SYSTEMATIC NAVIGATION

EXCEL APPLICATION FOR ASTRO NAVIGATION

USER MANUAL V7.0 1-JANUARY-2021

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1 January 2021

SFLNav70.doc Version 1-January-2021

Contents

1 Introduction

Systematic Navigation is a Windows and Excel-based solution for astro and offshore navigation.

The object of this manual is to help you get the most out of the application. This manual provides background on the use of *Systematic Navigation* and the methods used in its formulation. It also provides in a convenient form all the data you need for astronomical navigation and sight planning.

Systematic Navigation solves all the problems of calculating hour angles declination and sight reduction and then plots sight lines and statistical fixes for up to three sights. It is totally automated and removes the need for a pocket calculator, almanac or sight tables and provides:

- Position fixes from two or three sextant sights without an Almanac
- Automatic calculation of hour angles, declination and sight reduction
- Chart plots and full results print-outs of all angles and position lines
- Stars Charts for all 59 stars giving SHA, elevation and bearing
- Star Identification from angle and bearing
- Schedule of positions of all celestial bodies
- Sun and Moon rise and set including Sun transits

This guide does not try to teach astro navigation, however it is particularly suited to students of navigation who wish to learn the methodology. You can select calculation of hour angles and declination using:

- Aries Corrections
- Polynomial Coefficients (see *Compact Data* in the Bibliography)
- Almanac Data - Greenwich and Sidereal Hour Angles and Declination

Knowledge of the basic theories is assumed. A bibliography is given at the end of the guide in addition to the explanations of the formulae and algorithms used by the system.

We strongly recommend that you review each of the examples in turn with this manual and make sure that you understand the results produced. Registration entitles you to support so please contact Alastair Day if you need help or more information.

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Expiry Date: 31 December 2025

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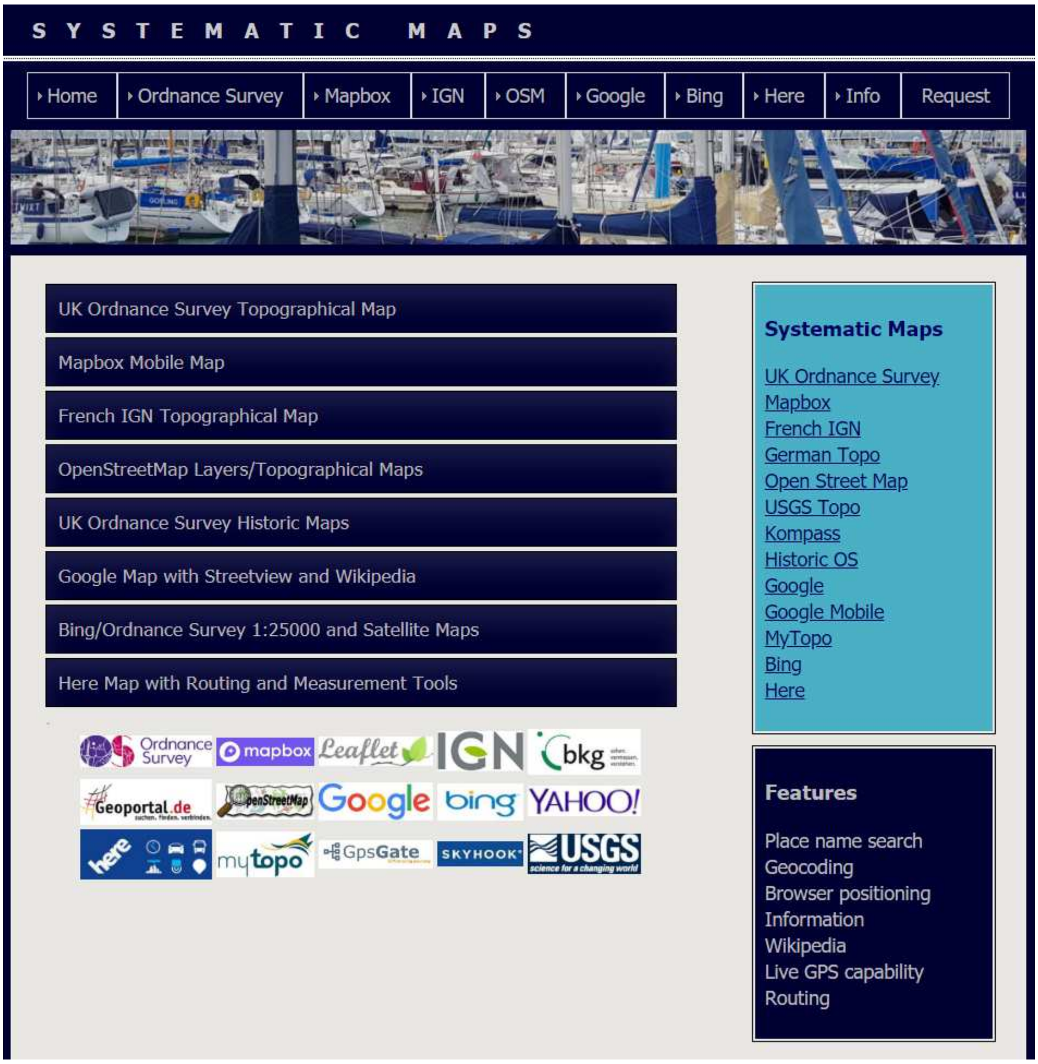
1.1 Systematic Maps – www.sysmaps.co.uk

