Astro Navigation with Tables

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In these days, when computers have found their way into just about every field of endeavour, an ability to find your position using just a sextant and tables is still a highly prized skill. This section reviews a general procedure for using Ephemeris and Sight Reduction tables to turn a sextant sight of the sun, moon or a star into a position line. However, if you are totally new to the subject, a better place to begin would be to familiarise yourself with the basic principles and terms used in astro navigation. The tutorial and **AstroCalc** program (downloadable from www.pangolin.co.nz) is good place to begin and a useful reference if you have difficulty in understanding any terms used in the worked example given below. With AstroCalc you can very quickly turn sextant sights into position lines that you can plot on a chart. Depending on how skilled you become you can expect results 10 or 100 times faster than you would obtain by using tables.

A Worked Example

*It's **30th August 1997 (UTC date)** and your best estimate of your current position is **36° 54'N 174° 51'E**. Your sextant sight of the sun's lower limb, taken at **21 hours, 14 minutes and 23 seconds UTC**, gave a reading of **27° 47.7'**. The index error of your sextant was **1' off the arc** and the sight was taken at a height of about **3 metres above sea level**. Calculate the **azimuth and intercept**.*

When working sights, as a reminder of the procedures, it's useful to use a Sight Form with boxes to fill in with the various data items and clues to show the next steps. The Sight Pro-Forma given here is designed for this purpose and can be printed out and copied. However, it's not a bad idea to draw up your own, as the process ensures that you really know it works.

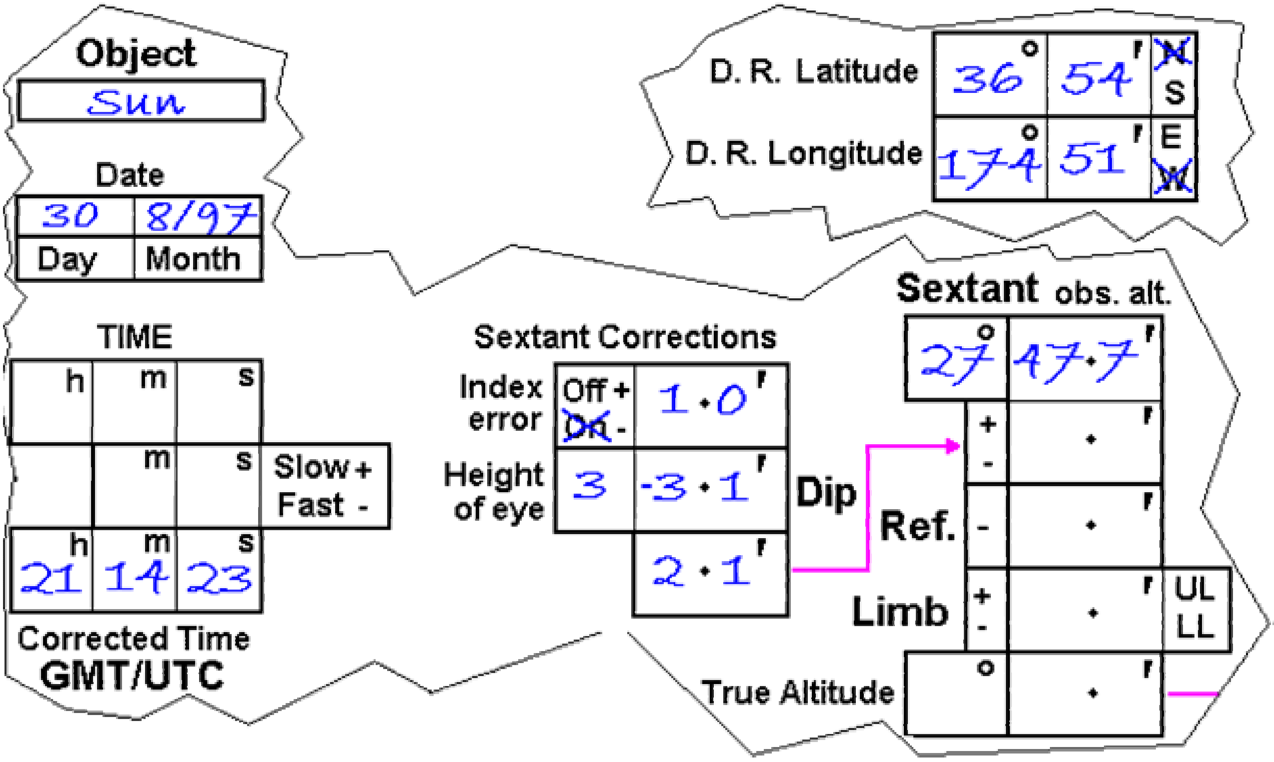
The overall process of working sights of this type consists of 4 steps:

1)	**After transferring the raw input data to the appropriate boxes in the pro-forma begin by finding the GHA and declination of the object observed at the time of the site**
2)	**Use the sight reduction tables to combine this with your assumed position to find the find the altitude and azimuth on which the object you observed would appear if you were actually at that position.**
3)	**Correct your observed sextant altitude for index error, then use the sextant altitude correction table to further correct it for dip, refraction, limb and any other smaller corrections.**
4)	**Calculate and plot the intercept.**

In working through this example we'll look at each step in turn and show how the various data items are entered into the sight form. To keep sight of the procedure as a whole, print out a copy of the Completed Sight Form and have this to hand while you work.

