to the sun’s g.p. represents the zenith distance
By inspection you can now see whether your latitude, ZQ(Zenith-eQuator), is the sum of zenith distance and declination, or is the difference between the two.In this case - which represents an observer in the southern hemisphere during the southern winter - it can be seen that we shall have to subtract the declination from the zenith distance to find the latitude.

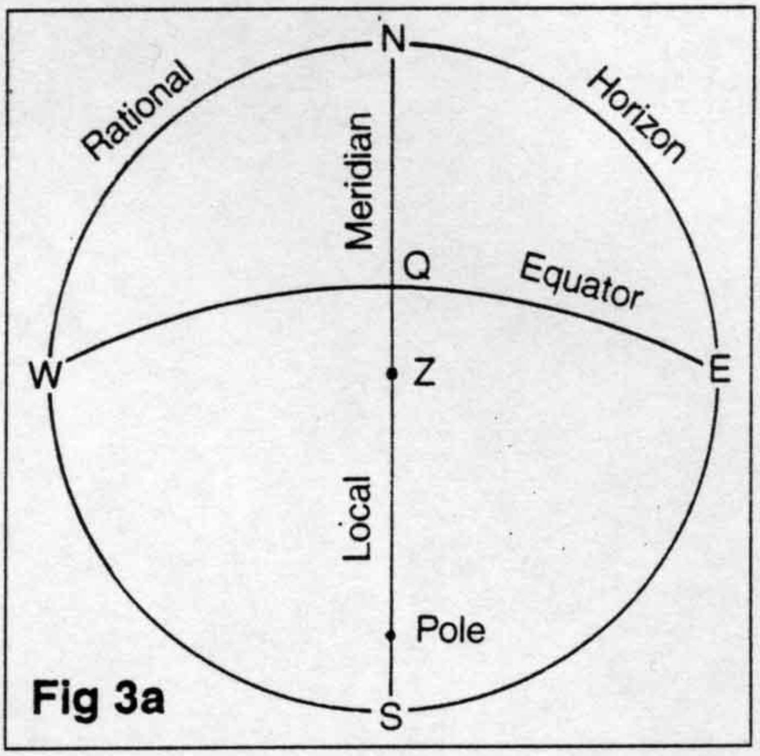


Fig 3a

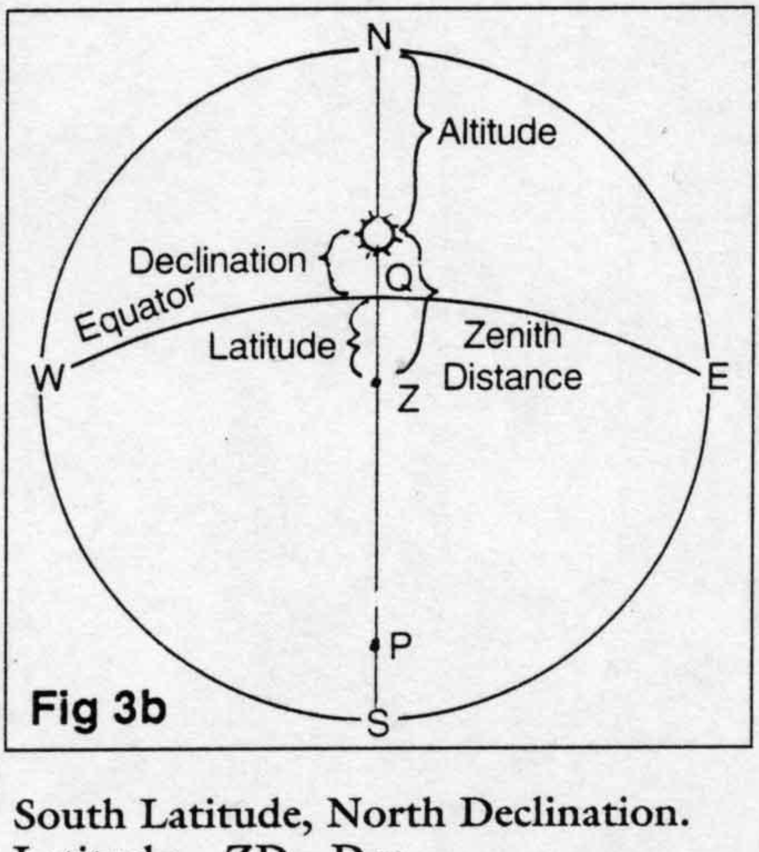
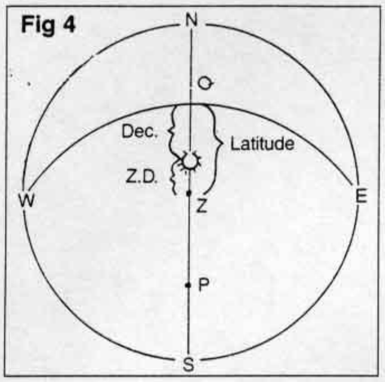
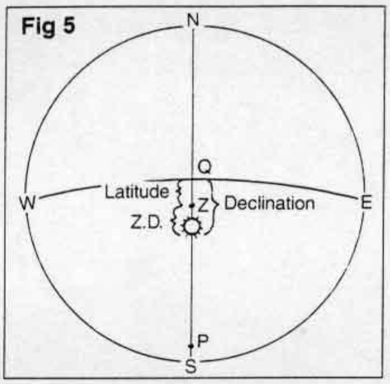


Fig 3b

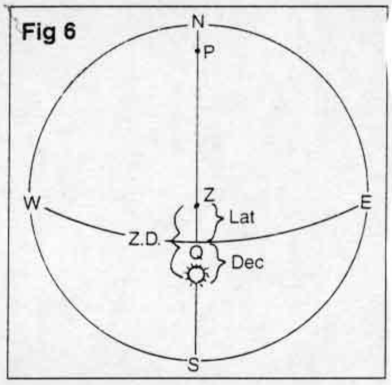
South Latitude, North Declination.
Latitude = ZD - Dec.



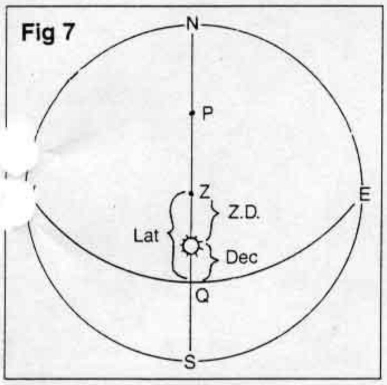
South latitude, south declination. Sun north of observer. Lat = ZD + Dec.



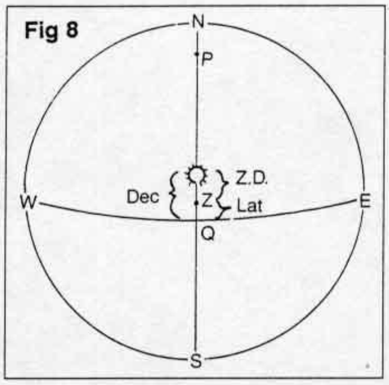
South latitude, south declination. Sun south of observer. Lat = Dec - ZD.
NB. The conditions shown in 5 & 8 can only occur when you are sailing in the tropics.



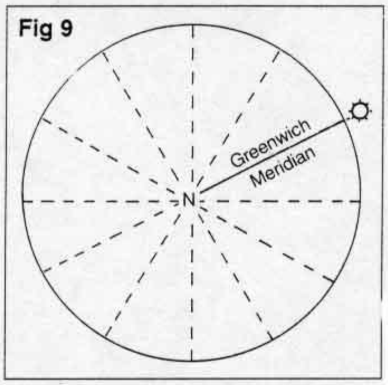
North latitude. South declination.
Lat = ZD - Dec.



North latitude. North declination, Sun south of observer.



North latitude. North declination, sun north of observer.
Lat = Dec. - ZD.



Noon at Greenwich occurs when the sun is directly over the Greenwich meridian.

You may find it pays to have a globe closes handy when doing this part of the work, failing that a grapefruit will suffice. Time spent mastering both the concept and the method of drawing these sketches, while not essential, will be rewarded as we shall be using them elsewhere in the course.

6.3 Local Apparent Noon

Noon is a word much misused by people ashore who usually use it to mean 12 o'clock local or zone time. For the navigator the use of the word is far more specific. We take it to mean the time at which the apparent sun, that is the one that we can see, is on the observer's meridian. This is the time at which the sun will be bearing either due north or south of us and it shall also be at its greatest altitude for the day. The strange thing is that, while landsfolk are so casual with the word 'noon' they still use the expressions a.m and p.m although these in fact mean *ante(before) meridien* and *post (after) meridien*.

To establish at what time noon will actually occur in our location we must first establish an approximate longitude, to the nearest 15´ will do. Then we must consult our almanac (figs 9 and 9a). In the bottom right hand corner of each of the daily pages you will find a small box which contains two items, the *equation of time* and the *time of meridian passage*. You will recall that the *mean* in GMT is due to us keeping time which is based on a mean sun as discussed in February. As the earth's orbit around the sun is in fact an ellipse the apparent sun crosses the Greenwich meridian at a slightly different time each day, this time varying from 1214 in February to 1154 in October. The equation of time is simply the difference in minutes and seconds between the passage of the mean and apparent suns for the two times stated. However for our purposes we can just use the time of meridian passage of the apparent sun at the Greenwich meridian which is listed to an accuracy of one minute of time. Let us say we are planning to take a meridian altitude on the 15th March, 1993. We can see that the apparent sun shall be on the Greenwich meridian at 1209 GMT. Now , on that day, the sun shall be on our meridian either sooner -if we are east - or later - if we are west - than it is on the Greenwich meridian.

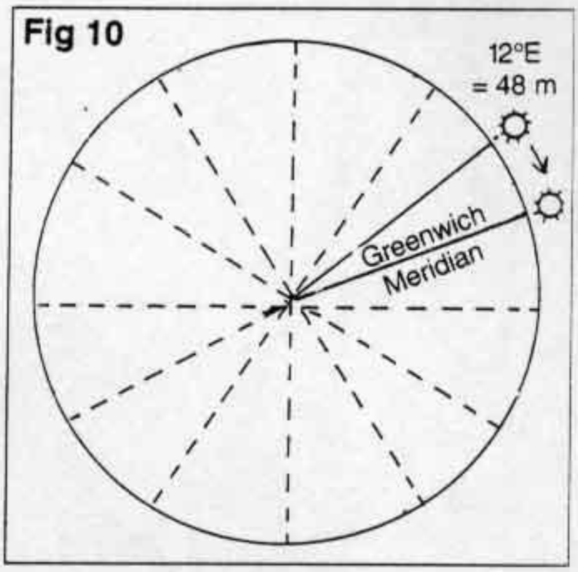
To find out how much sooner or later we must now convert our D.R. longitude into time where each 1°of longitude = 4 minutes in time.That is for every degree we are to the east of Greenwich the sun shall be on the meridian 4 minutes earlier. If we are in 12° East (somewhere in the Mediterranean perhaps) then the sun shall be on our meridian 48 minutes sooner (see fig 10). By simple subtraction we can now see that, in this longitude on the 15th of March, 1121 GMT is the time of <u>local apparent noon</u> (LAN) as the Americans know it or the <u>local time of meridian passage</u> as it is called in countries where British methods and traditions prevail.

Fig 9a

35	18 18	18 44	19 13
40	18 20	18 47	19 19
45	18 21	18 51	19 25
S 50	18 23	18 56	19 34
52	18 24	18 58	19 38
54	18 25	19 01	19 43
56	18 26	19 04	19 48
58	18 27	19 07	19 55
S 60	18 29	19 11	20 02

Day	SUN Eqn. of Time 00 h	12 h	Mer. Pass.
	m s	m s	h m
14	09 20	09 12	12 09
15	09 03	08 55	12 09
16	08 47	08 38	12 09

Fig 10



The sun shall cross the meridian of an observer in 12°E longitude 48 minutes before it crosses the Greenwich meridian.

There are two methods by which we may work out the time on our local meridian, one is to convert longitude into time manually by multiplying by four as we have just done. This is the preferred method when you are within, say, 30 degrees or so of Greenwich. Otherwise you may find it just as simple to use the longitude to time table which is found in the back of the almanac, in the sight reduction tables, and in the nautical tables.

For ready reference you may choose to jot down the following in your notebook:-

15° of longitude = 1 hour of time.
1° of longitude = 4 minutes of time.
15´ of longitude= 1 minute of time.

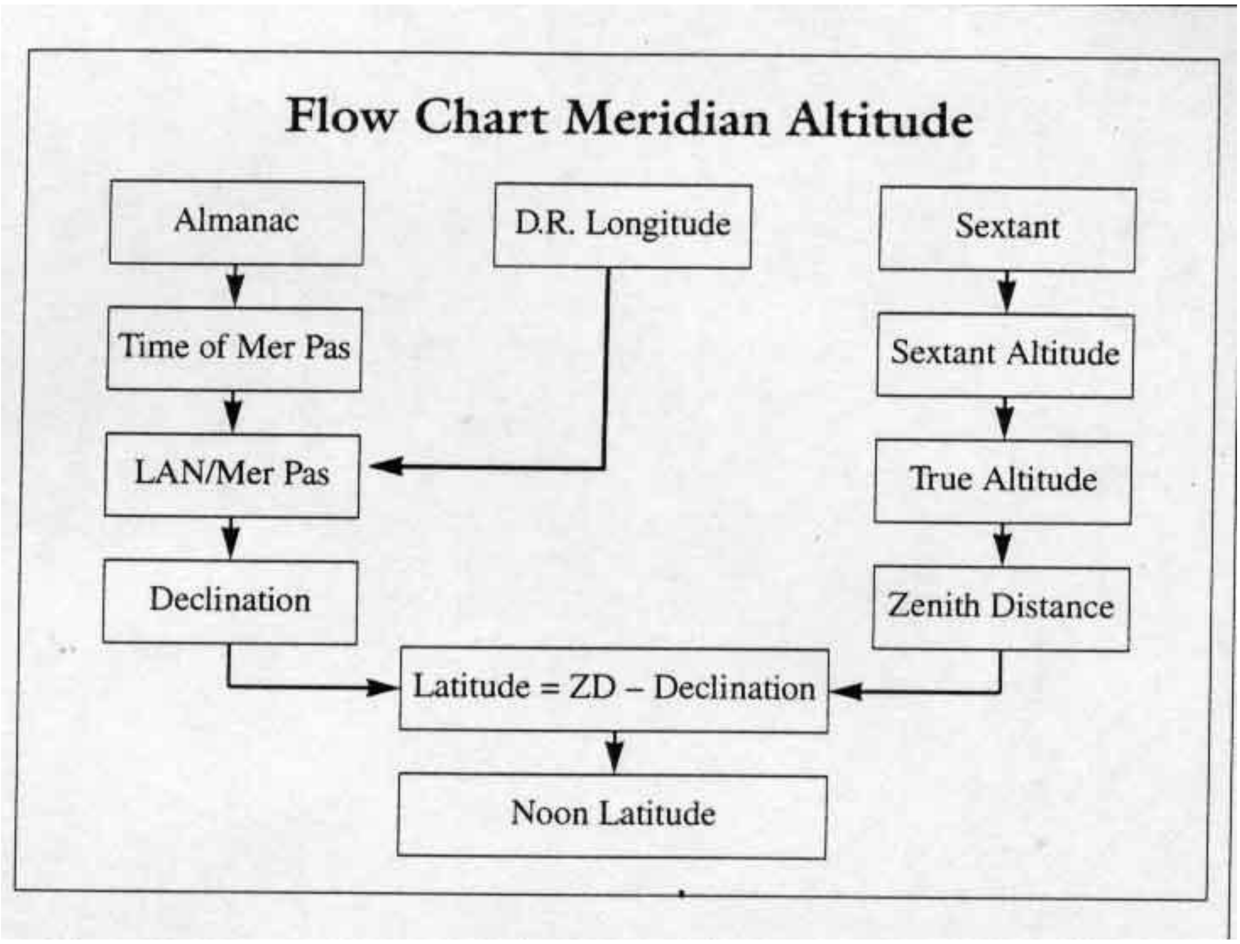
6.4 Establishing the Declination

Having established the time of meridian passage (LAN) the next step is to establish the sun’s declination at that time. This is done in the same manner as when working out a sight by the Marcq St Hilaire method. Just enter the daily pages of the almanac with the time of local apparent noon in hours and minutes, GMT, and lift it out. An exact time here is not essential, the nearest six minutes will give an accuracy of better than 0.1´ while an error of a whole hour will only introduce a maximum error into your latitude of 1.0´.

Fig 11

15	00	177	44.2	S 2	13.1
	01	192	44.4		12.1
	02	207	44.6		11.1
	03	222	44.7	. .	10.1
	04	237	44.9		09.1
	05	252	45.1		08.2
	06	267	45.3	S 2	07.2
	07	282	45.5		06.2
	08	297	45.6		05.2
M	09	312	45.8	. .	04.2
O	10	327	46.0		03.2
N	11	342	46.2		02.2
D	12	357	46.3	S 2	01.2
A	13	12	46.5	2	00.3
Y	14	27	46.7	1	59.3
	15	42	46.9	. .	58.3
	16	57	47.0		57.3
	17	72	47.2		56.3

More important by far is to know what day it is. I have said it before, keep your watch set to GMT <u>date</u> and time and this problem will never present itself. If you enter your almanac just one day out at the time of the equinoxes you will introduce an error into your latitude of up to 24´! More than enough to bring you well and truly undone if you are navigating near land.


Flow Chart Meridian Altitude
Almanac
D.R. Longitude
Sextant
Time of Mer Pas
Sextant Altitude
LAN/Mer Pas
True Altitude
Declination
Zenith Distance
Latitude = ZD – Declination
Noon Latitude

6.5 Sun - Run - Meridian Altitude

So let us now look at how this new found skill fits into our daily routine and how we can blend it into our day's work.

Having taken our morning sun sight and laid our position line on the plotting sheet it is now a good time to prepare for our meridian altitude or 'noon' sight.

The first thing to do is calculate an approximate d.r. position for noon, remembering that high accuracy here is not critical.

Next lift the time of meridian passage at Greenwich for that day from the almanac.

Convert your longitude into time.

Apply the longitude in time to the time of mer pass at Greenwich to establish the time of local apparent noon.

Go back into the almanac and ascertain the declination for that time.

About five minutes before noon go on deck with your sextantant b and establish the altitude of the sun, follow it across the sky as its altitude increases, when it is on your meridian it will 'hang' in the sky before its altitude starts to decrease. Note this maximum altitude, note also the timeto the nearest minute and the log reading.

Correct the altitude in the normal fashion and subtract it from 90° to establish the zenith distance, then apply the declination according to the rules.

You now have a noon latitude.

Mark this noon latitude as a position line on the chart. Run up you morning position line by the log distance sailed between morning sights and noon and lay off your transferred position line. Where the two position lines cut is your observed noon position.

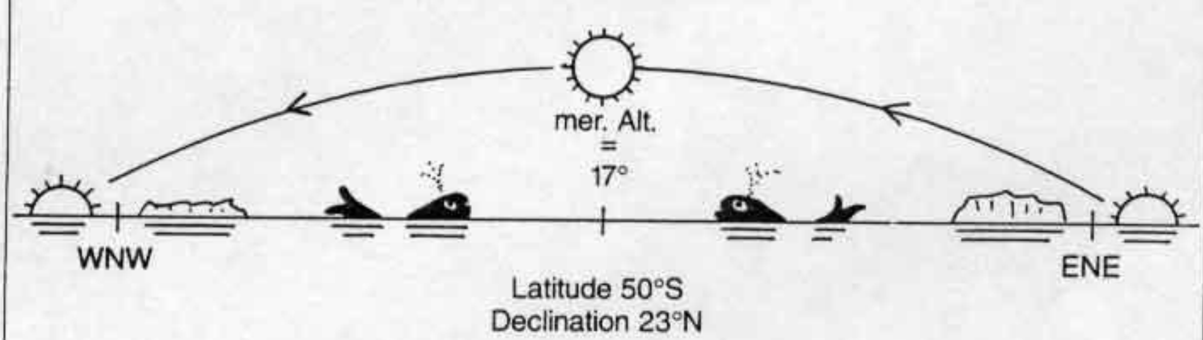
Now you may choose to calculate the distance between this position and the previous day's noon position and by dividing by the elapsed time you will find the speed made good over that period.