See also Systematic Maps at www.sysmaps.co.uk for free on-line mapping provided by government and collaborative organisations. This site offers more explanation of the astro navigation program together with a number of different maps:

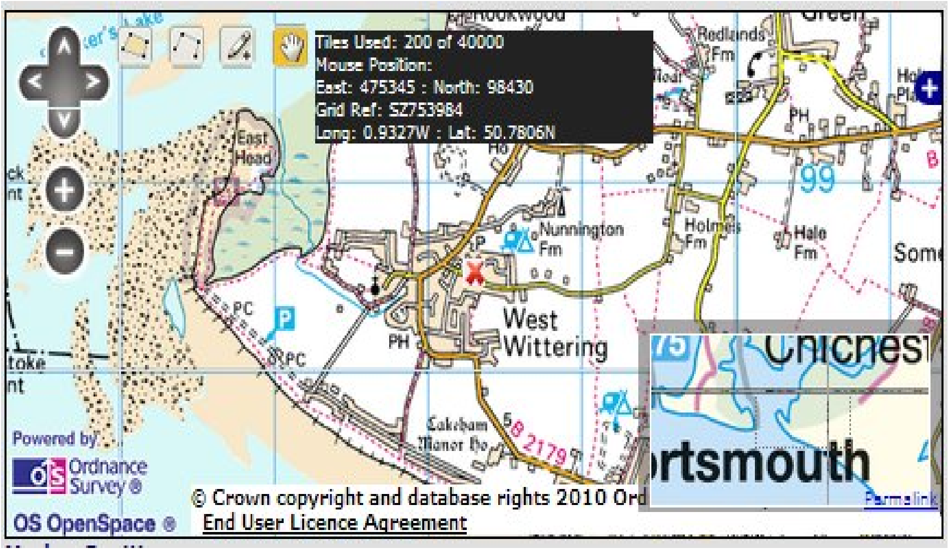
- UK Ordnance Survey topographical maps
- Mapbox open source world-wide maps
- French IGN topographical maps
- OpenStreetMap and German BKG topographical maps with Bing, Google, Yahoo, relief and other layers
- UK historic Ordnance Survey maps from 1888 to 1961
- Google maps with search and StreetView window
- Bing with street maps and UK 1:25000 Ordnance Survey
- Here maps with local search and routing

All the maps allow a GPS signal feed from Franson GPSGate software and are 'location aware' which positions the maps based on Wi-Fi signals. There are also other services such as search and geocoding which provide addresses and latitude/longitude positions. See the Information page at www.sysmaps.co.uk for a full specification.