Step 1 - Find the GHA and Declination of the sun at the sight time.

First transfer the date, time, best estimated position and sextant readings to the appropriate boxes in the sight pro-forma:



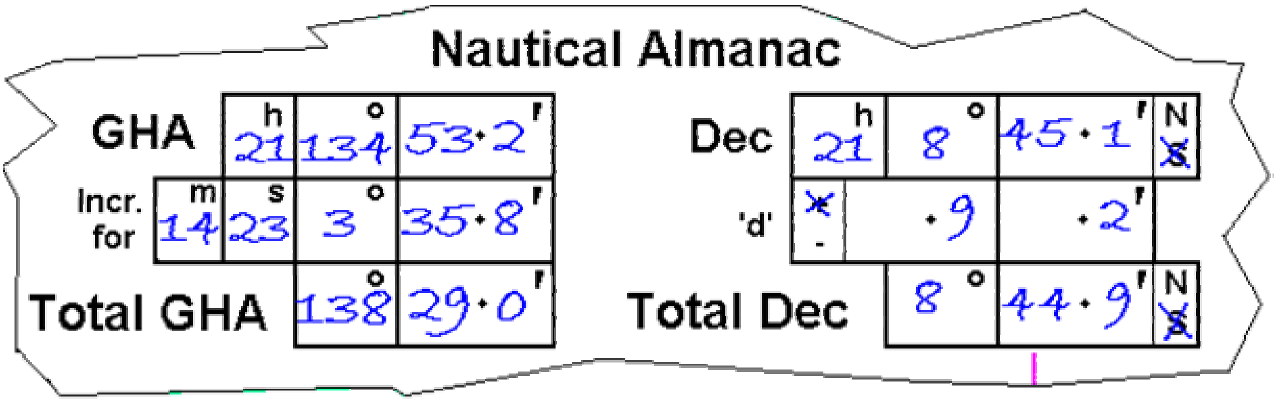
Now from the sun ephemeris table for the 30/August/1997extract the GHA and Dec for the the date and hour of the sight, also make a note of the **d** correction:

UT	SATURDAY 30/AUGUST/1997 SUN GHA	SUN Dec	ARIES GHA	MOON GHA	MOON v	MOON Dec
0	179 49.2	N 9 3.9	338 13.5	212 57.6	12.5	N15
.						
.						
.						
21	134 53.2	8 45 1	294 5.2	158 8.4	13.3	13 3
22	149 53.4	8 44.2	309 7.7	172 40.8	13.4	13 28
23	164 53.6	8 43.3	324 10.1	187 13.2	13.4	13 2
	SD=15.8	d= 0.9		SD=14.8		

Next look up the correction for 14 minutes and 23 seconds in the Increments and Corrections page:

MINUTE 14 Sec	SUN & PLANETS	ARIES	MOON	v or d	corr
00	3 30.0	3 30.6	3 20.4	0.0	0.0
01	3 30.3	3 30.8	3 20.7	0.1	0.0
.					
.					
.					
23	3 35.8	3 36.3	3 25.9	0.7	0.2
24	3 36.0	3 36.6	3 26.2	0.8	0.2
25	3 36.3	3 36.8	3 26.4	0.9	0.2
26	3 36.5	3 37.1	3 26.6	1.0	0.2

Then transfer these values to the Almanac section of the sight reduction form, adding the corrections to obtain the total GHA and Dec as follows:



Step 2 - Use the Sight Reduction tables to combine the GHA and Declination of the sun with your best estimated position to find the computed altitude and azimuth

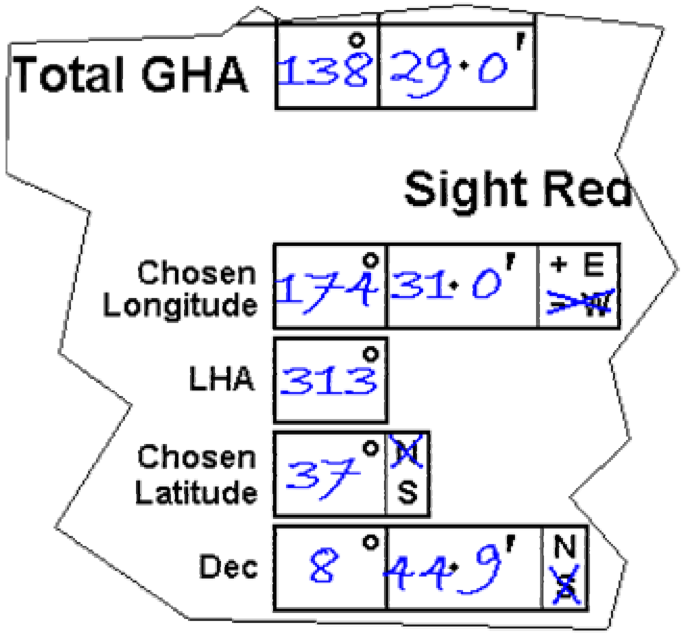
Sight reduction tables can only handle whole numbers of degrees of Latitude and Local hour angle (LHA). Because your best estimated position (36°54'N 174°51'E) does not fit this description, it's necessary to choose another that does. Rounding up the latitude to **37°** is simple enough but what about the longitude? From the relationship **LHA = GHA + or - Longitude** (ie minus for Westerly Longitude and plus for Easterly Longitude) we need to determine the amount to be added or subtracted from the Longitude so that when it's combined with the GHA, it produces a LHA that's a whole number of degrees.