6.6 Tips

After some practice taking meridian altitudes you may well find that you can not only precalculate you sextant corrections but also predict what the altitude should be at noon. Not only does this make your job at noon easier and faster it also lets you confuse your friends and amaze your enemies by reading the latitude directly off the sextant arc at noon. I shall let you figure out how to do it for yourself.
If you are landlocked but own a sextant you can get invaluable practice with meridian altitudes by using any flat horizon that comes to hand, fence, roofline, whatever, as the most difficult part of the operation is judging when the sun is in fact on the meridian.

If, for reasons best known to yourself, you are in the Southern Ocean during the winter the sun will be low in the sky to the north and both the altitude and azimuth of the sun will change at a steady rate. These are ideal conditions, if not for sailing then at least for taking meridian altitudes.

Fig 12



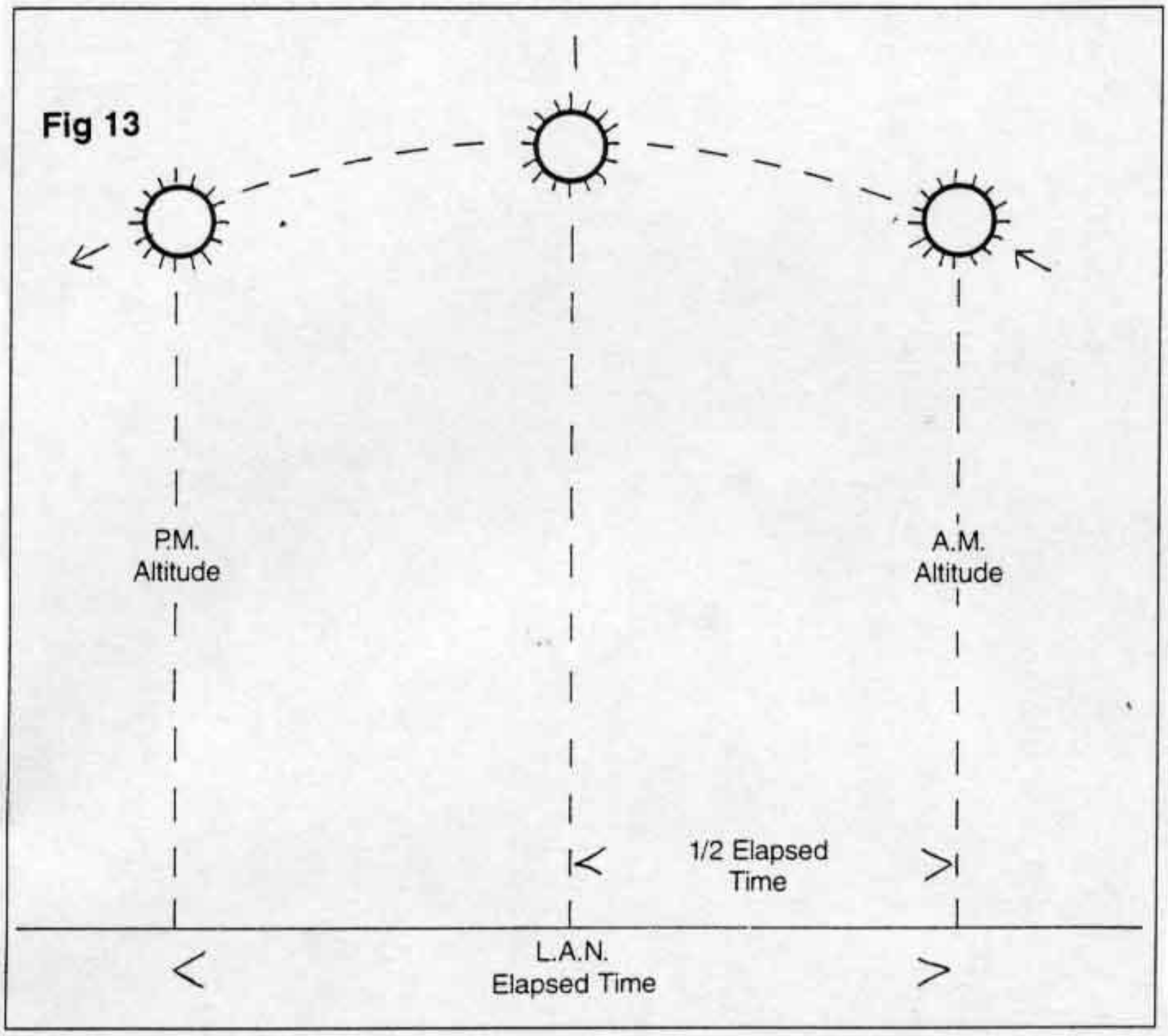
If however you are in the tropics and your latitude and the sun's declination are almost identical then the sun's azimuth will remain fairly steady in the east until just before noon while, at the same time, the altitude will be changing rapidly. When taking meridian altitudes in these conditions speed is of the essence as suddenly the azimuth will change rapidly to west and the sun's altitude will be decreasing at a fast rate. In these conditions you will find meridian altitudes quite difficult to take and, as your morning and afternoon sights will yield only longitudes, you may have to resort to another means of finding latitude.

6.7 Longitude by Equal Altitudes

The Marcq St Hilaire method of sight reduction is the mainstream method of finding longitude while out of sight of land but there is a method which can be employed if , for any reason only clock, sextant, and almanac are available on your yacht. This method is known as longitude by equal altitudes. In its simplest form - without even a sextant - this involves noting the GMT when the sun rises, noting it again when the sun sets and, by dividing the interval so found by 2, finding the time that it was on the meridian. If you have covered some distance between sunrise and sunset small errors, of little real consequence in the realms of emergency navigation, may creep in.

To be of use the sun's altitude must be changing at a fairly rapid rate and the method is prone to considerable error when used aboard a fast moving ship steering a north / south course. Aboard yachts speed will rarely be a problem but to establish if the rate of change of altitude is sufficient and to ascertain the best time for taking the sights we must resort to the Latitude difference Declination formula that I introduced you to in February.

It is a simple rule, if the Lat. ~ Dec is less than 60° then conditions are suitable. If the Lat ~ Dec is , lets say, 25° (Latitude 5° South, Declination 20° North) then the optimum time for the first sight is 25 minutes before local apparent noon.



The elapsed time divided by 2 and added to the time of the first sight will give the exact time of Local Apparent Noon.

Let us say that you take the first sight some thirty minutes before noon and after lunch take another. By dividing the elapsed time in two and adding this to the time of the first sight you will have found the precise time of meridian passage. Look up the sun's GHA for that time. Convert this GHA into Longitude and bingo, your longitude at the time of local apparent noon. This is a handy little standby method which, combined with a meridian altitude, will give a serviceable position.

One of the reasons that it is not used in preference to the intercept method in mainstream navigation is that you do not get a position until after the event and there is always the risk of the sun being obscuredby cloudn at the time of the second sight. To guard against the latter problem always take three a.m. altitudes, the sun should be visible for at least one of the matching p.m. altitudes.

6.8 The worked example

Sight Book – Yacht Ferret – 15/3/93

D.R. Lat	18° 37'S	Index Error	1' on arc
D.R. Long	82° 15'E	Height of Eye	3.3 metres
Ship's Time = GMT + 5h30m.			

Meridian Passage Greenwich	12h09m	GMT	Declination 15d06h	S2°07.2'
Longitude in Time			d = 1'	-0.7'
(82 1/4° X 4 = 329 minutes)	-05h29m		Declination 15d06h40m	S2°06.5'
Local Noon (LAN)	06h40m	GMT		
	12h10m	Ship's time		

Meridian Altitude	73° 13.2'	
I.E.	- 1.0'	
	73° 12.2'	
Dip	- 3.2'	
	73° 09.0'	
Total Corr.	+ 15.9'	
True Altitude	73° 24.9'	
Zenith Distance	16° 35.1'	(Z.D. = 90° – True Altitude)
Declination	2° 06.5'	
Latitude	18° 41.6'	South (Latitude = ZD + Dec)

Fig 14

Since last month the good ship ‘Ferret’ has found her way from the tasman sea and is now on passage from Darwin to Mauritius. At 1200 ship’s time we shall have an approximate D.R. position of Latitude 18° 27´South, Longitude 82° 15´East. Ship’s time as shown on the galley clock is 5h 30m ahead of G.M.T. Before we can establish our latitude we must first ascertain at what time the sun shall be on our meridian. By consulting the almanac we can see that on this day the sun shall be on the greenwich meridian at 1209 GMT. We are to the east of Greenwich so the sun shall be on our meridian sooner than that. By using the long to time conversion table or by simple multiplication we can see that it will be on our meridian at 0640 on the 15th.Ship’s time is 5h 30m ahead of GMT so that shall be at 1210 by the galley clock. By inspection we can see that the declination at 06h40m on the 15th of March shall be 2° 06.5´ South.

Step on deck with your sextant at about 1205 by the galley clock and start following the sun up - when it ‘hangs’ in the sky note the sextant altitude, the the time and the log reading.

Correct the sextant altitude in the normal way and subtract it from 90° to find the zenith distance. Establish which rule to use, in this case Latitude = ZD + Dec, and calculate the latitude.
All that now remains to be done is to lay off this position line on the plotting sheet (the sun's azimuth is 000° so the position line runs 090°/270°). Using the log reading at noon ascertain the distance run since your morning sight, run up your morning position line by this distance and where this cuts your noon latitude is your observed noon position.

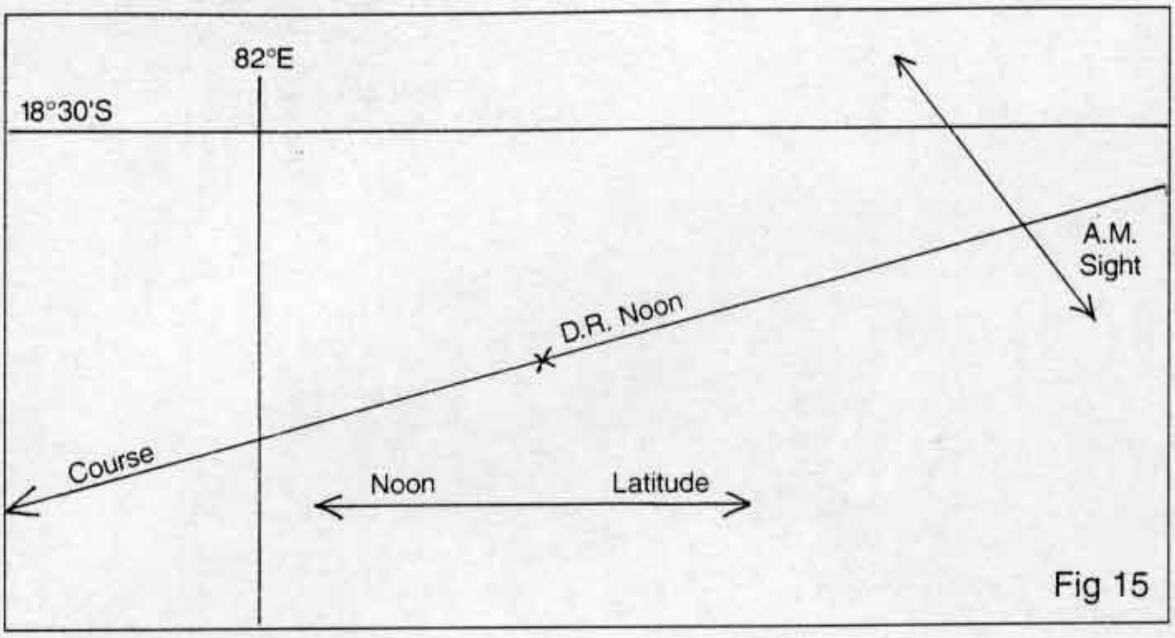


Fig 15

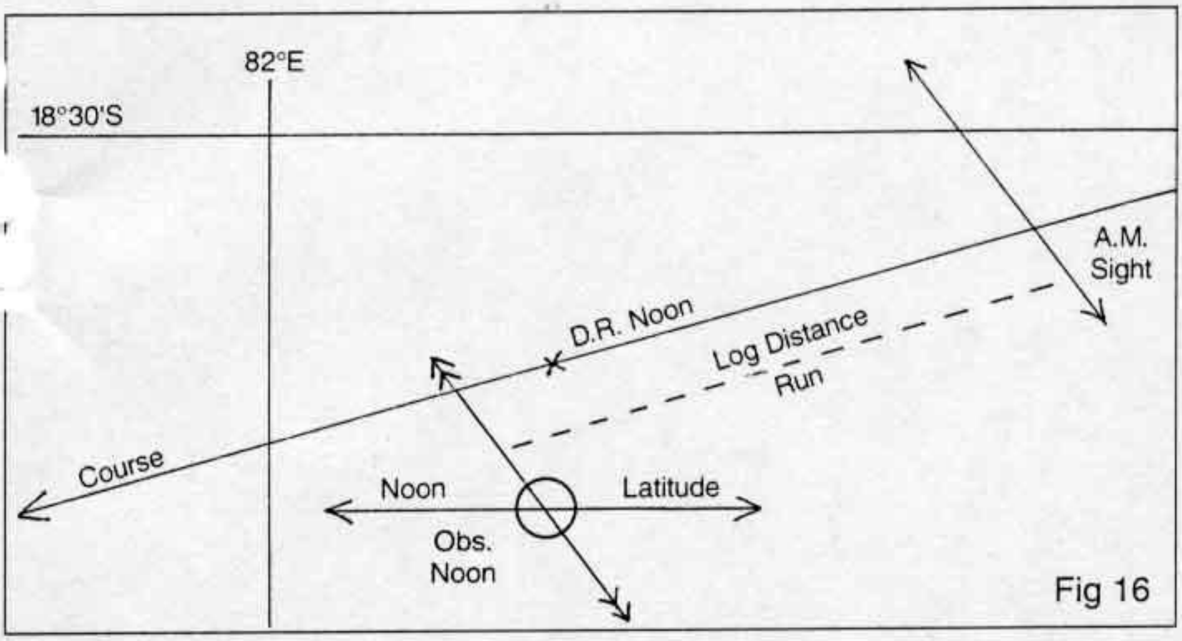


Fig 16

6.9 Part 6 - The Questions

1. a) On passage across the Bay of Biscay on the 21st July, 1993, you calculate that your D.R. position at 1200 GMT will be 47° 07´North, 5° 15´West. Meridian passage at Greenwich will be at 1206 GMT. At what time will the sun be on your meridian?

Time of Local Apparent Noon. .... GMT.

b) The sextant altitude of the sun when on the meridian (meridian altitude) is 62° 55´. Index error is 2´off the arc. Height of Eye is 3.3 metres. If the declination at this time is 20° 24.6´ North what is the noon latitude?

Latitude........

2. a) In the Red Sea on December 15th 1993 your D.R. position at 1200, Ship's Time, is 22° 05´North, 37° 15´East. Meridian passage at Greenwich shall be at 1155 GMT. At what time will the sun be on your meridian?

Time of L.A.N. .... GMT.

b) Aboard your yacht you are keeping Egyptian Standard Time (2 hours ahead of GMT), what will be the ship's time of meridian passage?

Time of L.A.N....... Ship's Time.

c) The sextant altitude of the sun when on your meridian is 44° 33.5´. Index error is 1´on the arc and your height of eye is 4.1 metres. The sun's declination at this time is 23° 16.5´South. What is your noon latitude?

Latitude. ....

3. a) Cruising in the Gulf of Benin on August 21st your D.R. position at noon is 2° 15´North, 6° 30´ East. On this day the sun shall be on the Greenwich meridian at 1203 GMT. At what time will it be on your meridian?

Time of L.A.N. ...... GMT.

b) The sextant altitude of the sun on the meridian is 71° 47.9´. The index error is 1.7´off the arc and height of eye is 3.3 metres. The declination at this time is 20° 25.0´North. What is your noon latitude?

Latitude. .....

4. a) You are approaching Fremantle from the west. At 0545 ship's time on the 15th of March, 1993 you fixed your position by morning star sights as 34° 15´South, 103° 21´East. You are steering 100° True and are making good 7 knots. Your ship's time is 7 hours ahead of GMT. What will be your D.R. position at 1200 ship's time on the 15th March?

D.R. Latitude. D.R. Longitude.

b) What will be the time of meridian passage at Greenwich on this day?

Meridian Passage. ....

c) What will be the time of meridian passage at your D.R. position?

Time of Meridian Passage... GMT Ship's Time

d) What will be the declination at this time?

Declination........

e) the sextant altitude of the sun at noon is 58 ° 08.2 ´ Index Error is 3.2´ on the arc and your height of eye is 3.3 metres. What is your noon latitude.

Latitude..........

5. a) A morning sun sight, taken at 0930 on the 2nd September, 1993 (ship's time), yields a position line that passes through 12° 21´South, 148° 32´West, at which time the sun's azimuth is 047° True. You are steering a course of 265° True at 10 knots and are keeping ship's time which is 10 hours behind GMT.
What will be the time of meridian passage at Greenwich on this day?

Meridian Passage GMT

b) At what time will the sun be on your local meridian?

L.A.N. .... GMT Ship's Time

c) What will be your D.R. position at this time.

Latitude.......... Longitude..

d) What will be the sun's declination at this time.

Declination ....

e) The sextant altitude taken when the sun is on your meridian is 70 ° 15.1´. The Index Error is 1.1´on the arc while your height of eye is 5.2 metres. What is your noon position?

Latitude............ Longitude............

6.10Part 5 - The Answers

1/

a/

Latitude...12° 01.5´S   Longitude...153°43´E

b/

T.Alt.....51°59´

c/

GHA....173°38.1´   Dec....7° 38.0´N

d/

Chosen Lat...12°S   Chosen Long...153° 21´ E

LHA........327°

e/

Tab Alt...51°46´   Intercept...13´T

Azimuth....062° T

f/

Longitude...153°37´E

2/

Latitude....33° 30.5´S   Longitude...101° 54´E

3/

Latitude...12° 56.5´N   Longitude....38°20´W

4/

a/

GHA...141° 17.9´   Declination...1° 51.8´S

b/

True Altitude...48°49.4´

c/

Chosen lat...34°N   Chosen long....162°17.9´W

LHA....339°

c/

Tab alt...49°03´   Intercept.....3.6´Away

Azimuth......146°T

d/

Longitude....162°26´W

5/

a/

Distance....217.2 miles or 217 miles

b/

Course...270°T

c/

Time to Go....1day3hours 8 minutes.

Fin.

Off The Planet

7 Off The Planet

So far we have done all our navigating simply with the aid of the sun but as you are well aware there are far more things than just the sun in the heavens. Over the next three months we shall have a look at the moon, the planets and the stars as they all have something to offer the mariner . Also we shall not just be relying on a few running fixes near the middle of the day to fix our position.

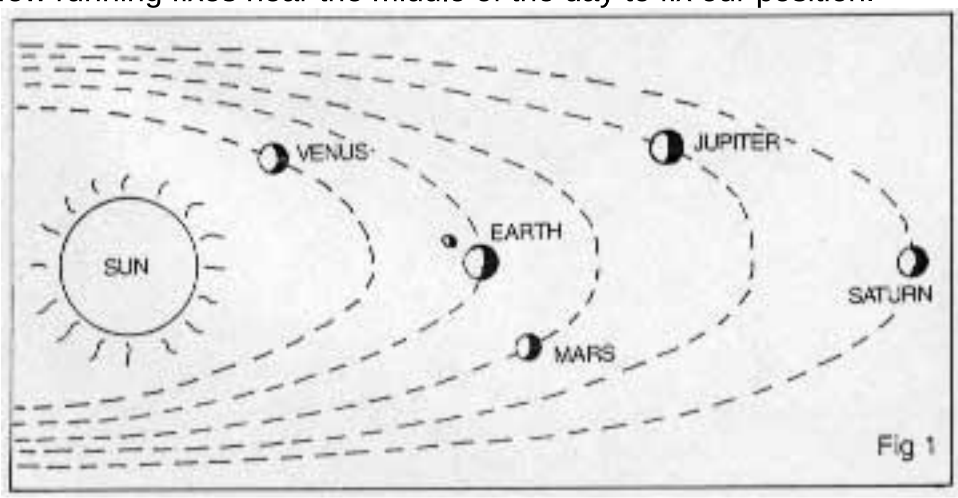
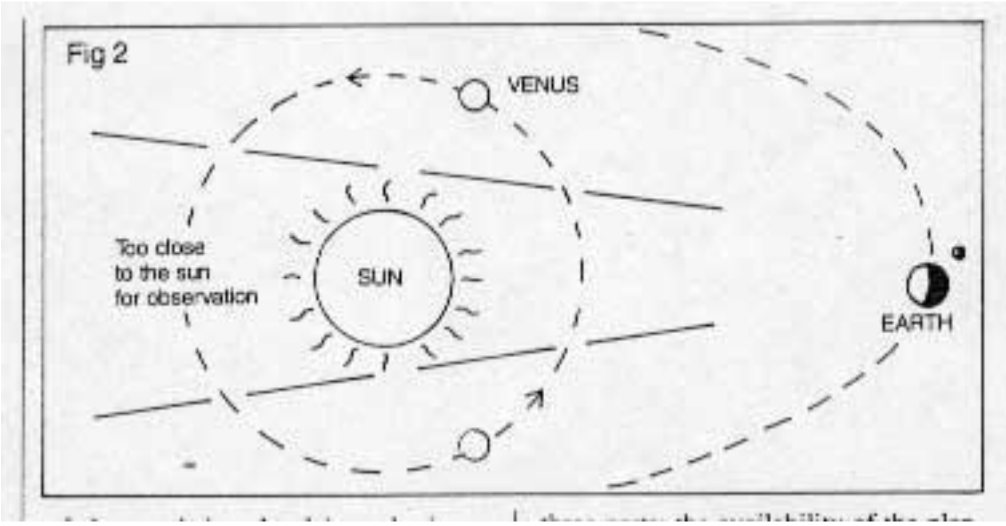


Fig 1

Only four of the eight planets in our solar system are of any use to the navigator: Venus, Mars, Jupiter and Saturn. A small number of complications present themselves with the planets, not least of which is that they are sometimes too close to the sun to be observed (fig 2) and - with one notable exception - they are only available to us at twilight, that time between sunset and ‘total’ darkness when both the planet and the horizon are visible at the same time. On the positive side most of the work involved in reducing a planet sight is identical to that involved in a sun sight and, as their orbits are in the same plane as that of the earth, their declinations are such that you may still use Volume 2 of the Sight Reduction Tables for Air Navigation.



We shall consider this problem in three parts, the availability of the planets, the correction of the sextant altitudes of the planets, and the establishment of both the local hour angle and the declination of the chosen planet at the time of taking the sight.
First we must find a way of identifying the planets. If you are beetling away at this course somewhere in Western Queensland and have a half built hull sitting in the house paddock it is not to soon to start. Like so much astro navigation you should have a lot of the groundwork laid before you leave port, even if the planning is just in your head. Don’t wait until the first night offshore before raising your eyes above the horizon.

7.1 Venus

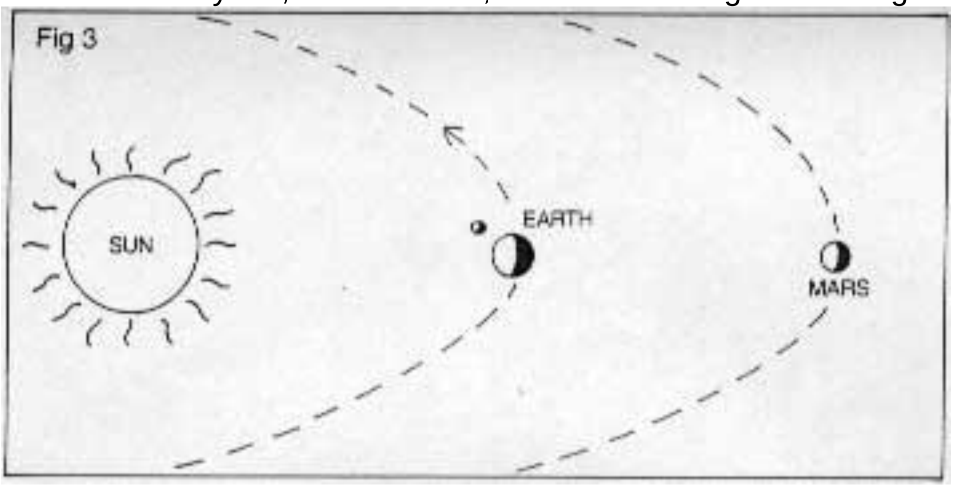
is the most versatile of the planets. The brightest body in the heavens (magnitude -4.0) - after the sun and the moon- it can be observed during daylight hours for many months of the year and may, at times be used in conjunction with the sun to get either an a.m. or p.m. fix.
Its orbit lies between the earth’s orbit and the sun and as a result it is never visible throughout the night. It is instead either a morning or an evening planet, typically rising a few hours ahead of, or setting a few hours after, the sun.
Throughout August, when this lesson will be published, it is a morning planet, rising some two and a half hours ahead of the sun. Its brilliance is such that you cannot mistake it for anything else in the morning sky. It will be exhibiting retrograde motion from then until the end of November when it shall be too close to the sun to be seen. It will reappear early in 1994 as an evening planet, setting an hour or two after the sun each day.

Taking a morning sight with Venus, or any other planet for that matter, is simple, just wait until your horizon is bright and firm enough to use and take a sight, working it out in the usual manner. When it is an evening planet you already have a horizon, you just have to wait until you can see the planet.
Now you may start to take advantage of Venus's versatility, as previously stated it is the brightest object in the sky and can be seen throughout the day when it is a sufficiently distance from the sun. Stick around and watch it after the sun rises, it will lose its brilliance and you may need a pair of binoculars but it is still there and may be used.
The traditional method of working with Venus during the day is to take it when it is on your meridian as it is a relatively simple matter of pre-calculating its altitude at this time. Take a meridian altitude of Venus and a standard sun sight at the same time and you will have a good fix which has not been degraded by unknown currents.

7.2 The Outer Planets

The orbits of these planets, Mars, Jupiter, and Saturn lie outside the earth's orbit and while at times they are passing behind the sun and cannot be seen there are other times when they will, unlike Venus, be visible throughout the night.

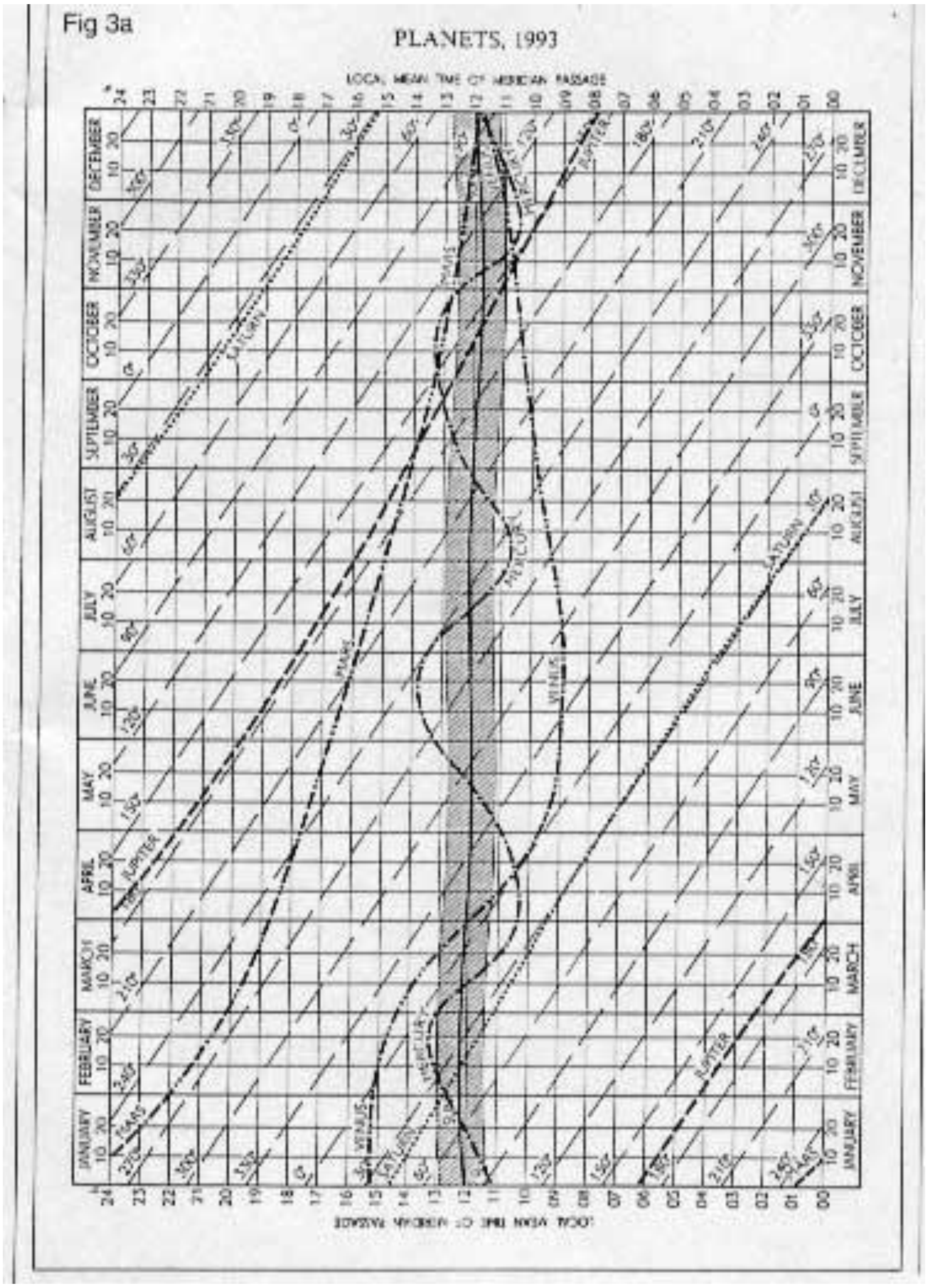
Fig 3



On the 21st of August Saturn, with a magnitude of 0.3, (its brightest for the year), will be on or near your local meridian at midnight at which time it will have a declination of 14° South. This means that it will be rising in the east as the sun sets and setting as the sun rises. At this time both Mars (magnitude 1.7) and Jupiter (magnitude -1.8) will be evening planets, setting some 2 hours after the sun. They will be fairly close together but Jupiter is the far brighter object.
As you can see from its magnitude Mars may be hard to pick out against the background of stars so you may have to fall back on some other clues to find it.
These clues are that Mars is reddish in colour, all planets shine rather than twinkle

and - if observed over several nights - planets will be seen to alter their position against the backdrop of the stars.

So that is where they will be in August but how do we find them at other times? Times of rising and setting are listed with the weather and tides in the major daily papers. At sea, where daily papers are few and far between, you may extract the time of their meridian passages from the bottom right hand corner of the daily pages and, from that, deduce the approximate time of their rising and setting. A third alternative is to use the ‘Planet Notes’ which are found near the front of the Nautical Almanac. These notes are quite comprehensive and include a full page chart showing the times of meridian passage for all four planets graphically. With a little practice you may well find this the easiest way of locating them.



7.3 Correcting the Altitude

Correction of the sextant altitudes of planets should pose no real problems and was covered in Lesson 2, March 1993. You apply the index error and dip corrections as for any other sights and then you apply the correction from the 'Stars and Planets' column of the Altitude Correction Tables. This is - in effect - just a correction for refraction as planets do not need to be corrected for semi-diameter and this correction is always negative. You will observe that auxiliary corrections have to made to the altitudes of both Mars and Venus throughout the year. These are small corrections for parallax and allow for the fact that these planets are relatively close to the earth.

Fig 4

STARS AND PLANETS

App. Alt.	Corr^n
° ′	′
9 56	
	−5·3
10 08	
	−5·2
10 20	
	−5·1
10 33	
	−5·0
10 46	
	−4·9
11 00	
	−4·8
11 14	
	−4·7
11 29	
	−4·6
11 45	
	−4·5
12 01	
	−4·4
12 18	
	−4·3
12 35	
	−4·2
12 54	
	−4·1
13 13	
	−4·0
13 35	
	−3·9
13 54	
	−3·8
14 16	
	−3·7
14 40	
	−3·6
15 04	
	−3·5
15 30	
	−3·4
15 57	
	−3·3
16 26	
	−3·2
16 56	
	−3·1
17 28	
	−3·0
18 02	
	−2·9
18 38	
	−2·8
19 17	
	−2·7
19 58	
	−2·6
20 42	
	−2·5
21 28	
	−2·4
22 19	
	−2·3
23 13	
	−2·2
24 11	
	−2·1
25 14	
	−2·0

App. Alt.	Additional Corr^n
1993	
VENUS	
Jan. 1–Feb. 2	
May 28–July 15	
°	′
0	
	+0·2
41	
	+0·1
76	
Feb. 3–Feb. 26	
May 5–May 27	
°	′
0	
	+0·3
34	
	+0·2
60	
	+0·1
80	
Feb. 27–Mar. 14	
Apr. 15–May 4	
°	′
0	
	+0·4
29	
	+0·3
51	
	+0·2
68	
	+0·1
83	
Mar. 15–Apr. 14	
°	′
0	
	+0·5
21	
	+0·4
45	
	+0·3
60	
	+0·2
73	
	+0·1
84	
July 16–Dec. 31	
°	′
0	
	+0·1
60	
MARS	
Jan. 1–Mar. 7	

7.4 Ascertaining the GHA and declination of a planet

In the daily pages of the almanac the hour angles of the sun, the moon, and the four navigational planets used for navigation are listed for every hour to an accuracy of 0.1´ of arc.

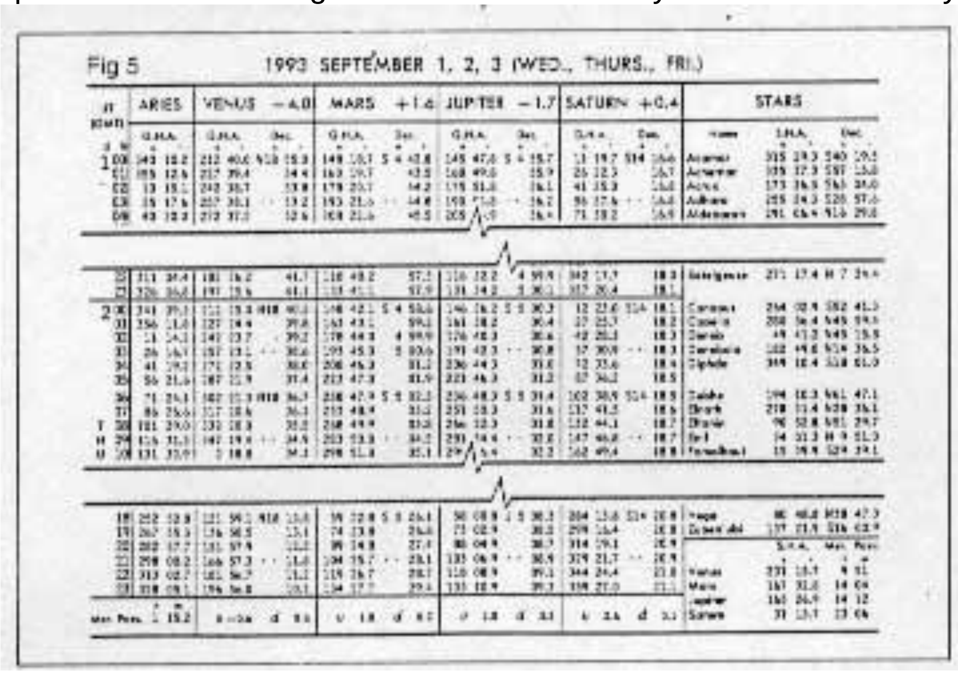


Fig 5

1993 SEPTEMBER 1, 2, 3 (WED., THURS., FRI.)

ARIES | VENUS −4.0 | MARS +1.6 | JUPITER −1.7 | SATURN +0.4 | STARS

In compiling the almanac, however, certain assumptions have to be made regarding the rate of change of the hour angles of these bodies as listed in the ‘Increments and Corrections’ pages of the almanac. Even the hour angle of the sun, which we assume to change at exactly 15° per hour usually changes by a few seconds of arc more or less than this. You may choose to confirm this by simply inspecting consecutive entries for the sun on the daily pages.

Now, while the rate at which the sun’s hour angle changes is as near to 15° per hour as makes no difference, that of the planets - due to the nature of their orbits and the effect that these orbits have on their apparent motion as viewed from the earth - varies by up to 4.0´ from this standard. So while we still use the increments column headed SUN/PLANETS - which is based on a change of exactly 15° per hour - we must allow a small correction. You have already seen the way to use the ‘d’ correction to allow for the hourly changes in the sun’s declination. In a similar manner there is a value listed for ‘v’ (velocity) at the bottom of each of the planet columns on the daily pages. If the value of ‘v’ for Mars on a particular day is 1.2´ this simply means that the hour angle of Mars shall increase at a rate of 15° 1.2´ per hour on that day. Failure to allow for the ‘v’ correction could introduce errors in longitude of up to 4.0´ into your calculations.

So to establish the exact Greenwich hour angle of a planet at a certain time you must first extract the Greenwich hour angle for the total hour from the daily pages together with the increment for the minutes and seconds from the column headed SUN/PLANETS in the Increments and Corrections pages .

Then, using the value of ‘v’ obtained from the daily pages you must establish the ‘v’ correction by referring to the Increments and Corrections pages . This correction is normally additive, the exception being for the planet Venus, which as it passes in front of the the sun experiences what is known as retrograde motion and has a negative ‘v’ correction.

This retrograde motion manifests itself in the following manner. If you observe any one of the planets over a number of nights you will notice that it ‘gains’ on the sun. That is it rises and sets earlier and takes up a more westerly position in the night sky. As Venus passes in front of the sun the opposite occurs and the planet appears to lag when compared with the sun. Thus the negative ‘v’ correction.

An allowance for the hourly change in the declination of the planets is made in the same manner as is done for the sun by using a ‘d’ correction. Normally small in size it is often a simple matter to mentally calculate this correction. A word of caution - this correction is not given a sign in the almanac, you must establish which way to apply it by inspection. The value of ‘d’ is given for each planet on the daily pages.

7.5 So what are the benefits of using planets?

One major plus is that - as their orbits are in the same plane as the earth’s orbit - their declinations are always such as to permit the use of the ‘Sight Reduction Tables for Air Navigation, Volume 2’ which we are already using for sun sights. Apart from the small additional correction applicable only to Mars and Venus the correction of the altitudes is fundamentally the same as the sun and you only need to remember to apply the ‘v’ correction to the hour angle.

Venus and Jupiter are the two most useful planets as their brightness is such that they are often observable through a thin veil of cloud that may render the taking of star sights impossible. With Venus the fact that you can observe it during the day makes it especially useful.

Mars and Saturn, on the other hand, are less bright than many stars and it is usually simpler to find and use a star such as Sirius. These two planets are, in fact, rarely used in practical navigation.

7.6 Some Worked Examples

7.6.1 Venus as a morning planet

Let us assume you are at the northern end of the Mozambique Channel on September 2nd, 1993. At morning twilight you take a sights of venus and several other stars. The sextant altitude is 21 53, the time is 02d02h43m07s GMT and your DR position is 11 53 south, 44 44 east. Your sextant has no index error and your height of eye is 4.4 metres. You are keeping Comoro Islands Standard Time which is three hours ahead of GMT. At the same time you take two star sights. After reducing these sights you can lay off all three on your plotting sheet to get a high quality morning fix (we shall deal with the star sights in the next part)

Fig 7

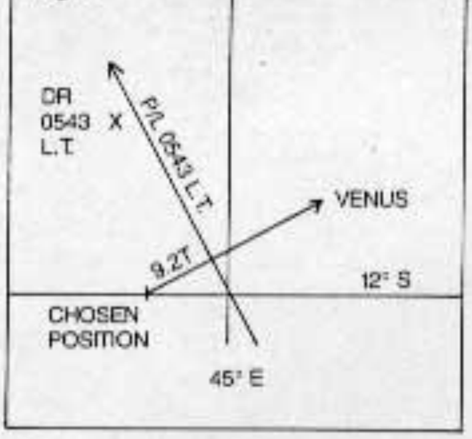


Fig 8 **Sight Book – Yacht "Ferret" – 2/9/93**

D.R. Lat	11° 35'S	GMT	02d02h43m07s
D.R. Long	44° 44'E	Ship's Time (GMT + 3h)	02d05h43m

…tant Altitude 21° 53' Index Error Nil Height of Eye 4.4 metres

…A	02d 02h		242° 23.7'	Sextant Altitude	21° 53.0'
…rement		43m07s	10° 46.8'	Index Error	- 0.0'
	02d 02h	43m07s	253° 10.5'	Observed Altitude	21° 53.0'
	v = -0.6		- 0.4'	Dip	- 3.7'
GHA	02d 02h	43m07s	253° 10.1'	Apparent Altitude	21° 49.5'
Chosen Longitude			E44° 49.9'	T. Corrn	- 2.4'
LHA			298° 00.0'		21° 47.1'
				Additional Corrn	+ 0.1'
Declination		02d02h	N18° 39.2'	True Altitude	21° 47.2'
	d = -0.6'		- 0.4'		
Declination		02d02h43m	N18° 38.8'		

LHA = 298° **Declination = 18°N** **Latitude = 12°S**

Tabulated Altitude	21° 52.0'		
"d" = - 22. Correction =	- 14.0'	Z	= 115°
Tabulated Altitude	21° 38.0'	Azimuth	= 180° - Z
Observed (True) Altitude	21° 47.2'	Azimuth	= 180° - 115°

Intercept 9.2' Towards Azimuth = 065° True

7.6.2 Venus on the Meridian

You are still in the Mozambique channel and expect to make a landfall in an area of strong but variable currents and unmarked shoals just before midday. You have already fixed your position at morning twilight with the aid of Venus and two stars but since then the current may have set you up to 20 miles off your track. The solution would appear to be to combine a sun sight with a sight of Venus on the meridian.