In this case, if we were to use our best position longitude this would give a LHA of

138°29.0' + 174°51.0' = 313°20'.

By using a longitude that's 20' less we get LHA =

138°29.0' + 174°31.0' = **313°**.
Enter these details on the pro-forma as shown:

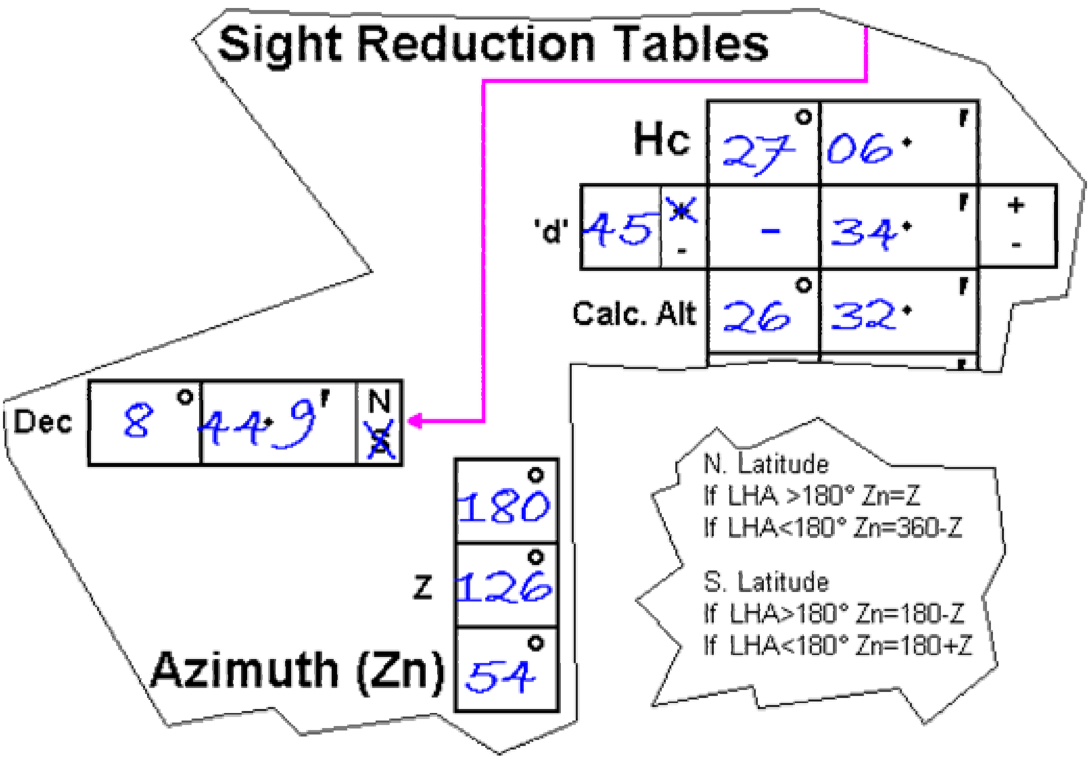


Turning to the Sight Reduction Table page for 37° Latitude. Because Latitude is named Southerly and Declination Northerly, use the table headed headed CONTRARY names with headings of 0° to 14° declination. LHA 313° is listed on the right side of the page, so read across to the 8°declination column as follows:

Latitude 37° Declination (0° - 14°) CONTRARY name to Latitude

		7°			8°			9°				
LHA	·	Hc	d	Z	Hc	d	Z	Hc	d	Z	·	LHA
	·	° '	'	°	° '	'	°	° '	'	°	·	
0	·	46 00	-60	-1	45 00	-60	180	44 00	-60	180	·	360
1	·	45 59	-60	179	44 59	-60	179	43 59	-60	179	·	359
2	·	45 58	-60	177	44 58	-60	177	43 58	-60	177	·	358
.	·	. .	.	.	. .	.	.	. .	.	.	·	.
.	·	. .	.	.	. .	.	.	. .	.	.	·	.
.	·	. .	.	.	. .	.	.	. .	.	.	·	.
45	·	29 09	-46	127	28 23	-46	127	27 37	-46	128	·	315
46	·	28 31	-46	126	27 45	-46	126	26 59	-46	127	·	314
47	·	27 51	-45	125	27 06	-45	126	26 21	-46	126	·	313
48	·	27 12	-45	124	26 27	-45	125	25 42	-45	125	·	312
49	·	26 32	-44	123	25 48	-45	124	25 03	-45	125	·	311
.	·	. .	.	.	. .	.	.	. .	.	.	·	.
.	·	. .	.	.	. .	.	.	. .	.	.	·	.
.	·	. .	.	.	. .	.	.	. .	.	.	·	.
		7°			8°			9°				

Now enter these figures in the sight form boxes and carrying across the -45 **d** adjustment::



From the Increments of Declination table look up the correction for 45 **d** and (horizontal axis) and 45 (44.9) minutes of declination. Copy the result (34') to the sight form as above and subtract it from **Hc** to obtain the **computed altitude.**

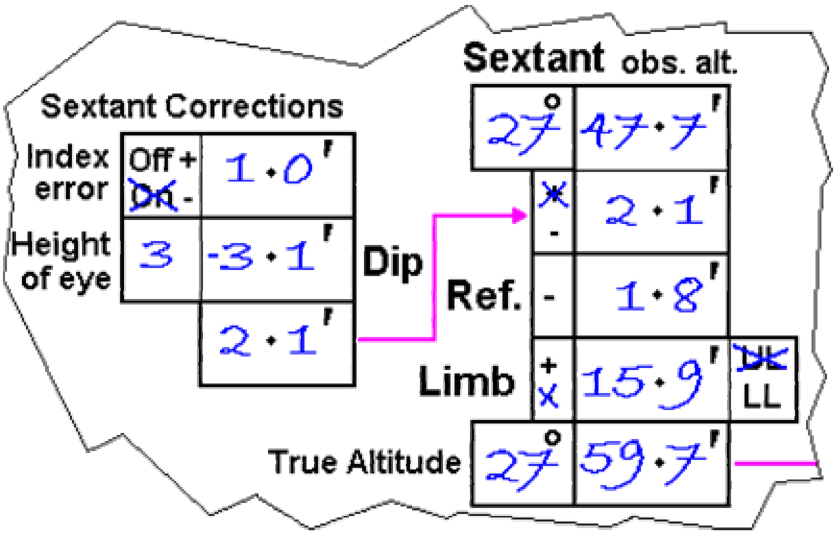
INCREMENTS OF DECLINATION –

d min	1	·	·	43	44	45	46	·	60	d min
0	0	·	·	0	0	0	·	·	0	0
1	0	·	·	1	1	1	·	·	·	1
2	0	·	·	1	1	2	·	·	·	2
3	0	·	·	2	2	2	·	·	·	3
4	0	·	·	3	3	3	·	·	·	4
45	·	·	·	32	33	34	·	·	·	45
46	·	·	·	33	34	34	·	·	·	46
47	·	·	·	34	34	35	·	·	·	47
48	·	·	·	34	35	36	·	·	·	48
49	·	·	·	35	36	37	·	·	·	49

After transferring **Z** to the sight form, the Azimuth **Zn** is calculated from the rules appearing on the table. In this case, we are in a Southerly Latitude and, the LHA (313°) is greater than 180°, so **Zn** is obtained by subtracting **Z** from 180°.

Step 3 - Correct your observed sextant altitude for index error, then use the Sextant Altitude Correction Table to further correct it for dip, refraction and limb.

Use the pro-forma to add or subtract the index error. Use the Altitude Correction table (shown below) to find the dip correction for the height of eye (i.e. height above sea level at which the observation was made) and enter these two quantities in the proforma.

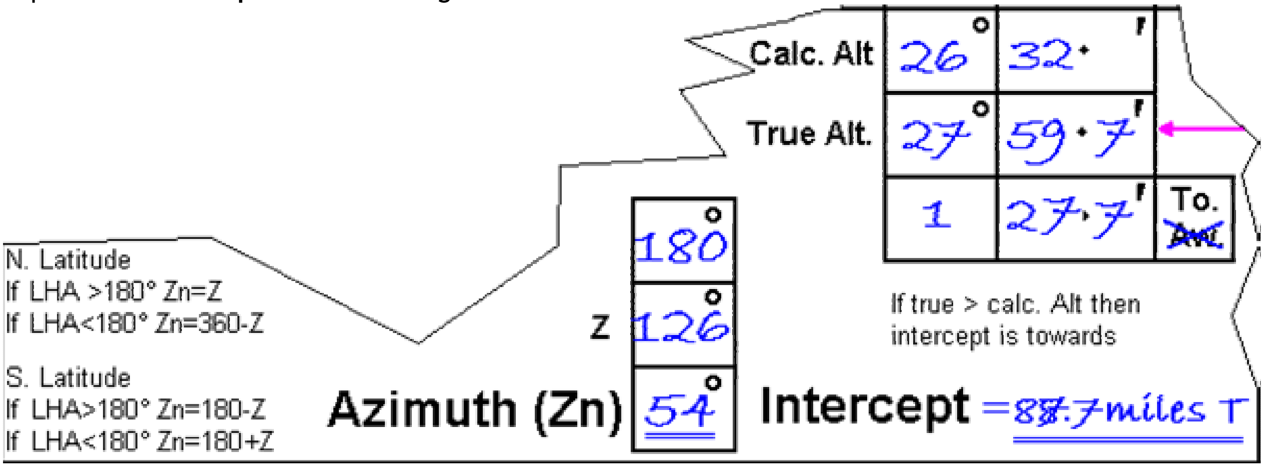


Sextant Angle Correction Table

DIP CORRECTION Ht.of eye(m)	Corr '	REFRACTION CORRECTIONS Alt ° '	Corr '	Alt ° '	Corr '
2.4					
	-2.8	· · · · · ·		· · · · · ·	
2.6					
	-2.9	· · · · · ·		· · · · · ·	
2.8					
	-3.0	11 14		24 11	
3.0			-4.7		-2.1
	-3.1	11 29		25 14	
3.2			-4.6		-2.0
	-3.2	11 45		26 22	
3.4			-4.5		-1.9
	-3.3	12.01		27 36	
3.6			-4.4		-1.8
	-3.4	12.18		28 56	
3.8					-1.7
	-3.5	· · · · · ·		30 24	
4.0					-1.6