When Venus is a morning planet it is on your local meridian in the forenoon, when it is an evening planet it is on your meridian in the afternoon

Often considered to be in the realms of advanced navigation this problem is simple enough when broken down into its component parts. This involves, in the planning stage, establishing when Venus will be on your meridian, what its declination will be at that time and, as it is hard to spot with the naked eye, what its altitude should be.

Having completed these simple steps in advance it only remains to take the sextant altitude of Venus on the meridian and work it out the same way you would a latitude by meridian altitude of the sun.

1/ The time at which Venus is on the Greenwich meridian is listed in the daily pages of the nautical almanac. Convert your DR longitude into time and apply it by adding, if in west longitude, or subtracting, if in east longitude, to find when it shall be on your meridian.

2/ Establish the declination at this time in the normal fashion and. With the aid of a rough sketch on the plane of the rational horizon, apply it to your DR latitude. This will let you establish what the zenith distance and hence the true altitude of Venus should be when on the meridian.

3/ By establishing what the correction would be for this altitude and adding them to – rather than subtracting them from- the predicted true altitude ascertain what the sextant altitude should be.

4/ Five minutes or so before you expect Venus to be on your meridian set this altitude on the arc of your sextant, point in the appropriate direction (either north or south) , find Venus and take a meridian altitude.

5/ Immediately after you have done this take a sun sight. Reduce and plot the pair of them and there you have a a high quality mid morning fix unaffected by any unknown currents.

This may all seem a little bit involved but take the time to work through it. You may never feel the need to use it in anger but one day this knowledge may just get you out of a spot of bother.

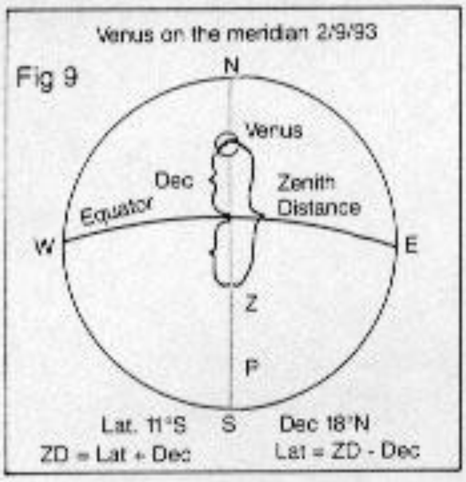


Fig 9

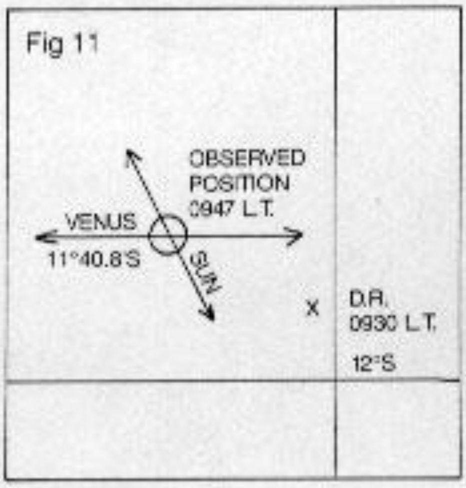


Fig 11

Fig 10 **Sight Book – Yacht "Ferret" – 2/9/93**

D.R. Latitude	11° 47' South	Approximate GMT	02d06h30m
D.R. Longitude	43° 57' East	Ship's Time (GMT + 3)	02d09h30m
Index Error	Nil	Height of Eye	4.4 metres

(1) Establishing the time of meridian passage

Meridian Passage Venus	09h51m GMT	(From the daily pages)
Longitude in time = (44° x 4 = 176 minutes)	02h56m	(E Longitude – subtract)
Time of local meridian passage	06h55m GMT	(09h55m Ship's Time)

(2) Calculating the declination of Venus when on the meridian

Declination	02d06h GMT	N18° 36.7'
d = - 0.6		- 0.5'
Declination	02d06h55m	N18° 36.2'

(3) Predicting the altitude of Venus when on the meridian (see sketch 9)

Declination		N18° 36.2'	
D.R. Latitude		S11° 47.0'	
Zenith Distance		30° 23.2'	(Zenith Distance = N Declination + S Latitude)
True Altitude		59° 36.8'	(True Altitude = 90° - Zenith Distance)
Aux Corrn	- 0.1' }		
Total Corrn	+ 0.6' }	= + 4.2'	(Reverse Name of Corrections, i.e. work backwards through the Altitude Correction Tables)
Dip	+ 3.6' }		
Index Error	Nil }		
Predicted Sextant Altitude		59° 41.0'	

(4) Taking the altitude and establishing the latitude

Sextant	59° 47.2'	(Venus on the Meridian)
Total Correction	- 4.2'	(from (3))
True Altitude	59° 43.0'	
Zenith Distance	30° 17.0'	(Zenith Distance = 90° - True Altitude)
Declination	N18° 36.2'	
Latitude	11° 40.8'	(Latitude = Zenith Distance - Declination) (See sketch 9)

(5) We shall assume you have reduced your simultaneous sun sight. You would now plot both your position lines on the plotting sheet.

7.7 Magnitude

You have been introduced to two new words this month, **twilight** which we shall deal with in detail next month, and **magnitude**. In navigation magnitude does not refer to size but is *a measure of brightness.* Astronomers group stars into six magnitudes ranging from the the brightest (those of the *first magnitude*) to the faintest (those of the *sixth magnitude)* .

We are only interested in those of the first two magnitudes, these are the only ones bright enough to be of use in navigation. The navigational stars are listed in the back of the almanac and also on the bookmark and each one has its magnitude listed against its name. Several stars are of greater brightness than the first magnitude and these are assigned a negative magnitude. For instance Sirius, the brightest of the stars, has a magnitude of –1.6.

The magnitude of the planets varies throughout the and as a result their magnitudes are listed at the top of the daily pages next to their names. With experience you will find that a knowledge of their magnitude is a good aid to identifying them.

INDEX TO SELECTED STARS, 1993

Name	No	Mag	SHA	Dec
			°	°
Acamar	7	3·1	315	S 40
Achernar	5	0·6	335	S 57
Acrux	30	1·1	173	S 63
Adhara	19	1·6	255	S 29
Aldebaran	10	1·1	291	N 16
Alioth	32	1·7	167	N 56
Alkaid	34	1·9	153	N 49
Al Na'ir	55	2·2	28	S 47
Alnilam	15	1·8	276	S 1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

No	Name	Mag	SHA	Dec
			°	°
1	*Alpheratz*	2·2	358	N 29
2	*Ankaa*	2·4	354	S 42
3	*Schedar*	2·5	350	N 57
4	*Diphda*	2·2	349	S 18
5	*Achernar*	0·6	336	S 57
6	*Hamal*	2·2	328	N 23
7	*Acamar*	3·1	315	S 40
8	*Menkar*	2·8	315	N 4
9	*Mirfak*	1·9	309	N 50
10	[illegible]	[illegible]	[illegible]	[illegible]

7.8 Help!

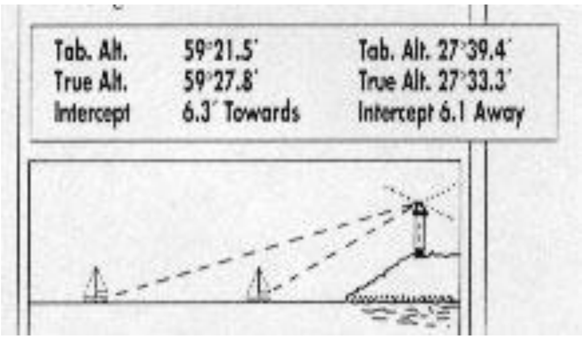
An area that is causing some confusion appears to concern the naming of the intercept when using the sight reduction tables. This is probably due in no small part to a small but vital error that crept into the example in the April issue. Remember that, using the lighthouse simile, the higher that the object of our attention (sun, star, moon or planet) is in the sky , that is the greater its altitude, the closer that we are to its geographical position.

Therefore it follows that

'**T**abulated altitude **T**iny - intercept **T**owards'

Write that on the inside front cover of your note book for ready reference.

Tabulated Altitude	59°21.5´	Tabulated Altitude	27°39.4´
True Altitude	59°27.8´	True Altitude	27°33.3´
Intercept	6.3´ **T**owards	Intercept	6.1´ **A**way



7.9 Part 7 – The Questions

Q 1. a)

In mid March Venus has a magnitude of - 4.5 while the magnitude of Saturn is + 0.9. Which is the brighter planet?

b)

Venus is visible throughout the night at certain times of the year. Is this true of false?

Q 2. a)

In mid February, 1993, the sextant altitude of Venus is 17°42´. Your sextant has an index error of 2.0´ on the arc and your height of eye is 3.9 metres. What is the true altitude?

b)

What is the Zenith Distance?

Q 3. a)

In January ,1993 the sextant altitude of Mars is 21° 19´. Your height of eye is 2.0 metres and your sextant has an index error of 1.5´ off the arc. What is the true altitude?

b)

What is the Zenith Distance?

Q4. a)

At 2100 GMT the GHA of Jupiter is 211°15.8´and the declination is 5° 11.2´ North. If, on this day, v = 1.8 and d = + 0.6 what will be the GHA and declination at 2130 GMT?

b)

At 0300 GMT the GHA of Venus is 75°12.0´ and the declination is 12° 17.0´ South. If v = - 2.0 and d = - 0.2 what will the GHA and declination be at 0330 GMT

Q 5.

You are sailing in the Coral Sea in March and at morning twilight on the 15th (local time) you take a sight of Jupiter and, immeadiately afterwards, a sight of the star Rigel Kent.

Your D.R. position is Latitude 12°15´ South, Longitude 152° 14´East. The sextant altitude of Jupiter was 31°43´, your height of eye is 11 feet and the index error on your sextant is 2.0 off the arc. You are keeping Eastern Australian Standard time on your yacht (10 hours ahead of GMT.). The ship's time when you took the sight was 15d05h00m. GMT at this time was 14d19h00m00s. (N.B. It is still the 14th of March at Greenwich).

a) What is the true altitude of Jupiter?

b) What is the GHA and the Declination of Jupiter at this time?

c) What is your chosen latitude and longitude and what LHA (Jupiter) will you enter the sight reduction tables with?

d) What is the intercept and what is the azimuth?

e) Immeadiately after taking the sight of Jupiter you took a sight of the star Rigel Kent. Having reduced and plotted this sight you find that Rigel Kent's azimuth is 198° and the position line that you have established runs through 12° 04´South, 152° 00´East.

What is your observed position at 0500 ship's time on the 15th?

Q 6. You are becalmed off the Moroccan coast on the 2nd of September, 1993 and are keeping G.M.T. aboard your yacht. Your D.R. position is 34° 15´ North, 12° 32´ West. Your height of eye is 3.9 metres and the index error on your sextant is nil. At what time will be on your meridian on this day? What will be its declination at this time?

Time of Mer Pass (Venus).... Declination.........

Assuming that you are actually in your d.r. latitude what will be the sextant altitude of Venus when it is on your meridian?

Sextant Altitude...........

When Venus is on your meridian you get a sextant altitude of 74° 15.0´, what is your observed latitude at this time?

Observed Latitude...........

Q 7

Continuing on from Question 6 let us assume that your observed latitude by meridian altitude of Venus was 34° 19´ North (which it wasn't!). One minute later, you took a sun sight which gave you a sextant altitude (lower limb) of 57° 53.9´. The GHA of the sun at this time was 340° 35´and the declination was 7° 49.8´North. Select a chosen position for use with the sight reduction tables.

Chosen latitude...... Chosen longitude.........

What LHA shall you enter the sight reduction tables with?

LHA..........

What is your intercept and what is the sun's azimuth at this time.

Intercept.......... Azimuth.......

b) having plotted both this position line and the observed latitude of 34° 19´ North what is your observed longitude?

Observed Longitude.

7.10Part 6 - The Answers

1. a)

Time of Local Apparent Noon. 1227 GMT.

b)

Latitude 47°15.3´

2. a)

Time of L.A.N. 0926 GMT.

b)

Time of L.A.N 1126 Ship's Time.

c)

Latitude. 21°59.3´North

3. a)

Time of L.A.N. 1137 GMT.

b)

Latitude 2° 27´North

4. a)

D.R. Latitude.34°23´S D.R. Longitude.104°13.5´ b)

Meridian Passage1209 GMT (exact)

c)

Time of Meridian Passage... 0512 GMT 1212 Ship's Time minute)

d)

Declination 2° 08´South

e)

Latitude.......... 33° 50.6´

n5. a)

Meridian Passage 1200   GMT

b)

L.A.N.   2156 GMT   1156 Ship's Time

c)

Latitude. 12°27.5´ South   Longitude..148°57´West

d)

Declination ....7°39.5´North

e)

Latitude............11° 54.9´South   Longitude............149° 32´West

8 Star Sights

Twinkle, Twinkle,
Little Star.
(how I wonders where I are)

By applying a little foresight to your navigation you will find that star sights are amongst the easiest and most versatile means of fixing your position when out of sight of land.

Over the last seven months you have acquired sufficient skills to enable you to find your way around the world without too much fuss. Unfortunately, apart from those occasions when you choose to use Venus on the meridian in conjunction with a sun sight, you are still dealing with running fixes which, as we have discussed before, are prone to error in areas of strong and unreliable currents. So while the knowledge that you have now acquired may be good enough for navigating the trackless wastes of the Southern Ocean or finding your way to and from Lord Howe Island you may well find them wanting when navigating amongst low lying coral atolls or making landfalls in areas of strong currents.

The ability to take star sights will get you out of this jam.

Prior to the 2nd World War it was neccesary for the navigator to be able to identify constellations and individual stars and then, having taken the altitudes, to reduce each star sight separately, and while some aspects of the calculations were common to each star the work involved was considerable, especially as each star sight had to be reduced by the Haversine method.
Thus the oft heard statement, “no stars this morning skipper, it was heavily overcast at twilight.”
Today we are fortunate in having Volume One of the Sight Reduction Tables for Air Navigation (Selected Stars) to assist us with this work. When using this volume no

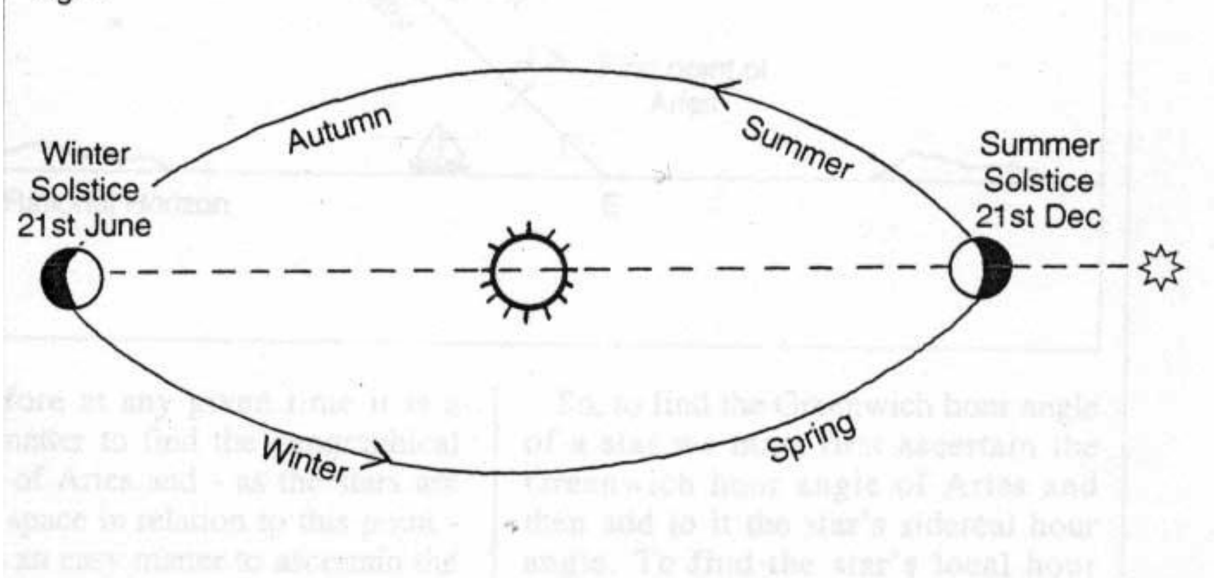
knowledge of constellations is required and the work involved in reducing the sights is simple in the extreme. You don't even need to raise your eyes above the horizon when taking the sights. You do however need to have some idea of the principles that lie behind the practice.

8.1 The Theory

Defining the geographical position of a star

The stars are such an immense distance from the earth that they appear to be fixed on the surface of the celestial sphere, each one maintaining its position relative to its neighbours and appearing to orbit the earth once every 23hours 56 minutes.

Fig. 1



A star that is overhead at midnight at the summer solstice shall be overhead at midday at the winter solstice.

Of all the stars in the heavens only 58 are of sufficient magnitude to be of use to the navigator but even with that small number to list the details of each of these stars in the nautical almanac would make it a very unwieldy volume. So, to get around this problem, we use a fixed point on the celestial equator known as the **First Point of Aries** as a reference point. The column in the daily pages headed 'Aries' gives us the Greenwich hour angle of this point (being on the celestial equator it has no declination) while it also has its own column in the 'increments' pages at the back of the almanac.

86 Fig 2a

UT (GMT)		ARIES		VENU	
		G.H.A.		G.H.A.	
d	h	°	′	°	′
25	00	213	01.3	210	43.8
	01	228	03.7	225	45.9
	02	243	06.2	240	47.9
	03	258	08.7	255	49.9
	04	273	11.1	270	51.9
	05	288	13.6	285	53.9
	06	303	16.1	300	56.0
	07	318	18.5	315	58.0
	08	333	21.0	331	00.0
S	09	348	23.5	346	02.0
U	10	3	25.9	1	04.0
N	11	18	28.4	16	06.0
D	12	33	30.8	31	08.0

Fig 2b

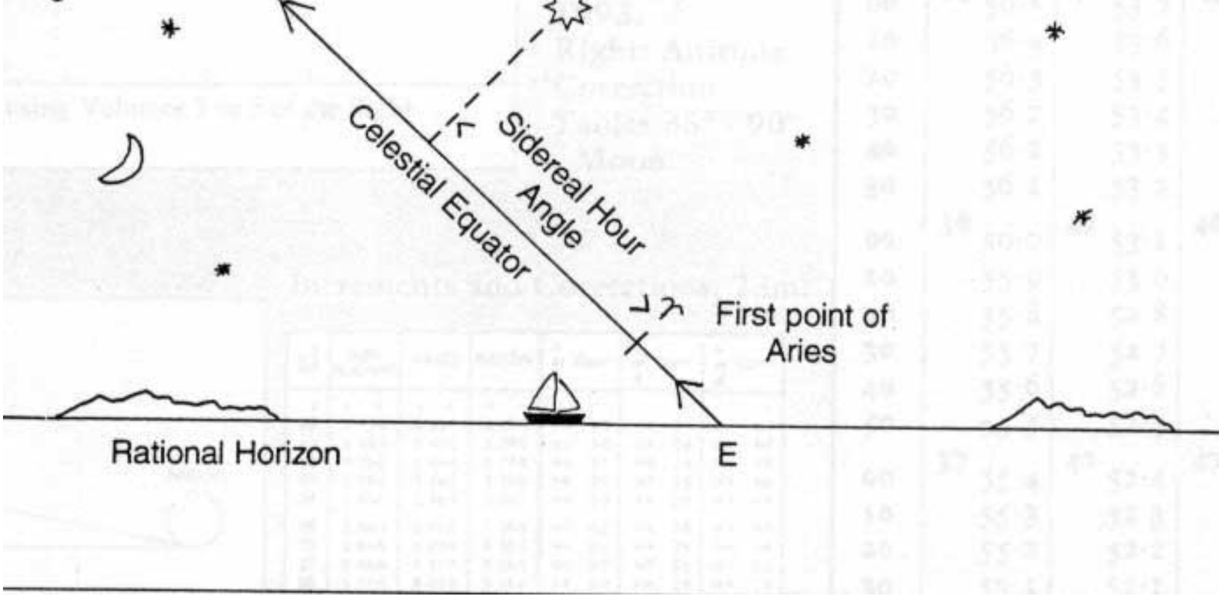
27m	SUN PLANETS	ARIES	MOON	v or d	Corrn	v or d	Corrn	v or d	Corrn
s	° ′	° ′	° ′	′	′	′	′	′	′
00	6 45·0	6 46·1	6 26·6	0·0	0·0	6·0	2·8	12·0	5·5
01	6 45·3	6 46·4	6 26·8	0·1	0·0	6·1	2·8	12·1	5·5
02	6 45·5	6 46·6	6 27·0	0·2	0·1	6·2	2·8	12·2	5·6
[illegible]	6 45·8	6 46·9	6 27·3	0·3	0·1	6·3	2·9	12·3	5·6
[illegible]	6 46·0	6 47·1	6 27·5	0·4	0·2	6·4	2·9	12·4	5·7
[illegible]	6 46·3	6 47·4	6 27·7	0·5	0·2	6·5	3·0	12·5	5·7
[illegible]	6 46·5	6 47·6	6 28·0	0·6	0·3	6·6	3·0	12·6	5·8
[illegible]	6 46·8	6 47·9	6 28·2	0·7	0·3	6·7	3·1	12·7	5·8
[illegible]	6 47·0	6 48·1	6 28·5	0·8	0·4	6·8	3·1	12·8	5·9
[illegible]	6 47·3	6 48·4	6 28·7	0·9	0·4	6·9	3·2	12·9	5·9
10	6 47·5	6 48·6	6 28·9	1·0	0·5	7·0	3·2	13·0	6·0
11	6 47·8	6 48·9	6 29·2	1·1	0·5	7·1	3·3	13·1	6·0
12	6 48·0	6 49·1	6 29·4	·2	0·6	7·2	3·3	13·2	6·1

Top and above: The Greenwich hour angle of the First Point of Aries is listed on the daily pages of the Almanac and a separate increments column is used.