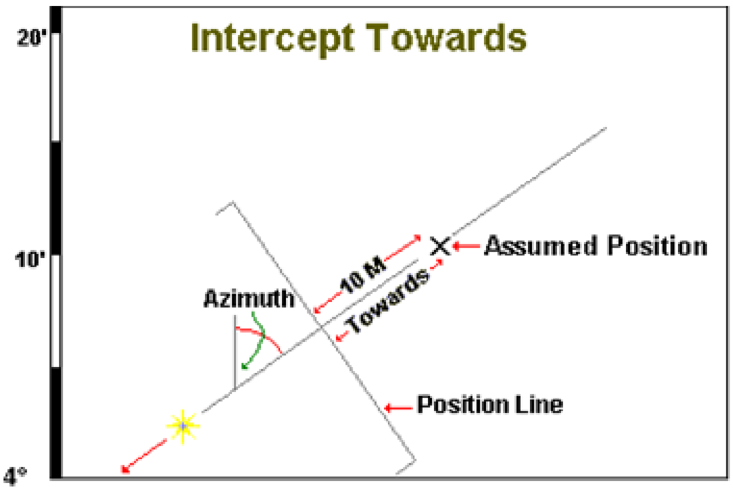
Step 4 - Calculate and plot the intercept.

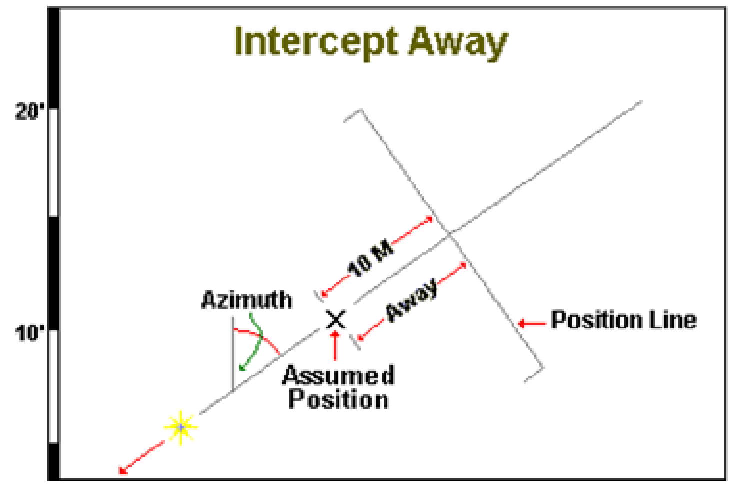
Subtract your corrected and measured altitude (ie **True altitude**) from the **Calculated Altitude**. If the result is a positive number the **intercept** is labelled '**Away**' and conversely, if negative, it is '**towards**'. Express the **intercept** in minutes to give its distance in nautical miles.



To plot the **intercept** as a position line on the chart:

1. Draw a line through your assumed position at the azimuth angle. This will point in the direction of your observed object.
2. Step off of the intercept along the line, measured from your assumed position *either* **Towards** or **Away** from the direction of the observed object (The diagrams below show the two cases).
3. At this point draw in your position line at right angles to the azimuth.

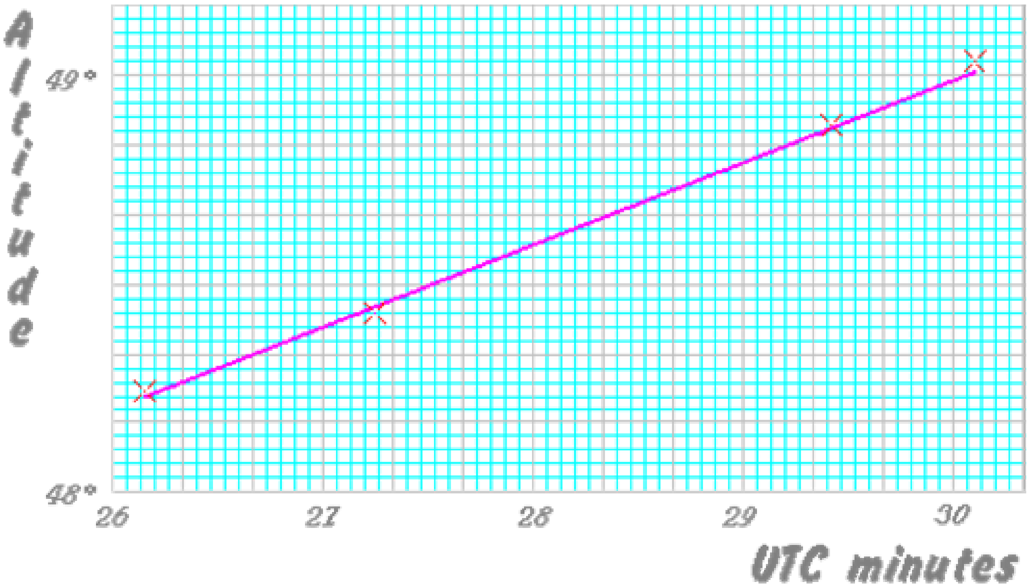




Improving Accuracy by taking consecutive sights

A major source of error in taking sights from a small boat is caused by the vessel's movment. Under rough sea conditions uncertainties in your final position can be in the order of 10 miles. If the errors from this source are assumed to be randomly distributed about a mean value, averaging the results from a number of consecutive sights can improve the result.

Instead of reducing each sight independently, time can be saved by plotting out the group on a graph of altitude vs time. In this way, sights that radically deviate from the general trend can be ignored. After obtaining the best result from the remainder, just one sight need be reduced to obtain an optimum intercept.

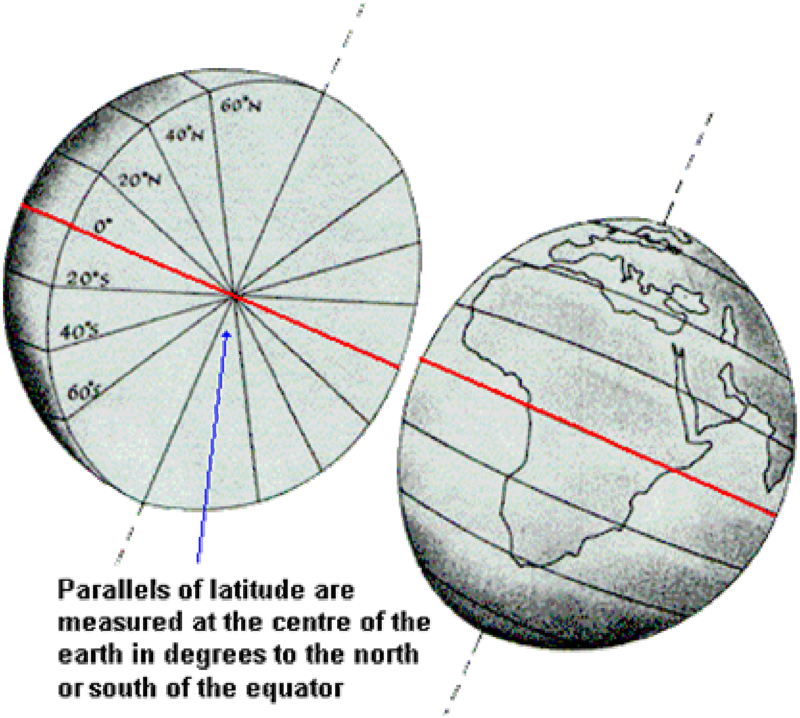


Terms Explained

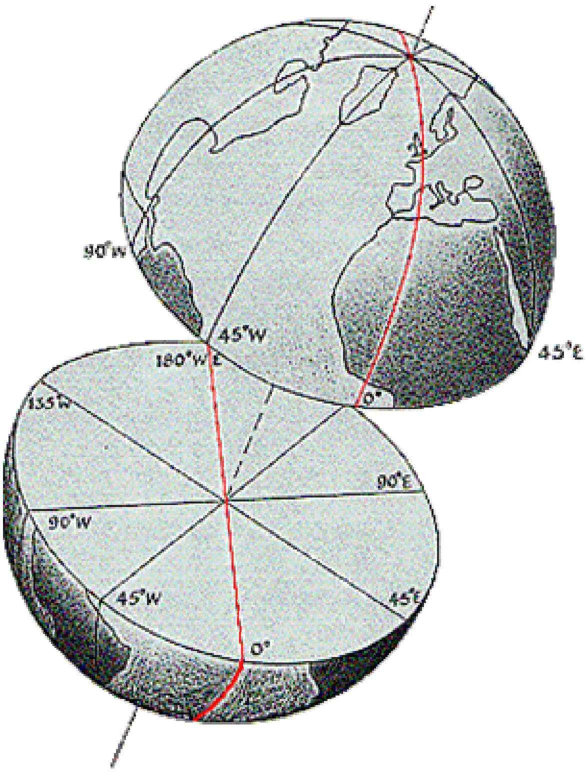
[Latitude and Longitude Co-ordinates]
[The Nautical Mile]
[Declination]
[Hour Angles]
[Sidereal Hour Angle(SHA)]
[Greenwich Hour Angle (GHA)]
[Local Hour Angle (LHA)]
[Greenwich Mean Time (GMT)]
[Greenwich Date]

To make effective use of the data produced by **Almanac** a clear understanding of basic terms used in navigation is essential. This section contains explanations of some basic terminology and concepts.

Latitude and Longitude Co-ordinates



Latitude and ***longitude*** are both angular distances measured at a point in the centre of the Earth. The following two illustrations show how these angles are used to construct a co-ordinate grid system covering the whole earth's surface, with lines of latitude running parallel to the equator. They are named as being north or south of the equator and given values ranging from zero at the equator to 90 degrees at the poles.



Longitude is named as east or west of the Greenwich meridian which, like all meridians, is a line joining the poles, though this one passes through the old Greenwich observatory in London. Longitudes can have values ranging from zero to 180 degrees, measured to the east or west of Greenwich.

The Nautical Mile

As mentioned above, angles of latitude are measured at an imaginary point in the centre of the Earth. The distance that one minute of angular measurement makes at the surface is defined as one ***Nautical Mile***. This is an important concept and one that we'll return to later.