Therefore at any given time it is a simple matter to find the geographical position of Aries and - as the stars are fixed in space in relation to this point - it is also an easy matter to ascertain the geographical position of any one of them.
The necessary details for each of the navigation stars also listed on the right hand side of the page. This consists of the declination of each star - which is constant and can be lifted directly from the page - and what is called the star's **sidereal hour angle (SHA).**

JRN +0.9		STARS		Fig 3
A.	Dec.	Name	S.H.A.	Dec.
	° ′		° ′	° ′
9.0	S13 03.8	Acamar	315 30.1	S40 19.9
1.3	03.7	Achernar	335 38.4	S57 16.1
3.6	03.7	Acrux	173 25.6	S63 04.0
5.9	· · 03.6	Adhara	255 24.5	S28 58.1
8.2	03.6	Aldebaran	291 07.0	N16 29.7
0.5	03.5			
2.8	S13 03.4	Alioth	166 33.3	N55 59.7
5.1	03.4	Alkaid	153 10.2	N49 20.7
7.4	03.3	Al Na'ir	28 02.7	S46 59.4
9.7	· · 03.3	Alnilam	276 01.9	S 1 12.5
2.0	03.2	Alphard	218 10.8	S 8 38.0
4.3	03.2			
6.5	S13 03.1	Alphecca	126 23.4	N26 44.0
8.8	03.1	Alpheratz	357 59.4	N29 03.1
1.1	03.0	Altair	62 22.9	N 8 50.9
3.4	· · 03.0	Ankaa	353 30.8	S42 20.4
5.7	02.9	Antares	112 44.4	S26 25.1
0	02.8			

Fig. 4



This hour angle is the angular distance between that particular star and Aries and remains constant as the star and Aries maintain their positions relative to each other. So, to find the Greenwich hour angle of a star we must first ascertain the Greenwich hour angle of Aries and then add to it the star's sidereal hour angle. To find the star's

local hour angle we just apply our longitude to the Gha * (star), adding it (if easterlylongitude) or subtracting it (if westerly longitude),
A simple enough procedure but if you are taking six stars twice a day for weeks on end you will soon tire of it, especially if, as was the case, you then have to reduce each sight by ‘longhand’ methods.

Fig.5a

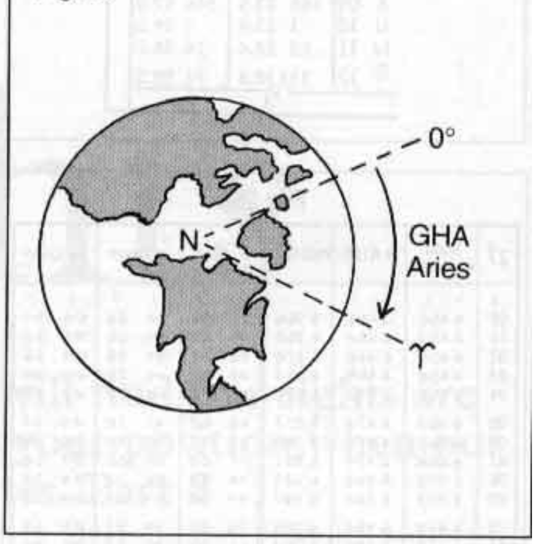


Fig. 5b

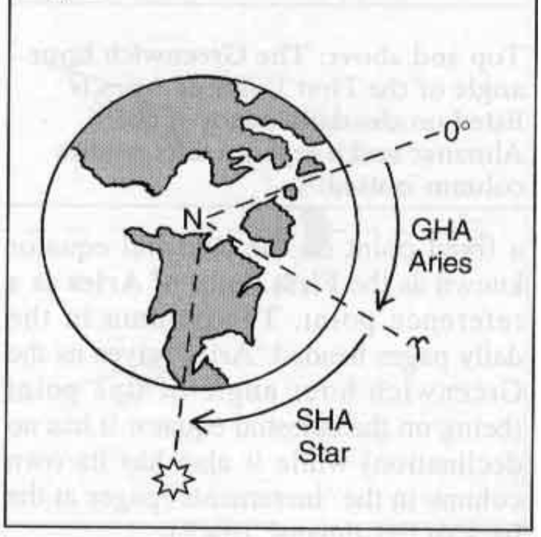
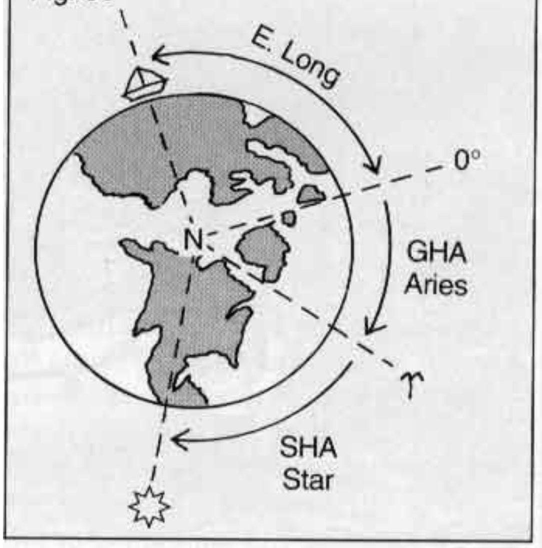


Fig. 5c



8.2 Stars in Practice

8.2.1 The planning

The taking of stars in conjunction with Volume One has to be tackled in several stages. Rule number one with stars is to do your preparation well in advance, leave it until a few minutes before sunset and your ‘stars’ are most certainly doomed to failure.

The first step, as ever, is to work out a D.R. position.

Then you must ascertain at what time you shall be taking your star sights.

To do this you must find out at what time **twilight** shall occur. Twilight is that period of half light when both stars and horizon are visible shortly before sunrise and shortly after sunset. There are several technical ways of defining twilight - astronomical, nautical or civil- and it is the latter which is best suited to our purposes being that time at which the sun is 6° below the horizon. This time varies with latitude and time of year and is listed, for an observer on the Greenwich meridian, in the daily pages of the almanac.

8.2.2 The execution

Let us assume that we are taking morning stars, we have a cloudless sky, the stars are there by their thousands but we have no visible horizon.

About 15 minutes before twilight lay your card under the appropriate LHA Aries in the sight reduction tables. By now the horizon should be starting to lighten and firm up in the east. Select a star in a general easterly direction and extract both its tabulated altitude and azimuth from the tables. Set this altitude on your sextant arc, step out on deck and point in the required direction. Sweep the horizon and the selected star should swim into view. The star you are looking for is normally far brighter than its neighbours so there should be little cause for confusion.

When the horizon is firm enough sit the star upon it, take the sight, and note the time. Slip below, or have your assistant note the time, the name of the star and its sextant altitude in your sight book. Check the time, adjust your LHA Aries if required, select a second star (it pays to work clockwise around the sky), set the altitude on the arc of your sextant, step on deck and repeat the procedure. Within ten minutes you should have at least three or four stars in your sight book.Read the log, go below, put on the kettle and make a second cup of tea.

In the evening you shall have a good horizon, you are now waiting for the stars to come out. So, as it shall be the first star to appear, select a bright 1st magnitude star which is somewhere to the east of you. Just repeat your morning procedure, if you have a semi-decent sextant the star shall appear in your sextant telescope long before you can spot it with your naked eye.

8.2.3 The Calculation

For the purpose of this exercise we shall assume that we have 4 stars in our book, this being the optimum number for any star session.

The first step is to correct each altitude. This involves simply applying the index error and height of eye correction and then applying the total correction. Note that like the planet correction it is always negative, being only a correction for refraction.
Now, taking one star at a time, use the exact GMT at which that sight was taken to calculate the GHA of Aries.
Using your DR longitude as a guide establish a chosen longitude for this particular sight and establish an LHA of Aries for this star.
Enter the Vol One with that LHA and lift out the Tabulated Altitude and Azimuth for that star.
Compare the True Altitude with the Tabulated altitude and establish the Intercept, remembering that Tabulated (altitude) Tiny (intercept) Towards.

Repeat this procedure for each of the sights that you have taken.

Now you may plot these position lines on your plotting sheet.
Taking one star at a time mark in the chosen longitude that you have used for that sight and then lay off the star's azimuth from this point. Then - taking care to apply it the correct way - mark in your intercept. All that now remains is to draw in the position line at right angles to the intercept. Repeat this procedure for each of the four stars that you have taken. You should, if you have done everthing correctly, now have a high quality fix on your plotting sheet.
A little mental interpolation is required to obtain the time in a particular latitude and then you simply apply your longitude in time.

Fig 6

	Lat.	Twilight Naut.	Twilight Civil	Sunrise	2
H.P.	°	h m	h m	h m	h
′	N 72	////	////	02 31	
56.1	N 70	////	00 52	02 59	
56.1	68	////	01 51	03 21	
56.1	66	////	02 24	03 37	04
56.1	64	00 46	02 48	03 51	04
56.1	62	01 38	03 06	04 02	05
56.2	60	02 08	03 21	04 12	05
56.2	N 58	02 30	03 34	04 20	05
56.2	56	02 48	03 45	04 28	06
56.2	54	03 02	03 54	04 34	06
56.3	52	03 14	04 03	04 40	06
56.3	50	03 25	04 10	04 46	06
56.3	45	03 46	04 25	04 57	06
56.3	N 40	04 03	04 38	05 07	07
56.3	35	04 16	04 48	05 15	07
56.4	30	04 27	04 57	05 22	07
56.4	20	04 44	05 11	05 34	08
56.4	N 10	04 58	05 23	05 45	08
56.4	0	05 08	05 33	05 54	08
56.5	S 10	05 18	05 43	06 04	08
56.5	20	05 26	05 52	06 14	09
56.5	30	05 33	06 01	06 26	09
56.5	35	05 37	06 06	06 32	09
56.5	40	05 40	06 12	06 40	10
56.6	45	05 44	06 18	06 49	10
56.6	S 50	05 47	06 25	06 59	10
56.6	52	05 49	06 28	07 04	10
56.6	54	05 50	06 32	07 09	11

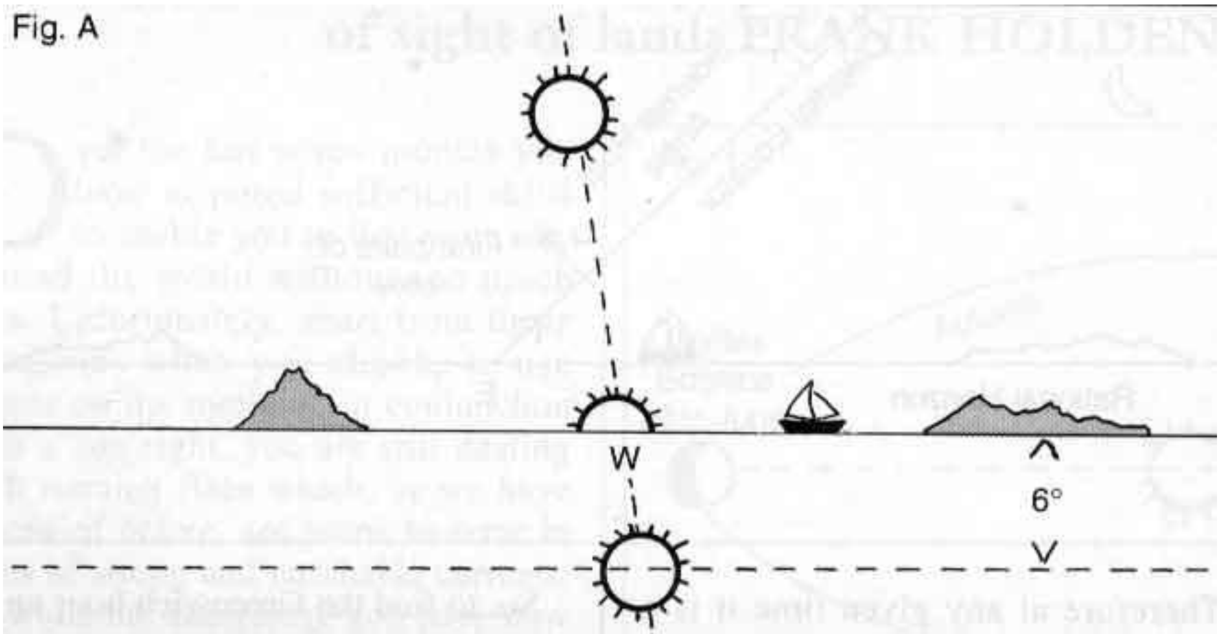
****

8.3 Twilight

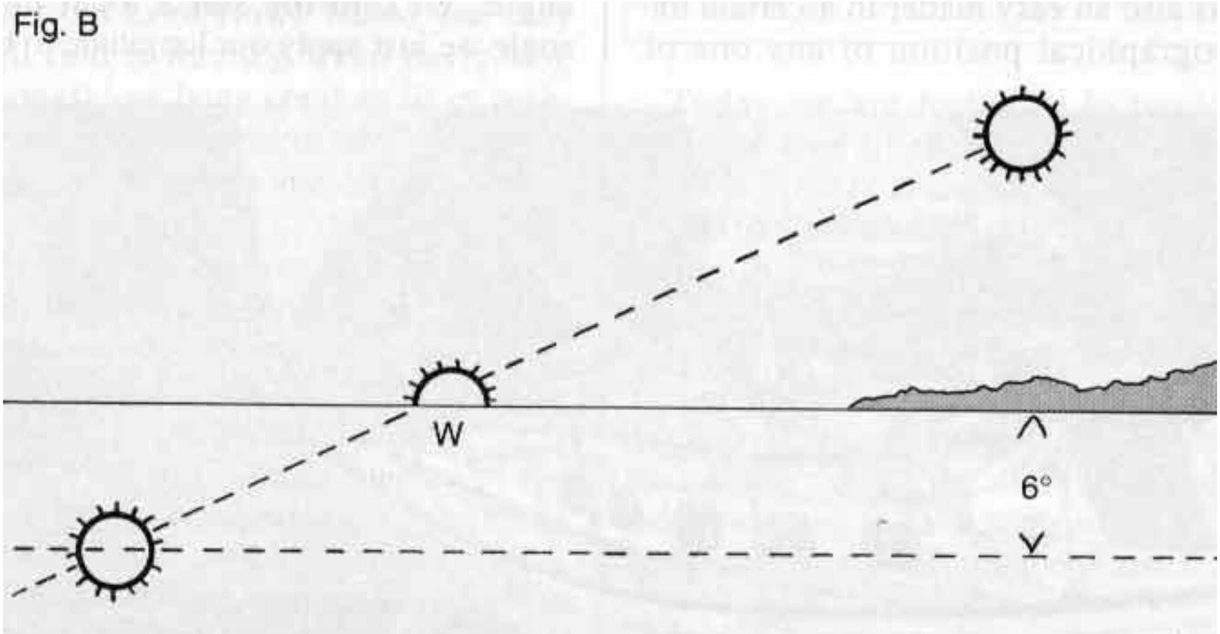
Twilight is that time of half light that occurs between sunset and 'total' darkness and between 'total' darkness and the dawn. Its duration varies in a given location with the seasons and on any given day the length of twilight varies with the latitude of the observer. This manifests itself as the very rapid change from daylight to darkness in the tropics and, at the other extreme, the twilight that lasts all night during mid-summer in the north of Scotland, for instance.

This difference is due to the angle at which the sun cuts the horizon as it sets or rises. As seen by an observer on the equator at the equinox, for example, the sun appears to drop vertically 'into' the sea while in the Tasmanian summer, to take a local example, it slips away at quite an angle and thus takes far longer to reach the critical 6° mark. Thus a star gazer in high latitudes will have far longer to potter away with his sight book. The tropical navigator, on the other hand, shall need to look sharp while taking stars.

Fig. A



On the equator the sun appears to drop vertically into the sea.



In high latitudes the sun slips below the horizon at quite an angle and longer twilights are the result

The exact time of twilight is not critical so mental interpolation should suffice as shown in this example.

D.R Latitude 33° South D.R. Long 121°30´East

Civil Twilight 30° S 1827
35° S 1831 Civil Twilight 33°S = 1829

Longitude in time = 121.5° x 4/60 =8h 06m

Twilight in 121°30´East = 18h29m - 8h06m = 10h23m gMT
If you are keeping time 8 hours ahead of GMT then
evening twilight shall be at 1823Local time.

You may note that the time of sunrise and sunset can be calculated in the same manner.

****

Having found out at what approximate time "stars" shall occur you may now calculate the local hour angle of Aries for this time.
Using the nearest whole number of degrees of latitude (i.e. your chose latitude) open your copy of Volume One to the pages covering this chosen latitude and run your finger down the page until you reach your LHA Aries.
To the right of this figure you will see 7 stars listed and underneath each one a column of tabulated altitudes (Hc) and a column of azimuths (Zn)

Fig 7

LAT 12°S

LHA ♈	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn
	♦ VEGA		ALTAIR		♦ FOMALHAUT		Peacock		RIGIL KENT.		♦ ANTARES		ARCTURUS	
270	38 30	009	55 31	054	19 24	117	37 18	156	29 08	205	64 13	233	26 30	299
271	38 39	008	56 18	053	20 16	117	37 42	156	28 43	206	63 26	234	25 39	298
272	38 47	007	57 04	052	21 09	117	38 05	157	28 17	206	62 39	235	24 47	298
273	38 54	006	57 50	051	22 01	117	38 28	157	27 52	206	61 51	235	23 55	298
274	38 59	005	58 35	049	22 53	117	38 50	158	27 26	206	61 02	236	23 03	297
275	39 04	004	59 19	048	23 45	117	39 12	158	26 59	207	60 13	237	22 10	297
276	39 08	003	60 03	047	24 37	117	39 33	159	26 33	207	59 24	238	21 18	296
277	39 11	002	60 45	045	25 29	117	39 54	160	26 06	207	58 34	238	20 25	296
278	39 13	001	61 26	044	26 21	117	40 14	160	25 39	207	57 44	239	19 32	296
279	39 13	000	62 06	042	27 13	117	40 34	161	25 12	208	56 53	240	18 39	295
280	39 13	359	62 45	041	28 06	117	40 53	161	24 45	208	56 03	240	17 46	295
281	39 12	358	63 23	039	28 58	117	41 12	162	24 18	208	55 12	241	16 53	295
282	39 09	357	63 59	037	29 50	117	41 30	162	23 50	208	54 20	241	16 00	294
283	39 06	356	64 34	036	30 42	118	41 47	163	23 22	208	53 29	241	15 06	294
284	39 01	355	65 08	034	31 34	118	42 04	164	22 54	208	52 37	242	14 12	294
	♦ DENEB		♦ FOMALHAUT		Peacock		RIGIL KENT.		♦ ANTARES		Rasalhague		VEGA	
285	28 20	020	32 26	118	42 20	164	22 26	209	51 45	242	57 35	319	38 56	354
286	28 40	019	33 18	118	42 36	165	21 58	209	50 53	243	56 55	317	38 49	353
287	28 59	019	34 10	118	42 51	166	21 30	209	50 01	243	56 15	316	38 42	352
288	29 17	018	35 02	118	43 05	166	21 01	209	49 09	243	55 34	315	38 34	351

Let us have a brief look at what we have found here. The stars whose names are written in upper case are those of the 1st magnitude while those in lower case are of the 2nd magnitude.
You will also note that three of the stars have a diamond ( ) alongside there names. These are the three stars which shall give you the best "cut" when laid out on your plotting sheet.
Also note that the azimuth (Zn) listed here is a true bearing of the star and needs no further treatment. You may like to compare this with the azimuth(Z) as listed in Volume Two of the sight reduction tables.