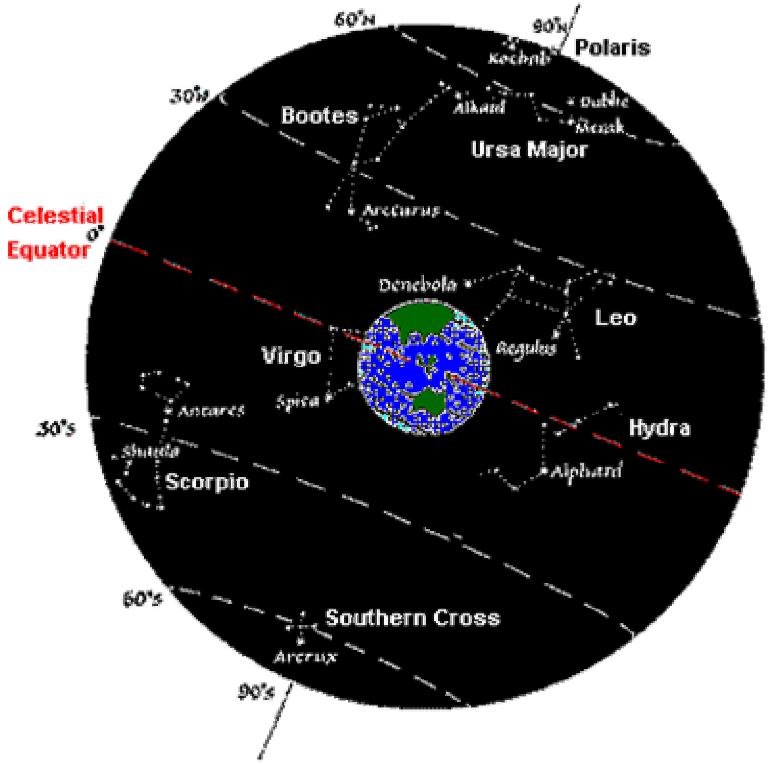
Because the Earth is not a perfect sphere but slightly flattened at the poles, the exact distance that one-minute of latitude makes along the surface at the equator is a little less than the same distance at the poles. The difference is just 19 metres but this can make quite a difference if you are comparing distances of several hundred miles.

The system used for defining positions in the 'Celestial Sphere'

For navigational purposes, it is convenient to think of the Earth as being totally enclosed within a hollow 'celestial' sphere. Sun, Moon, planets and stars appear as small blobs or points painted on its inside surface. It's a gross oversimplification of course but for the moment the analogy does help to show how the system for defining sky positions is simply an extension of the latitude and longitude system.

Declination

This is the sky equivalent of latitude. Simply imagine those rings of latitude projected out onto the sky sphere as an inside view of one hemisphere shown below. Like Earthly latitude, ***declination*** is also measured either to the north or south of a sky equator.

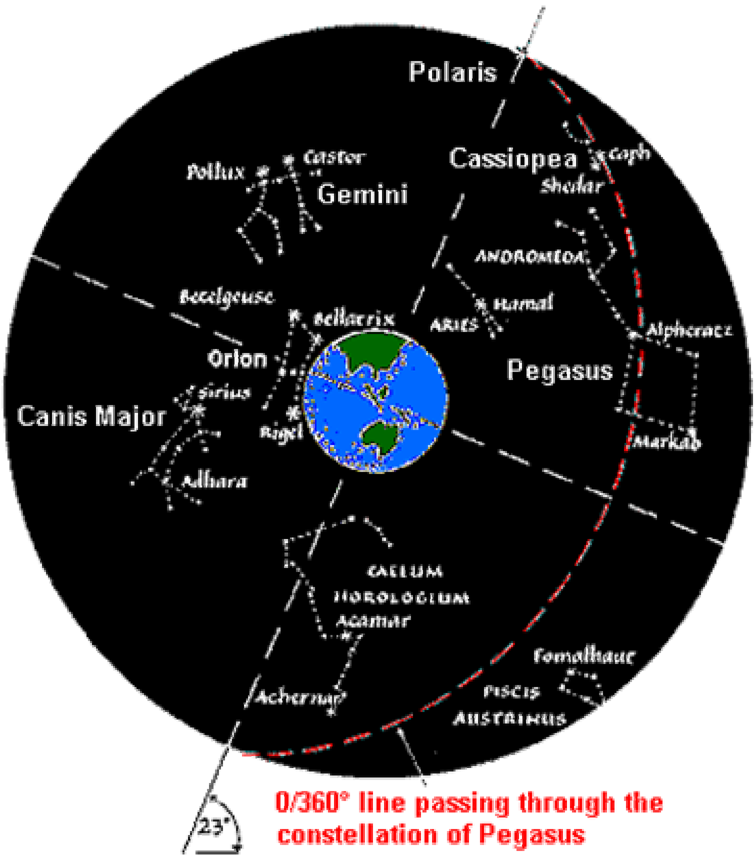


Hour Angles

Hour angles are comparable with longitude but with a slight difference. Whereas longitudes have values of up to 180 degrees and are measured either to the east or west of the Greenwich meridian, hour angles are measured only to the WEST and have values of up to 360 degrees. Three kinds of hour angles are important in astro-navigation :-