You now know what the LHA of Aries shall be at twilight but, unless you are exceptionally proficient your star session shall spread over at least 10 or 15 minutes so make yourself a little card. On this mark the time of twilight and the time at 4 minute increments before and after twilight, say 12 minutes before and 12 minutes after. Now as the LHA Aries increases at a rate of 1° every 4 minutes mark in also the LHA Aries for each of these times. As all is now in readiness lay your sight book, your copy of Volume One and your Nautical Almanac out on the chart table and settle down to have a nice cup of tea.

LAT 12°S

Fig 8

LHA ♈	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn
	◆ Alpheratz		Hamal		ALDEBARAN		◆ RIGEL		ACHERNAR		◆ FOMALHAUT		Enif	
0	48 53	003	42 54	041	16 10	069	12 48	096	41 03	163	67 08	217	49 45	301
1	48 56	001	43 32	040	17 05	068	13 46	096	41 20	163	66 32	219	48 55	301
2	48 56	000	44 10	039	17 59	068	14 45	095	41 36	164	65 54	220	48 04	300
	[illegible]	359	44 46	038	18 54	068	15 43	095	41 52	165	65 16	222	47 13	299
			[illegible]	037	19 48	067	16 41	095	42 07	165	64 36	223	46 22	298
5	48 50	356	[illegible]			[illegible]	17 40	[illegible]	42 22	166	63 56	224	45 30	298
6	48 46	355	46 32	035	[illegible]			[illegible]	42 36	167	63 15	225	44 38	297
7	48 39	353	47 06	034	22 30	066	[illegible]			[illegible]	62 32	227	43 45	296
8	48 32	352	47 38	033	23 23	066	20 35	094	[illegible]			[illegible]	42 53	296
9	48 23	351	48 10	032	24 17	066	21 34	094	43 14	169	[illegible]			[illegible]
10	48 13	350	48 41	031	25 10	065	22 32	094	43 25	169	60 21	230	41 07	[illegible]
11	48 02	348	49 10	030	26 03	065	23 31	094	43 35	170	59 36	230	40 13	294
12	47 49	347	49 39	029	26 56	064	24 30	094	43 45	171	58 51	231	39 19	294
13	47 36	346	50 06	027	27 49	064	25 28	093	43 54	171	58 05	232	38 26	293
	CAPELLA		POLLUX		◆ SIRIUS		CANOPUS		◆ ACHERNAR		Diphda		◆ Hamal	
60	29 31	015	22 27	053	49 51	102	40 11	152	37 13	203	42 16	256	45 03	322
61	29 46	014	23 13	052	50 48	102	40 38	153	36 50	204	41 19	256	44 26	321
62	30 00	014	24 00	052	51 46	102	41 05	153	36 26	204	40 22	256	43 49	320
63	30 14	013	24 46	051	52 43	102	41 31	154	36 02	205	39 25	256	43 11	319
64	30 26	012	25 31	051	53 41	102	41 56	154	35 37	205	38 28	256	42 32	318
65	30 38	011	26 16	050	54 38	102	42 21	155	35 12	206	37 31	256	41 53	317
66	30 49	011	27 01	050	55 35	102	42 46	156	34 46	206	36 33	256	41 13	317
67	31 00	010	27 46	049	56 33	102	43 10	156	34 21	206	35 36	256	40 32	316
68	31 09	009	28 30	049	57 30	102	43 33	157	33 54	207	34 39	256	39 51	315
69	31 18	008	29 14	048	58 27	102	43 56	158	33 28	207	33 42	256	39 09	314
70	31 26	007	29 57	047	59 25	103	44 18	158	33 01	207	32 45	256	38 27	313
71	31 33	007	30 40	047	60 22	103	44 39	159	32 34	208	31 48	256	37 44	313
72	31 39	006	31 23	046	61 19	103	45 00	160	32 06	208	30 51	256	37 01	312
73	31 45	005	32 05	046	62 16	103	45 20	160	31 38	208	29 55	256	36 17	311
74	31 50	004	32 46	045	63 14	103	45 40	161	31 10	209	28 58	256	35 33	311

Twilight

L.T.	0500	0504	0508	0512	0516
LHA ♈	065°	066°	067°	068°	069°

8.4 The Worked Example

On passage from Geraldton to the Seychelles the Ferret shall be in about 12°South, 68 1/2° East at sunrise on the 2nd September, 1993. We are keeping ship's time which is 4 hours ahead of GMT. Your index error is 2´ off the arc and your height of eye is 4.1 metres.

From the daily pages of the almanac we can establish that civil twilight in this latitude shall be at 0542 GMT for an observer on the Greenwich meridian. In our longitude it shall be some 4hours 34 minutes earlier and shall occur at 02d 01h 08m GMT. Using a chosen longitude of 68° 47.9´ East we can see that the LHA Aries at this time shall be 067°.

The next step is to fill in our card and opening the Sight Reduction Tables to our latitude of 12° (Fig 8) place it under the LHA of 067°. You can now see which stars you shall be using this morning.

The horizon is bright enough at 0500 local time to take our first sight of Veus and you can see that it shall be bearing 102° with an approximate altitude of 54° 38´. You get an altidude of Sirius at 0100 GMT precisely and sights of Canopus, Achernar and Hamal follow within the next ten minutes. As soon as you have taken the last altitude you read the log.

It is now simply a matter of reducing each sight in turn by
a) correcting the altitude.
b) working out an LHA at the time of taking the sight. (you shall have to use a different chosen longitude for each sight)
c) extracting the tabulated altitude (Hc) and azimuth (Zn) for this LHA
d) establishing an intercept and laying it off on the chart.

You should now have the equivalent of a 4 bearing fix on your plotting sheet. In the example you can see that the position line for Canopus is well out so as we would appear to have either used the wrong star or made an error in reading either the time or our sextant we shall ignore it.

THE WORKED EXAMPLE (see fig 8)

Sight Book – Yacht Ferret – 2/9/93

(The planning)

D.R. Lat	12°S	Index Error	2' off the arc
D.R. Long	68 1/2° E	Height of Eye	4.1 metres
Ships Time = GMT + 4h 00m			

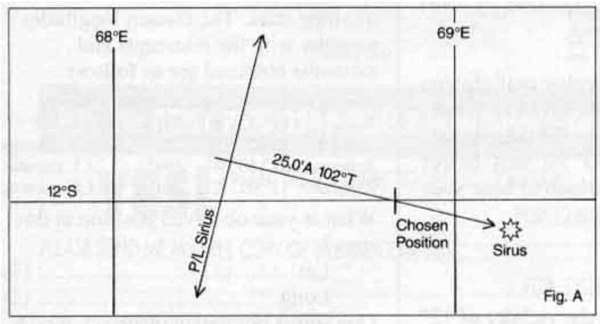
Twilight 10°S	0541 GMT		
Twilight 20°S	0546 GMT	Twilight 12°S	05h42m GMT
Longitude in Time (68 1/2° x 4 = 274 minutes)			-4h34m
Twilight at observer's position			01h08m GMT
			05h08m Ship's Time

GHA Aries	02d01h	356°11.8'
Increment	08m	2°00.3'
GHA Aries	02d01h08m	358°12.1'
Chosen Longitude		68°47.9 East
		427°00.0'
		-360°
LHA Aries	02d01h08m	067°

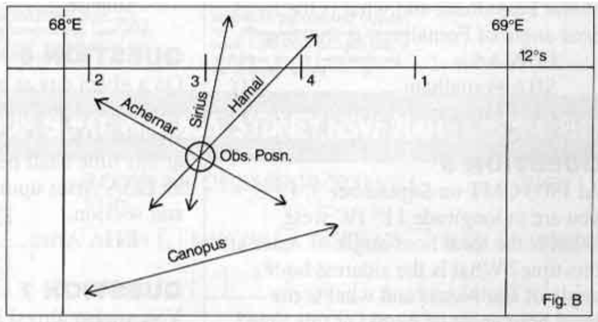
(The execution)

Star	1. Sirius	2. Canopus	3. Achernar	4. Hamal
Sext. Alt.	54°15.3'	42°59.6'	34°59.0'	40°36.7'
I.E.	+2.0'	+2.0'	+2.0'	+2.0'
	54°17.3'	43°01.6'	35°01.0'	40°38.7'
Dip	-3.6'	-3.6'	-3.6'	-3.6'
	54°13.7'	42°58.0'	34°57.4'	40°35.1'
T. Corrn	-0.7'	-1.0'	-1.4'	-1.1'
True Altitude	54°13.0'	42°57.0'	34°56.0'	40°34.0'
Time (GMT) 02d	01h00m00s	01h03m00s	01h06m00s	01h09m00s
GHA Aries	356°11.8'	356°11.8'	356°11.8'	356°11.8'
Increment	00.0'	0°45.1'	1°30.2'	2°15.4'
GHA Aries	356°11.8'	356°56.9'	357°42.0'	358°27.2'
Chosen Long	68°48.2'	68°03.1'	68°18.0'	68°32.8'
LHA Aries	65°	65°	66°	67°
True Altitude	54°13.0'	42°57.0'	34°56.0'	40°34.0'
Tab Altitude (Hc)	54°38.0'	42°21.0'	34°46.0'	40°32.0'
Intercept	25.0' A	36.0' T	10.0' T	2.0' T
Azimuth (Zn)	102°	155°	206°	316°

Observed Position @ 0509 Ship's Time Lat 12°11'S Long 068°20'E
Log @ 0509 Ship's Time 1237 miles



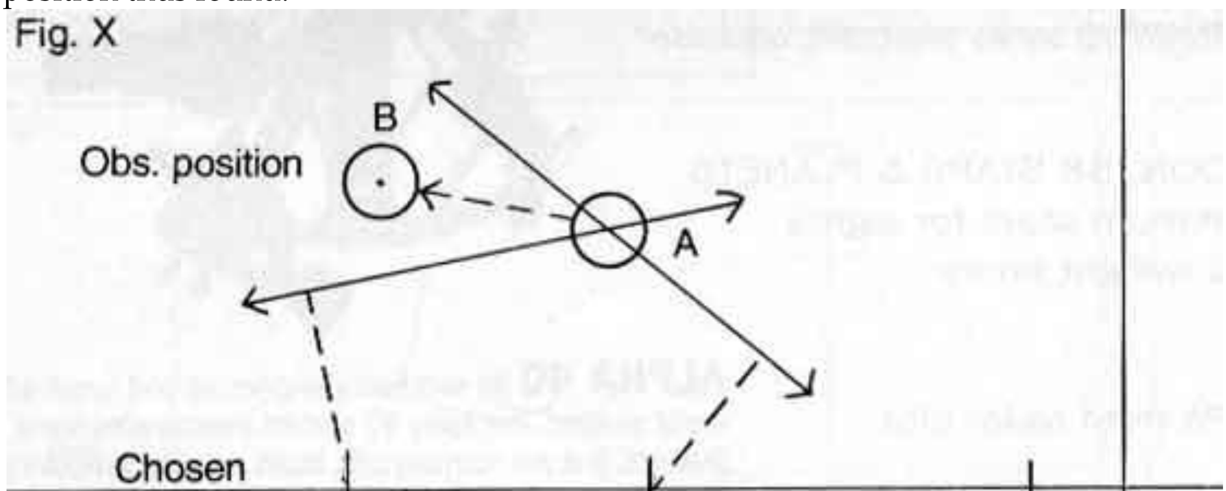
Our first star is plotted in the normal way.



All four stars on the plotting sheet. The chosen positions are numbered consecutively.

8.5 Precession and Nutation

In a perfect universe the SHA and declination of the stars would remain fixed forever. Unfortunately, while the changes are small enough to be ignored on a daily basis, there are indeed changes even if they only amount to 1´ per year. The first of these, precession, is due to the stars appearing to creep slowly across the heavens over the years. The other, nutation, is due to the earth wobbling ever so slightly on its axis in the same manner that a spinning top is seen to wobble as it slows down.
There is a table of corrections which allows for their combined effects in the back of the Sight Reduction tables. If you are using the latest edition of Volume One for the 1995 Epoch no corrections are required for either 1994 or 1995. However, towards the end of the life of this edition the correction can amount to as much as 4´.
The correction may be applied to each position line in turn but an easier method is to complete the plotting of all the stars and then apply the correction in one go to the position thus found.



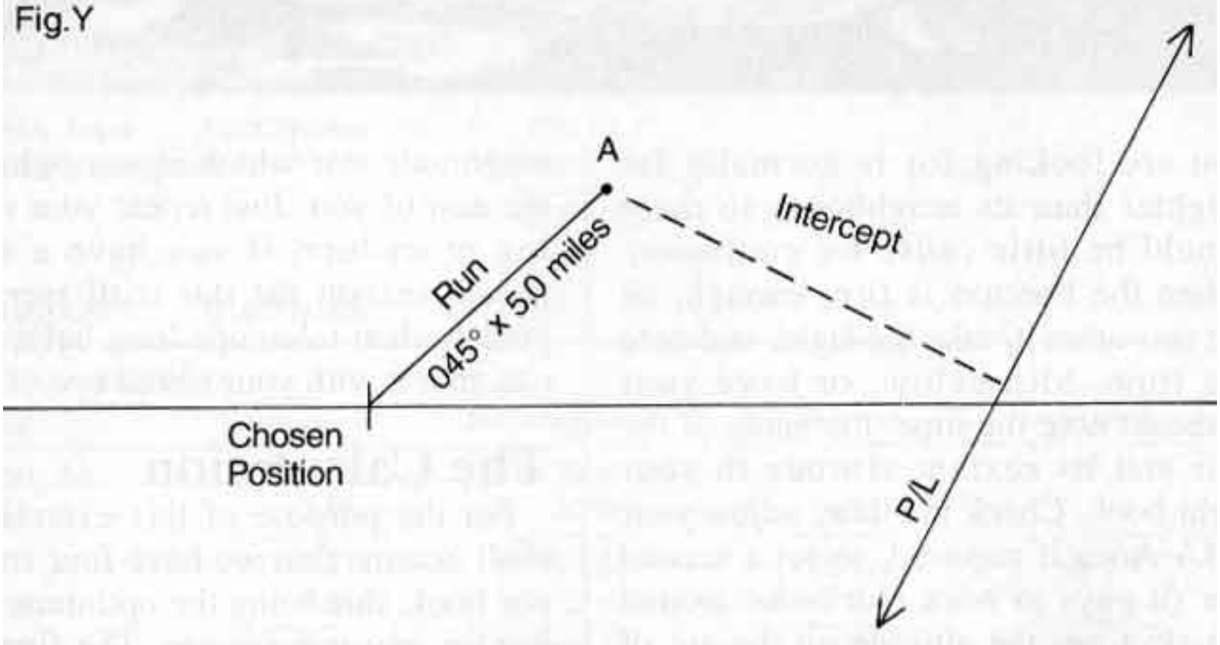
The correction for precession and nutation is applied after plotting the stars on the sheet. This effectively shifts the observed position from A to B

8.6 Applying the run

If your yacht is being sailed hard and your stars have taken, say, 20 minutes to take then you will have covered a measurable distance between taking the first one and the last one. To allow for this run, without our plot ending up looking like a rat's nest, each chosen position should be advanced in the direction of our course a distance equal to the run up to the last star taken. Lets say that we are steering 045° True at 15 knots (!) and twenty minutes have elapsed between the first and last sight. You simply shift the chosen position for the first star some 5 miles in an 045° direction and then lay off the intercept from the position so found.
Fortunately the Ferret does not travel at such speeds and we spend no more than 10 minutes taking our stars. Therefore we shall ignore the run as it shall never exceed one mile!

In practice the decision whether to allow for run or not shall be up to you, the navigator.

Fig.Y



After applying the run the intercept is laid off from position A

8.7 The Three Volumes of Sight Reduction Tables

This month we have been working with Volume One of the Sight Reduction Tables. A new edition of this volume is issued every 5 years and is good for 9 years. The latest edition is for epoch 1995 and will last you until the end of 1999.
Volumes Two and Three of the Sight Reduction Tables will, on the other hand ,last you indefinately. Designed primarily for use with the sun, moon and planets they only permit you to use bodies with declinations of under 28°. Volume Two can be used in latitudes out to 40° and it is only if you plan to sail in higher latitudes that you need purchase a copy of Volume Three which covers the latitude range from 39° to 89°.

fin

9 Azimuths, Polaris and the moon

We have now covered all of the heavenly bodies required for day to day navigation. However there remain two bodies which are of use to the navigator, even if only occasionally.

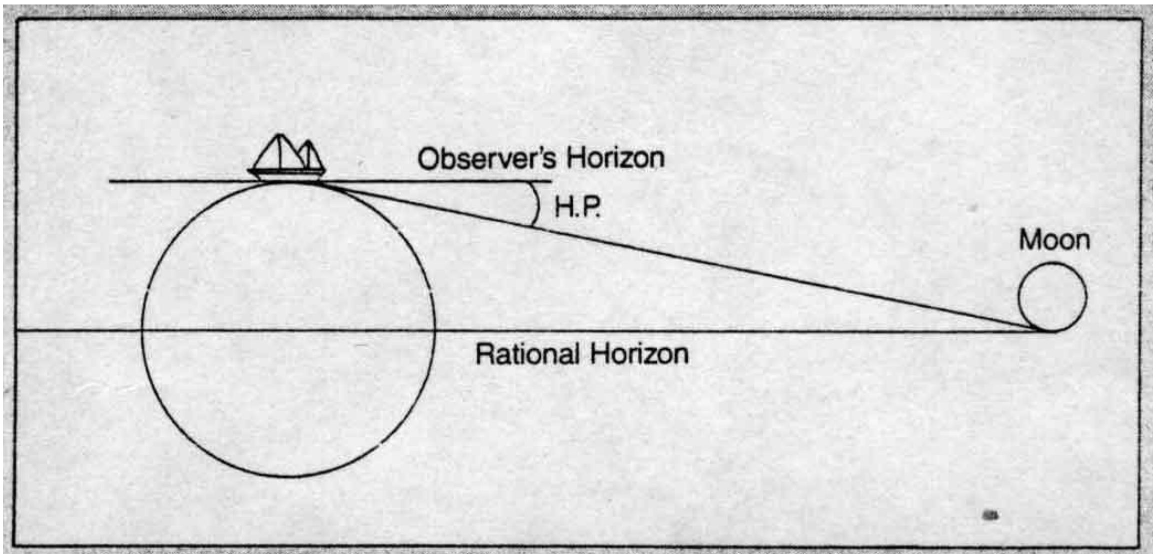
The first of them, the moon, is probably the most infrequently used of all. The reason for this is that , although the actual reduction of a lunar sight is no different to reducing a sun or planet sight and utilises either Volume 2 or 3 of the *Sight Reduction Tables for Air Navigation,* the preliminary work involved in correcting the altitude and establishing the LHA and declination of the moon is more complex and is prone to error if sufficient care is not taken.

The ability to take lunar sights may, however, come in handy for the very same reasons Venus is useful in daylight hours. There may come a time when we are able to get a good fix on our position by taking simultaneous sun and moon sights when approaching a low lying and dangerous coast. At other times the moon may be all that is visible at twilight through a thin veil of cloud.

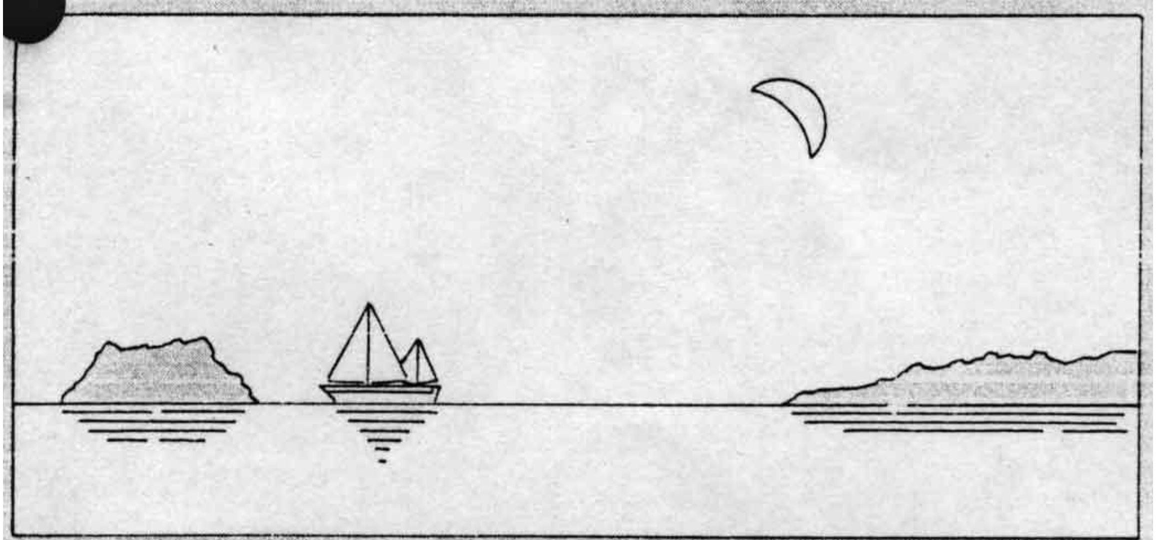
The reason why lunar sights are more complex is due, in the main, to the moon's relative proximity to the earth. Now this closeness to the earth, combined with the fact that the moon's orbit is an ellipse, means that the hourly *rate of change* of the moon's GHA varies considerably over the lunar month, as does its declination. So, while it is a simple matter to lift the GHA and declination from the almanac for a whole hour, you invariably have to apply large 'v' and 'd' corrections for increments of an hour.

The application of these corrections is not new to us – we have already seen how to apply them when working with the planets- but with the moon they are of far greater magnitude and a simple mistake in applying them can result in an error in our position of more than 30 miles.

Completely new to us, however, are the corrections we have to apply to the moon's observed altitude – after we have corrected the sextant altitude for index error and our height of eye – to obtain a true altitude. Because it is so close to the earth the amount of parallax associated with the moon is considerable. You may recall that with the sun parallax has a maximum value of 0.15´ at 0˚ altitude decreasing to zero at 90˚ altitude. With the moon, its parallax at 0˚ altitude (known as its *horizontal parallax* or HP) is a whopping 50´ and this amount varies on a daily basis as the moon's distance from earth either increases or decreases.



The proximity of the moon means horizontal parallax is considerable.



It is often only possible to obtain an altitude of the moon's upper limb.

This HP is listed for every hour on the daily pages of the almanac along with an hourly ‘v’ and ‘d’ correction and the moon actually has two full pages of corrections given over to it in the back of the almanac for the correction of its altitude. These corrections are total corrections and are applied to the apparent altitude i.e. the sextant altitude which has already been corrected for index error and dip. The method of using this table is fully described in the almanac but we shall run over it here anyway.

WORKED EXAMPLE 1

You have taken a moon sight at 05h23m07s GMT on September 2, 1993. The sextant altitude of the moon’s lower limb (L) is 37° 19.3´, your height of eye is 3.3m and your index error is nil. What is the true altitude of the moon and what is the GHA and declination of the moon at this time?

Sight Book – Yacht ‘Ferret’ – 2/9/93

GHA (Moon)	02d05h	65°43.0'	v = 15.8	d = 11.1		HP = 54.1
	23m07s	5°31.0'				
GHA (Moon)		71°14.0'	Declination	02d05h		1°13.6' N
‘v’ Correction		6.2'	‘d’ Correction		+	4.3'
GHA (Moon)	02d05h23m07s	71°20.2'	Declination	02d05h23m		1°17.9' N

Sextant Altitude	37°19.3'
Index Error	NIL
Observed Altitude	37°19.3'
Dip	-3.2'
Apparent Altitude	37°16.1'
Total Correction	+55.2'
	38°11.3'
HP Adjustment (L)	1.2'
True Altitude	38°12.5'

The sight may now be reduced in the normal way using Volumes 2 or 3 of the Sight Reduction Tables for Air Navigation.

Having taken a sight and applied index error and dip to the sextant altitude the next task is to extract the HP for the hour (GMT) at which you have taken the sight. You then go to the table of corrections and - entering the table with apparent altitude as an argument - lift out the main part of the correction that is then added to the apparent altitude. Then, still working in the same column and using HP as an argument lift out the secondary correction: you also add this to your apparent altitude. Make sure that you take it from either the upper (U) or lower (L) limb column as required. If you happen to be using the upper limb, which is not uncommon with moon sights, you now have to subtract 30´ from the altitude so found.

As you will have noticed while inspecting the table quite a bit of interpolation is required in this operation and you could have knocked over half a dozen stars in the time taken to reduce one moon sight. This is one of the reasons moon sights are given a wide berth by most navigators.

Extract from Nautical Almanac September 2nd 1993

UT (GMT)	SUN		MOON				
	G.H.A.	Dec.	G.H.A.	v	Dec.	d	H.P.
d h	° ′	° ′	° ′	′	° ′	′	′
2 00	180 03.0	N 7 59.5	352 48.7	15.8	N 0 18.0	11.1	54.1
01	195 03.2	58.6	7 23.5	15.9	0 29.1	11.1	54.1
02	210 03.4	57.7	21 58.4	15.8	0 40.2	11.2	54.1
03	225 03.6	. . 56.7	36 33.2	15.9	0 51.4	11.1	54.1
04	240 03.8	55.8	51 08.1	15.9	1 02.5	11.1	54.1
05	255 04.0	54.9	65 43.0	15.8	1 13.6	11.1	54.1
06	270 04.2	N 7 54.0	80 17.8	15.9	N 1 24.7	11.1	54.1
07	285 04.4	53.1	94 52.7	15.9	1 35.8	11.1	54.1
T 08	300 04.6	52.2	109 27.6	15.9	1 46.9	11.1	54.1
H 09	315 04.8	. . 51.3	124 02.5	15.8	1 58.0	11.0	54.1
U 10	330 05.0	50.4	138 37.3	15.9	2 09.0	11.1	54.1
R 11	345 05.2	49.4	153 12.2	15.9	2 20.1	11.0	54.1
S 12	0 05.4	N 7 48.5	167 47.1	15.9	N 2 31.1	11.1	54.1
D 13	15 05.6	47.6	182 22.0	15.8	2 42.2	11.0	54.1
A 14	30 05.8	46.7	196 56.8	15.9	2 53.2	11.0	54.1
Y 15	45 06.0	. . 45.8	211 31.7	15.9	3 04.2	11.0	54.1
16	60 06.2	44.9	226 06.6	15.8	3 15.2	11.0	54.0
17	75 06.4	44.0	240 41.4	15.9	3 26.2	10.9	54.0
18	90 06.6	N 7 43.0	255 16.3	15.9	N 3 37.1	11.0	54.0
19	105 06.8	42.1	269 51.2	15.8	3 48.1	10.9	54.0
20	120 07.0	41.2	284 26.0	15.8	3 59.0	10.9	54.0
21	135 07.2	. . 40.3	299 00.8	15.9	4 09.9	10.9	54.0
22	150 07.4	39.4	313 35.7	15.8	4 20.8	10.8	54.0
23	165 07.6	38.5	328 10.5	15.8	4 31.6	10.9	54.0

Altitude Correction Tables 35º-90º- Moon.

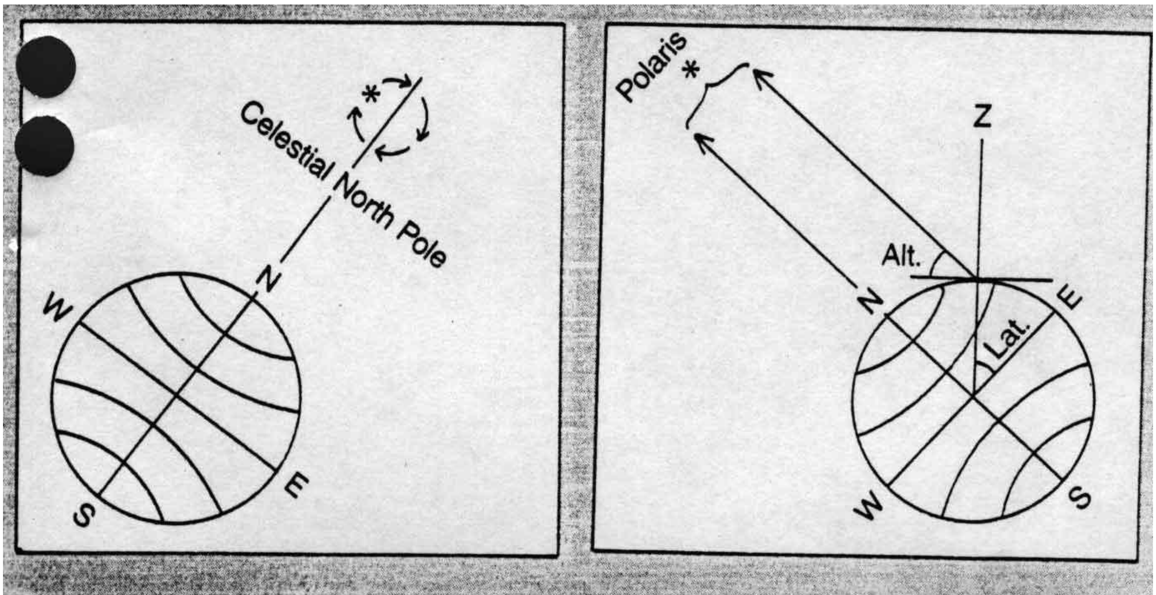
App. Alt.	35°–39° Corr^n	40°–44° Corr^n	45°–49° Corr^n
′	° ′	° ′	° ′
00	35 56.5	40 53.7	45 50.5
10	56.4	53.6	50.4
20	56.3	53.5	50.2
30	56.2	53.4	50.1
40	56.2	53.3	50.0
50	56.1	53.2	49.9
00	36 56.0	41 53.1	46 49.8
10	55.9	53.0	49.7
20	55.8	52.8	49.5
30	55.7	52.7	49.4
40	55.6	52.6	49.3
50	55.5	52.5	49.2
00	37 55.4	42 52.4	47 49.1
10	55.3	52.3	49.0
20	55.2	52.2	48.8
30	55.1	52.1	48.7
40	55.0	52.0	48.6
50	55.0	51.9	48.5
00	38 54.9	43 51.8	48 48.4
10	54.8	51.7	48.2
20	54.7	51.6	48.1
30	54.6	51.5	48.0
40	54.5	51.4	47.9
50	54.4	51.2	47.8
00	39 54.3	44 51.1	49 47.6
10	54.2	51.0	47.5
20	54.1	50.9	47.4
30	54.0	50.8	47.3
40	53.9	50.7	47.2
50	53.8	50.6	47.0

H.P.	L	U	L	U	L	U
′	′	′	′	′	′	′
54.0	1.1	1.7	1.3	1.9	1.5	2.1
54.3	1.4	1.8	1.6	2.0	1.8	2.2
54.6	1.7	2.0	1.9	2.2	2.1	2.4
54.9	2.0	2.2	2.2	2.3	2.3	2.5
55.2	2.3	2.3	2.5	2.4	2.6	2.6
55.5	2.7	2.5	2.8	2.6	2.9	2.7
55.8	3.0	2.6	3.1	2.7	3.2	2.8
56.1	3.3	2.8	3.4	2.9	3.5	3.0
56.4	3.6	2.9	3.7	3.0	3.8	3.1
56.7	3.9	3.1	4.0	3.1	4.1	3.2
57.0	4.3	3.2	4.3	3.3	4.3	3.3

Increments and Corrections, 23m

23^m	SUN PLANETS	ARIES	MOON	v or Corr^n d		v or Corr^n d		v or Corr^n d	
s	° ′	° ′	° ′	′	′	′	′	′	′
00	5 45·0	5 45·9	5 29·3	0·0	0·0	6·0	2·4	12·0	4·7
01	5 45·3	5 46·2	5 29·5	0·1	0·0	6·1	2·4	12·1	4·7
02	5 45·5	5 46·4	5 29·8	0·2	0·1	6·2	2·4	12·2	4·8
03	5 45·8	5 46·7	5 30·0	0·3	0·1	6·3	2·5	12·3	4·8
04	5 46·0	5 46·9	5 30·2	0·4	0·2	6·4	2·5	12·4	4·9
05	5 46·3	5 47·2	5 30·5	0·5	0·2	6·5	2·5	12·5	4·9
06	5 46·5	5 47·4	5 30·7	0·6	0·2	6·6	2·6	12·6	4·9
07	5 46·8	5 47·7	5 31·0	0·7	0·3	6·7	2·6	12·7	5·0
08	5 47·0	5 48·0	5 31·2	0·8	0·3	6·8	2·7	12·8	5·0
09	5 47·3	5 48·2	5 31·4	0·9	0·4	6·9	2·7	12·9	5·1
10	5 47·5	5 48·5	5 31·7	1·0	0·4	7·0	2·7	13·0	5·1
11	5 47·8	5 48·7	5 31·9	1·1	0·4	7·1	2·8	13·1	5·1
12	5 48·0	5 49·0	5 32·1	1·2	0·5	7·2	2·8	13·2	5·2
13	5 48·3	5 49·2	5 32·4	1·3	0·5	7·3	2·9	13·3	5·2
14	5 48·5	5 49·5	5 32·6	1·4	0·5	7·4	2·9	13·4	5·2
15	5 48·8	5 49·7	5 32·9	1·5	0·6	7·5	2·9	13·5	5·3
16	5 49·0	5 50·0	5 33·1	1·6	0·6	7·6	3·0	13·6	5·3
17	5 49·3	5 50·2	5 33·3	1·7	0·7	7·7	3·0	13·7	5·4
18	5 49·5	5 50·5	5 33·6	1·8	0·7	7·8	3·1	13·8	5·4
19	5 49·8	5 50·7	5 33·8	1·9	0·7	7·9	3·1	13·9	5·4
20	5 50·0	5 51·0	5 34·1	2·0	0·8	8·0	3·1	14·0	5·5
21	5 50·3	5 51·2	5 34·3	2·1	0·8	8·1	3·2	14·1	5·5
22	5 50·5	5 51·5	5 34·5	2·2	0·9	8·2	3·2	14·2	5·6
23	5 50·8	5 51·7	5 34·8	2·3	0·9	8·3	3·3	14·3	5·6
24	5 51·0	5 52·0	5 35·0	2·4	0·9	8·4	3·3	14·4	5·6
25	5 51·3	5 52·2	5 35·2	2·5	1·0	8·5	3·3	14·5	5·7
26	5 51·5	5 52·5	5 35·5	2·6	1·0	8·6	3·4	14·6	5·7
27	5 51·8	5 52·7	5 35·7	2·7	1·1	8·7	3·4	14·7	5·8
28	5 52·0	5 53·0	5 36·0	2·8	1·1	8·8	3·4	14·8	5·8
29	5 52·3	5 53·2	5 36·2	2·9	1·1	8·9	3·5	14·9	5·8
30	5 52·5	5 53·5	5 36·4	3·0	1·2	9·0	3·5	15·0	5·9
31	5 52·8	5 53·7	5 36·7	3·1	1·2	9·1	3·6	15·1	5·9
32	5 53·0	5 54·0	5 36·9	3·2	1·3	9·2	3·6	15·2	6·0
33	5 53·3	5 54·2	5 37·2	3·3	1·3	9·3	3·6	15·3	6·0
34	5 53·5	5 54·5	5 37·4	3·4	1·3	9·4	3·7	15·4	6·0
35	5 53·8	5 54·7	5 37·6	3·5	1·4	9·5	3·7	15·5	6·1
36	5 54·0	5 55·0	5 37·9	3·6	1·4	9·6	3·8	15·6	6·1
37	5 54·3	5 55·2	5 38·1	3·7	1·4	9·7	3·8	15·7	6·1
38	5 54·5	5 55·5	5 38·4	3·8	1·5	9·8	3·8	15·8	6·2
39	5 54·8	5 55·7	5 38·6	3·9	1·5	9·9	3·9	15·9	6·2
40	5 55·0	5 56·0	5 38·8	4·0	1·6	10·0	3·9	16·0	6·3
41	5 55·3	5 56·2	5 39·1	4·1	1·6	10·1	4·0	16·1	6·3
42	5 55·5	5 56·5	5 39·3	4·2	1·6	10·2	4·0	16·2	6·3
43	5 55·8	5 56·7	5 39·5	4·3	1·7	10·3	4·0	16·3	6·4
44	5 56·0	5 57·0	5 39·8	4·4	1·7	10·4	4·1	16·4	6·4
45	5 56·3	5 57·2	5 40·0	4·5	1·8	10·5	4·1	16·5	6·5
46	5 56·5	5 57·5	5 40·3	4·6	1·8	10·6	4·2	16·6	6·5
47	5 56·8	5 57·7	5 40·5	4·7	1·8	10·7	4·2	16·7	6·5
48	5 57·0	5 58·0	5 40·7	4·8	1·9	10·8	4·2	16·8	6·6
49	5 57·3	5 58·2	5 41·0	4·9	1·9	10·9	4·3	16·9	6·6
50	5 57·5	5 58·5	5 41·2	5·0	2·0	11·0	4·3	17·0	6·7
51	5 57·8	5 58·7	5 41·5	5·1	2·0	11·1	4·3	17·1	6·7
52	5 58·0	5 59·0	5 41·7	5·2	2·0	11·2	4·4	17·2	6·7
53	5 58·3	5 59·2	5 41·9	5·3	2·1	11·3	4·4	17·3	6·8
54	5 58·5	5 59·5	5 42·2	5·4	2·1	11·4	4·5	17·4	6·8
55	5 58·8	5 59·7	5 42·4	5·5	2·2	11·5	4·5	17·5	6·9
56	5 59·0	6 00·0	5 42·6	5·6	2·2	11·6	4·5	17·6	6·9
57	5 59·3	6 00·2	5 42·9	5·7	2·2	11·7	4·6	17·7	6·9
58	5 59·5	6 00·5	5 43·1	5·8	2·3	11·8	4·6	17·8	7·0

9.1 Latitude by Polaris



Polaris appears to describe a small circle around the celestial North Pole.

In theory the true altitude of Polaris equals the observer's latitude.

Polaris is the one star that remains to be looked at. Unfortunately it will not be of a great deal of use to you while you restrict your sailing to the Southern Hemisphere, in fact it will be of no use at all. However it is useful if you are sailing in the Northern Hemisphere, especially in the middle latitudes.

Polaris is also known as the Pole Star and was used for navigation by the Norsemen and the Arabs long before anyone thought of compiling tables of the sun's declination.

You may recall when we looked at how to find our latitude by meridian altitude of the sun, if the sun is directly over the equator then our latitude was equal to the sun’s zenith distance. A body directly over the North or South Pole can be used in a similar manner. In this case its true altitude would equal our latitude and no further work would be needed.

Unfortunately Polaris is not directly over the North Pole but has a declination of about 89˚ 15´. This it appears to describe a small circle around the north celestial pole once every sidereal day. Therefore the altitude must be adjusted by using a three page table that you will find towards the back of the almanac or by using a table included with Volume one of the Sight Reduction Tables

(Selected Stars). While the latter table is easier to use a little bit of accuracy is sacrificed but the results are still better than +/- 1 mile and are within acceptable limits for offshore navigation.

While Polaris is not the brightest of stars, with a magnitude of only 2.1, establishing latitude with it is simplicity itself. The first step is to take your altitude and note down the time (GMT) to the nearest minute. Correct the altitude for index error, dip and refraction to establish a true altitude and then calculate the LHA of Aries.

If you are using the almanac you then proceed as follows – use the LHA Aires to establish which column to use and then lift out the three corrections, A0, A1, and A2. The latter two may be lifted out directly; the first may need some interpolation. Add these three corrections to the true altitude and then subtract 1˚ from the answer. This gives you your latitude when in your DR longitude. Lift the azimuth from the bottom of the page and now you have a position line which is never much more than 1 away from east / west (090/270).