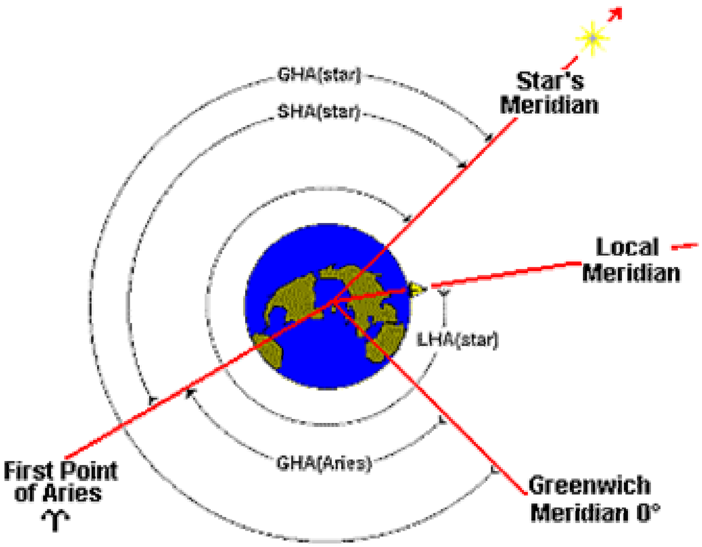
1) Sidereal Hour Angle(SHA)

In specifying the positions of stars it is convenient to refer their hour angles to a meridian line, the sky counterpart of the Greenwich meridian. As with all meridians, this line is in a plane passing through the poles. Instead of Greenwich, it passes through a point in the sky known as the ***first point of Aries***, or the vernal equinox. Actually the line no longer passes through the constellation of Aries, it goes through the square of Pegasus but this doesn't matter a bit since, like the Greenwich meridian, it's simply a reference:



2) Greenwich Hour Angle (GHA)

Imagine the Greenwich meridian line projected out onto the sky sphere. Since the earth is rotating once in every 24 hours, in this time, the line will pass every object in the sky once. At any moment in time the angular distance WESTWARDS from the meridian, to any particular star, is its Greenwich Hour Angle. The following illustration shows how the Greenwich hour angle of a star is the sum of its SHA and the GHA of Aries.



GHA(star) = SHA + GHA(Aries)

3) Local Hour Angle (LHA)

This is the angle between an observer's meridian and the meridian of an object in the sky. Again the angle is measured WESTWARDS from the observer's meridian. For stars the LHA is given by: -

LHA(star) = SHA + GHA(Aries) ± observers Longitude

For the Sun or Moon the expression is :-

LHA (body) = GHA (body) ± observers Longitude

In both of these expressions the convention is that easterly longitudes are added and westerly longitudes subtracted. If the LHA is greater than 360 degrees then 360 degrees is subtracted from it.

Greenwich Mean Time (GMT)

Greenwich Mean Time is the time kept at any point along the Greenwich meridian. Here the middle of the day occurs at around 12.00 hours GMT and the middle of the night at about 24.00 hours. Unfortunately, the rest of the world does not experience things in quite the same way. Mid-day for anywhere else in the world will be at a time difference from GMT that depends upon its longitude. North Island, New Zealand for example, will see mid-day at around 24.00 GMT. For local convenience different parts of the world adopt different time systems to compensate for this. For astro-navigators this can produce all manner of difficulties. That is, unless they stick rigidly to Greenwich Mean Time, the only time system that that will be used in this program.

You may encounter Universal Time (UT) which is synonymous with GMT or Universal Coordinated Time upon which Radio time systems are based. UTC may differ from GMT by 0.9 seconds which, for our purposes here, is small enough to ignore. Radio time signals can be obtained from radio stations across the world and the Admiralty List of Radio Signals volume 5 gives details of time systems and the transmission location, format and frequency.

Greenwich Date

This is the date kept at Greenwich and, as with GMT, the only type of date that astro-navigators need be concerned with.

Astro Sight Pro-Forma

Object

Date

Day | Month

Log .

Course ° T

D. R. Latitude ° ' N S

D. R. Longitude ° ' E W

TIME

h m s

m s Slow + Fast -

h m s

Corrected Time

GMT/UTC

Sextant Corrections

Index error Off + On - ' .

Height of eye ' .

' .

Dip

Sextant obs. alt. ° ' .

+ - ' .

Ref. - ' .

Limb + - ' . UL LL

True Altitude ° ' .

Nautical Almanac

GHA h ° ' .

Incr. for m s ° ' .

Total GHA ° ' .

Dec h ° ' . N S

'd' + - . ' .

Total Dec ° ' . N S

Sight Reduction Tables

Chosen Longitude ° ' . + E − W

LHA °

Chosen Latitude ° N S

Dec ° ' . N S

Hc ° ' .

'd' + - ' . + -

Calc. Alt ° ' .

True Alt. ° ' .

' . To. AW.

N. Latitude
If LHA >180° Zn=Z
If LHA<180° Zn=360-Z

S. Latitude
If LHA>180° Zn=180-Z
If LHA<180° Zn=180+Z

Z °

°

Azimuth (Zn) °

If true > calc. Alt then intercept is towards

Intercept