If you use the table in Volume 1 (Selected Stars) then all the hard work (!) has been done for you. Just enter the table with your LHA to the nearest degree, lift out the precomputed correction 'Q' and apply it to your true altitude. The table is rounded off to the nearest 1 of arc but, as stated before, it is sufficiently accurate for all practical purposes.

9.2 Worked Example

At 0623 GMT on March 15th, 1993, you take an altitude of Polaris when in DR longitude 101° 05' East. Your height of Eye is 3.3m, the index error is nil, and the sextant altitude is 47° 11'.

Sight Book – Yacht 'Ferret' – 15/3/93

GHA (Aries)	15d06h	262°51.4'	Sextant Altitude	47°11.0'
Increment	27m	5°45.9'	Index Error	NIL
GHA (Aries)	15d06h27m	268°37.3'	Observed Altitude	47°11.0'
D.R. Longitude		101°05.0'	Dip	-3.2'
LHA (Aries)		369°42.3'	Apparent Altitude	47°07.8'
		-360°00.0'	Total Correction	-0.9'
LHA (Aries)		9°42.3'	True Altitude	47°06.9'

Nautical Almanac		Volume 1 (Selected Stars)	
True Altitude	47°06.9'	True Altitude	47°06.9'
		'Q'	-40.0'
		Observed Latitude	46°26.9' North
A0	17.9'		
A1	0.6'		
A2	0.5'		
	47°25.9'		
	-1°00.0'		
Observed Latitude	46°25.9' North		
Azimuth	000.6° T	Azimuth	000.5°T

POLARIS TABLES

LHA ARIES	0° – 9°	10° – 19°	20° – 29°	30° – 39°
	a_0	a_0	a_0	a_0
°	° ′	° ′	° ′	° ′
0	0 22·0	0 17·8	0 14·9	0 13·3
1	21·6	17·5	14·7	13·2
2	21·1	17·1	14·5	13·1
3	20·7	16·8	14·3	13·1
4	20·2	16·5	14·1	13·0
5	0 19·8	0 16·2	0 13·9	0 13·0
6	19·4	15·9	13·8	13·0
7	19·0	15·6	13·6	13·0
8	18·6	15·4	13·5	13·0
9	18·2	15·1	13·4	13·0
10	0 17·8	0 14·9	0 13·3	0 13·1
Lat.	a_1	a_1	a_1	a_1
°	′	′	′	′
0	0·5	0·6	0·6	0·6
10	·5	·6	·6	·6
20	·5	·6	·6	·6
30	·5	·6	·6	·6
40	0·6	0·6	0·6	0·6
4[illegible]	·6	·6	·6	·6
50	·6	·6	·6	·6
55	·6	·6	·6	·6
6[illegible]	·6	·6	·6	·6
Month	a_2	a_2	a_2	a_2
	′	′	′	′
Jan.	0·7	0·8	0·8	0·8
Feb.	·7	·7	·8	·8
Mar.	·5	·6	·6	·7
Apr.	0·4	0·4	0·5	0·6
May	·3	·3	·4	·4
June	·2	·2	·3	·3
July	0·3	0·3	0·3	0·3
Aug.	·4	·4	·3	·3
Sept.	·6	·5	·5	·4

Lat.				
°	°	°	°	°
0	0·4	0·3	0·2	0·0
20	0·4	0·3	0·2	0·0
40	0·5	0·4	0·2	0·0
50	0·6	0·4	0·2	0·0
55	0·7	0·5	0·3	0·0
60	0·8	0·6	0·3	0·0
65	1·0	0·7	0·4	0·0

TABLE 6 - CORRECTION (Q) FOR POLARIS

LHA ♈	Q	LHA ♈	Q	LHA ♈	Q	LHA ♈
° ′	′	° ′	′	° ′	′	
358 46		86 00		120 50		153 3
	−36		−29		− 4	
0 50		87 38		122 07		154 5
	−37		−28		− 3	
3 01		89 14		123 23		156 2
	−38		−27		− 2	
5 20		90 49		124 39		157 5
	−39		−26		− 1	
7 48		92 21		125 54		159 2
	−40		−25		0	
10 29		93 52		127 11		160 5
	−41		−24		+ 1	
13 27		95 21		128 27		162 2
	−42		−23		+ 2	
16·49		96 49		129 43		164 0
	−43		−22		+ 3	
20 50		98 15		130 59		165 3
	−44		−21		+ 4	
26 13		99 40		132 16		167 1
	−45		−20		+ 5	
47 38		101 05		133 32		168 5
	−44		−19		+ 6	
53 01		102 28		134 49		170 4

TABLE 7 - AZIMUTH OF POLARIS

LHA ♈	Latitude 0°	30°	50°	55°	60°	65
°	°	°	°	°	°	
0	0·5	0·5	0·7	0·8	0·9	1·1
10	0·3	0·4	0·5	0·6	0·7	0·8
20	0·2	0·3	0·3	0·4	0·4	0·5
30	0·1	0·1	0·1	0·2	0·2	0·2
40	0·0	0·0	359·9	359·9	359·9	359·9
50	359·8	359·8	359·7	359·7	359·7	359·6
60	359·7	359·7	359·5	359·5	359·4	359·3

9.3 The Seagoing Compass

Before heading offshore you should ensure you compass is in good seagoing condition and that you are familiar with its deviation on various headings. Once on passage you should check the compass error frequently - once every few days at least - for two good reasons: one is that the magnetic variation shall be steadily altering as your geographical location changes.

The second reason, which is of greatest concern to people with steel boats, is that your compass deviation itself may be changing. This is especially true if it is a long time since you last had your compass ‘swung’. If you have sailed from Australia to the Mediterranean or Japan for instance you would be well advised to swing your compass again on arrival.

The reason for this is that the effect of the earth’s magnetic field upon the induced magnetism in your boat changes as your latitude changes. The effect of this change is most noticeable on easterly or westerly courses.

On passage and out of sight of land there are two simple means by which you can check your compass error.

9.4 The amplitude method

This is by far the easier of the two and involves taking a bearing, or amplitude, of the sun when it is on the rational horizon at either sunrise or sunset. Its simplicity relies upon the fact that you are solving a simple (!) right-angled spherical triangle. The amplitude of the sun should be observed when the sun is 1/2 a diameter above the visible horizon.

The amplitude table is then entered with the two arguments, observer's latitude and sun's declination, and yields the sun's true amplitude. This amplitude takes the same name as the sun's declination and is also named either west at sunset or east at sunrise. Thus the true amplitude of the sun at sunset in the northern summer will always be north-west. Note here that the amplitude as found is applied to either east (090˚) or west (270˚). Thus an amplitude of N10˚W is in fact 280˚ True. You now simply compare this with your observed amplitude and there you have your compass error.

Resist the temptation to simply point ship at the sun, this will only give you the compass error on that heading which may be quite different to the error on the course you are steering.

AMPLITUDE METHOD

WORKED EXAMPLE 3

You are in latitude 14°S and the sun's declination is 10 1/2°N. At sunrise you establish that the amplitude by compass is 085°C. What is the sun's true amplitude and what is the compass error?

Latitude 14°S Declination 10 1/2°N
True amplitude = E10.8°N
= 079.2° true
Compass Error = 5.8°W

WORKED EXAMPLE 4

You are in latitude 6°N and the sun's declination is 14°S, you establish a compass amplitude of 248°C at sunset. What is the true amplitude and what is the compass error?

Latitude 6°N Declination 14°S
True amplitude = W14.1°S
= 255.9° true
Compass Error = 7.9°E

TRUE AMPLITUDES

Lat.	Declination 1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
2	1·0	2·0	3·0	4·0	5·0	6·0	7·0	8·0	9·0	10·0	11·0	12·0	13·0	14·0	15·0
4	1·0	2·0	3·0	4·0	5·0	6·0	7·0	8·0	9·0	10·0	11·0	12·0	13·0	14·0	15·0
6	1·0	2·0	3·0	4·0	5·0	6·0	7·1	8·1	9·1	10·1	11·1	12·1	13·1	14·1	15·1
8	1·0	2·0	3·0	4·1	5·1	6·1	7·1	8·1	9·1	10·1	11·1	12·1	13·1	14·1	15·2
10	1·0	2·0	3·1	4·1	5·1	6·1	7·1	8·1	9·2	10·2	11·2	12·2	13·2	14·2	15·3
12	1·0	2·1	3·1	4·1	5·1	6·1	7·2	8·2	9·2	10·2	11·3	12·3	13·3	14·3	15·4
14	1·0	2·1	3·1	4·1	5·2	6·2	7·2	8·3	9·3	10·3	11·3	12·4	13·4	14·4	15·5
16	1·1	2·1	3·1	4·2	5·2	6·2	7·3	8·3	9·4	10·4	11·5	12·5	13·5	14·6	15·6
18	1·1	2·1	3·2	4·2	5·3	6·3	7·4	8·4	9·5	10·5	11·6	12·6	13·7	14·7	15·8
20	1·1	2·1	3·2	4·3	5·3	6·4	7·5	8·5	9·6	10·7	11·7	12·8	13·9	14·9	15·9
22	1·1	2·2	3·2	4·3	5·4	6·5	7·6	8·6	9·7	10·8	11·9	13·0	14·1	15·1	16·2
24	1·1	2·2	3·3	4·4	5·5	6·6	7·7	8·8	9·9	11·0	12·1	13·2	14·3	15·4	16·5
26	1·1	2·2	3·4	4·5	5·6	6·7	7·8	8·9	10·0	11·2	12·3	13·4	14·5	15·6	16·8

9.5 The azimuth method

If the horizon was obscured at dawn, possibly by cloud, you will have to resort to find the sun's azimuth by another means. Azimuth by the way is just a fancy name for the bearing of the sun or, indeed, of any other heavenly body.

This method is relevant for establishing the compass error and also has a place in sight reduction itself.

Before you work out a sight using the position line method you must know the azimuth of the sun at the time of taking the sight. When using the sight reduction tables it is a simple matter to extract the information as you work out the sight.

There are times however when this method is not available. One of these occasions is when we are using the haversine method of sight reduction; other occasions may be when we simply want to establish the error in our compass.

We could simply rework the Haversine formula so that by using latitude, declination and hour angle as arguments we found the azimuth rather than the zenith distance but that would be doing it hard. Fortunately over the years a number of quick methods have been evolved which simplify our task. The most common of these are the ABC tables found in Nories Tables. We still need to know the LHA of the body we are using together with declination and latitude, but what the producers of the table have done is split the haversine formula into two parts which then form part A and part B of the tables. Part A is entered with latitude and LHA as arguments. Part B is entered with declination and LHA. The parts are named according to the simple rules at the bottom of the page and then are either added or subtracted. . Enter Part C of the tables with A+/-B and latitude as arguments and 'lo and behold', an azimuth.

The azimuth obtained from Part C is expressed in quadrantal notation and is named east if the body has an LHA of between 180˚ and 360˚ (i.e. it lies east of you) and west if the LHA is between 000˚ and 180˚ (i.e. is west of the observer). Whether it is north or south depends on the name of the A=/-B correction

You must convert this azimuth from quadrantal to 360˚ notation for it to be of use.

Having found the true azimuth we can now use it to establish the direction of our position line or, having taken a compass bearing, compared true with compass and established the compass error. Some binnacle mounted compasses, such as those manufactured by Suunto, have a shadow stick in the centre of the card which provides a simple means of establishing the sun’s compass bearing at the time of sight and thus lets us establish a position line and check our compass at on and the same time.

9.6 Worked example

Let us say we are in 8º south and have taken an afternoon sun sight. The LHA at the time of the sight is 063º and the sun's declination is 8º south. First we enter the left hand page of the ABC tables with LHA and latitude as arguments and extract an "A" value of 0.7N. Using the LHA and declination we get a 'B' value of 0.32 South. With the ABC tables the rule is same name sum, different name difference. So in this case the c value is 0.25 S. This yields an azimuth of S77.2ºW or, in 360º notation 257ºT. If we had the fore sight to take a compass bearing of the sun when we took our sight, using the shadow stick perhaps, we could now compare the compass azimuth with the true azimuth and get a check on our compass error.

You will often find especially near noon that some interpolation is needed to get an accurate answer. In the early days stick to using the ABC tables either early or late in the day. Those are also the times that shall yield the best results for compass work.

AZIMUTH METHOD WORKED EXAMPLE 5

Afternoon sun sight 6/11/93

Latitude 8° South — LHA Sun 063° — Declination 16° South

A = 0.7 North	(Named opposite to latitude <u>except</u> when LHA is between 090° -270°)	
B = 0.32 South	<u>Always</u> named the same as declination.	
C = 0.25 South	(Different names – difference i.e. subtract)	
Azimuth =	77.2°	(The azimuth takes the combined name of the "C" correction and the hour angle).
=	South 77.2° West	
=	257° True	
Compass bearing =	251° Compass	
Compass error =	6° East	

TABLE A HOUR ANGLE

A - Named opposite to Latitude, except when Hour Angle is between 90° and 270°

Lat. °	60° 300°	61° 299°	62° 298°	63° 297°	64° 296°	65° 295°	66° 294°	67° 293°
0	·00	·00	·00	·00	·00	·00	·00	·00
1	·01	·01	·01	·01	·01	·01	·01	·01
2	·02	·02	·02	·02	·02	·02	·02	·02
3	·03	·03	·03	·03	·03	·02	·02	·02
4	·04	·04	·04	·04	·03	·03	·03	·03
5	·05	·05	·05	·04	·04	·04	·04	·04
6	·06	·06	·06	·05	·05	·05	·05	·05
7	·07	·07	·07	·06	·06	·06	·06	·05
8	·08	·08	·07	·07	·07	·07	:06	·06
9	·09	·09	·08	·08	·08	·07	·07	·07
10	·10	·10	·09	·09	·09	·08	·08	·08
11	·11	·11	·10	·10	·10	·09	·09	·08
12	·12	·12	·11	·11	·10	·10	·10	·09
13	·13	·13	·12	·12	·11	·11	·10	·10
14	·14	·14	·13	·13	·12	·12	·11	·11
15	·15	·15	·14	·14	·13	·12	·12	·11
16	·17	·16	·15	·15	·14	·13	·13	·12
17	·18	·17	·16	·16	·15	·14	·14	·13
18	·19	·18	·17	·17	·16	·15	·15	·14
19	·20	·19	·18	·18	·17	·16	·15	·15
20	·21	·20	·19	·19	·18	·17	·16	·15
21	·22	·21	·20	·20	·19	·18	·17	·16
22	·23	·22	·21	·21	·20	·19	·18	·17
23	·25	·24	·23	·22	·21	·20	·19	·18
24	·26	·25	·24	·23	·22	·21	·20	·19
25	·27	·26	·25	·24	·23	·22	·21	·20
26	·28	·27	·26	·25	·24	·23	·22	·21
27	·29	·28	·27	·26	·25	·24	·23	·22
28	·31	·29	·28	·27	·26	·25	·24	·23
29	·32	·31	·29	·28	·27	·26	·25	·24
30	·33	·32	·31	·29	·28	·27	·26	·25
31	·35	·33	·32	·31	·29	·28	·27	·26
32	·36	·35	·33	·32	·31	·29	·28	·27
33	·37	·36	·35	·33	·32	·30	·29	·28
34	·39	·37	·36	·34	·33	·31	·30	·29
35	·40	·39	·37	·36	·34	·33	·31	·30
36	·42	·40	·39	·37	·35	·34	·32	·31
37	·44	·42	·40	·38	·37	·35	·34	·32
38	·45	·43	·42	·40	·38	·36	·35	·33

TABLE B HOUR ANGLE

B - Always named the **same** as Declination

Dec. °	60° 300°	61° 299°	62° 298°	63° 297°	64° 296°	65° 295°	66° 294°	67° 293°
0	·00	·00	·00	·00	·00	·00	·00	·00
1	·02	·02	·02	·02	·02	·02	·02	·02
2	·04	·04	·04	·04	·04	·04	·04	·04
3	·06	·06	·06	·06	·06	·06	·06	·06
4	·08	·08	·08	·08	·08	·08	·08	·08
5	·10	·10	·10	·10	·10	·10	·10	·10
6	·12	·12	·12	·12	·12	·12	·12	·11
7	·14	·14	·14	·14	·14	·14	·13	·13
8	·16	·16	·16	·16	·16	·16	·15	·15
9	·18	·18	·18	·18	·18	·17	·17	·17
10	·20	·20	·20	·20	·20	·19	·19	·19
11	·22	·22	·22	·22	·22	·21	·21	·21
12	·25	·24	·24	·24	·24	·23	·23	·23
13	·27	·26	·26	·26	·26	·25	·25	·25
14	·29	·29	·28	·28	·28	·28	·27	·27
15	·31	·31	·30	·30	·30	·30	·29	·29
16	·33	·33	·32	·32	·32	·32	·31	·31
17	·35	·35	·35	·34	·34	·34	·33	·33
18	·38	·37	·37	·36	·36	·36	·36	·35
19	·40	·39	·39	·39	·38	·38	·38	·37
20	·42	·42	·41	·41	·41	·40	·40	·40
21	·44	·44	·43	·43	·43	·42	·42	·42
22	·47	·46	·46	·45	·45	·45	·44	·44
23	·49	·49	·48	·48	·47	·47	·46	·46
24	·51	·51	·50	·50	·50	·49	·49	·48
25	·54	·53	·53	·52	·52	·52	·51	·51
26	·56	·56	·55	·55	·54	·54	·53	·53
27	·59	·58	·58	·57	·57	·56	·56	·55
28	·61	·61	·60	·60	·59	·59	·58	·58
29	·64	·63	·63	·62	·62	·61	·61	·60
30	·67	·66	·65	·65	·64	·64	·63	·63
31	·69	·69	·68	·67	·67	·66	·66	·65
32	·72	·71	·71	·70	·70	·69	·68	·68
33	·75	·74	·74	·73	·72	·72	·71	·71
34	·78	·77	·76	·76	·75	·75	·74	·73
35	·81	·80	·79	·79	·78	·77	·77	·76
36	·84	·83	·82	·82	·81	·80	·80	·79
37	·87	·86	·85	·85	·84	·83	·82	·82
38	·90	·89	·88	·88	·87	·86	·86	·85

TABLE C

A & B CORRECTION.

AZIMUTHS

A ± B =	·15′	·16′	·17′	·18′	·19′	·20′	·21′	·22′	·23′	·24′	·25′	·26′	·27′	·28′	·29′	·30′ = A ± B	
Lat. °	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	Lat. °
0	81·5	80·9	80·4	79·8	79·2	78·7	78·1	77·6	77·0	76·5	76·0	75·4	74·9	74·4	73·8	73·3	0
5	81·5	80·9	80·4	79·8	79·3	78·7	78·2	77·6	77·1	76·6	76·0	75·5	74·9	74·4	73·9	73·4	5
10	81·6	81·0	80·5	79·9	79·4	78·9	78·3	77·8	77·2	76·7	76·2	75·6	75·1	74·6	74·1	73·5	10
14	81·7	81·2	80·6	80·1	79·6	79·1	78·5	78·0	77·4	76·9	76·4	75·8	75·3	74·8	74·3	73·7	14
18	81·9	81·3	80·8	80·3	79·8	79·2	78·7	78·2	77·7	77·1	76·6	76·1	75·6	75·1	74·6	74·1	18
20	82·0	81·4	80·9	80·4	79·9	79·4	78·8	78·3	77·8	77·3	76·8	76·3	75·8	75·3	74·8	74·3	20
22	82·1	81·6	81·0	80·5	80·0	79·5	79·0	78·5	78·0	77·5	76·9	76·4	75·9	75·4	75·0	74·5	22
24	82·2	81·7	81·2	80·7	80·2	79·6	79·1	78·6	78·1	77·6	77·1	76·6	76·1	75·7	75·2	74·7	24
26	82·3	81·8	81·3	80·8	80·3	79·8	79·3	78·8	78·3	77·8	77·3	76·8	76·4	75·9	75·4	74·9	26
28	82·5	82·0	81·5	81·0	80·5	80·0	79·5	79·0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
A ± B =	·15′	·16′	·17′	·18′	·19′	·20′	·21′	·22′	·23′	·24′	·25′	·26′	·27′	·28′	·29′	·30′ = A ± B	

A & B take Same Names Sum. (add) } RULE TO FIND C CORRECTION { A & B take Different names Difference (Sub.).

C CORRECTION. (A ± B) is named the same as the greater of these quantities.

AZIMUTH takes combined names of **C** Correction and Hour Angle

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