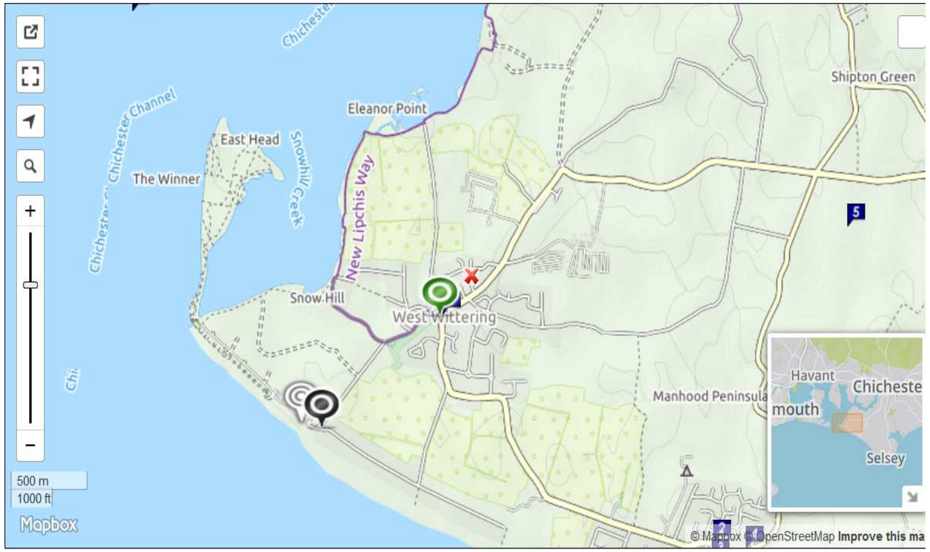


Specimen maps are on the next page:

- UK Ordnance Survey
- Mapbox open source
- French IGN
- Here maps

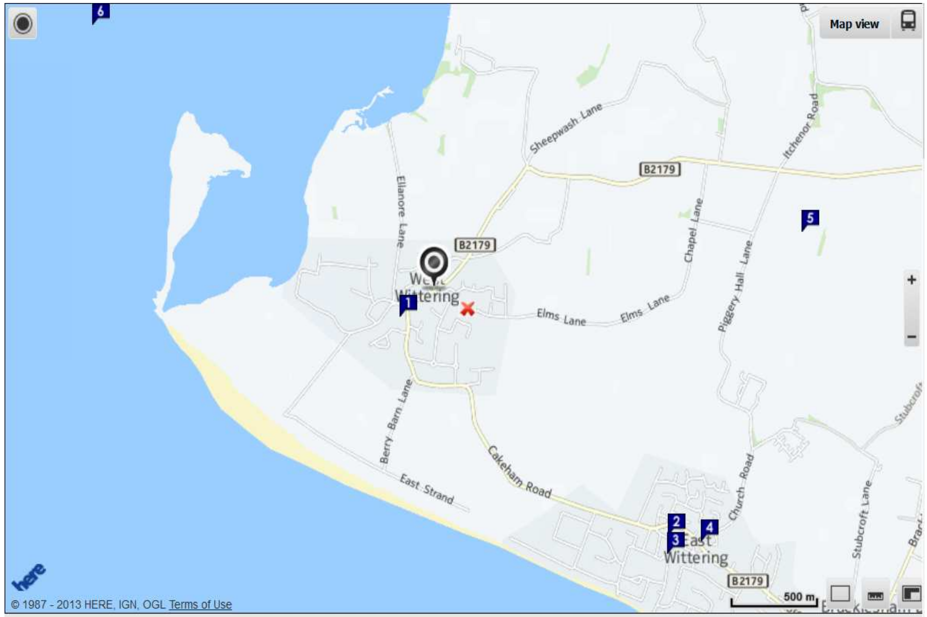


Tiles Used: 200 of 40000
Mouse Position:
East: 475345 : North: 98430
Grid Ref: SZ753984
Long: 0.9327W : Lat: 50.7806N
East Head
Nunnington Fm
Holmes Fm
Hale Fm
West Wittering
Cakeham Manor Ho
B 2179
Powered by
Ordnance Survey
OS OpenSpace
© Crown copyright and database rights 2010 Ord
End User Licence Agreement
Permalink



Shipton Green
Eleanor Point
East Head
The Winner
Chichester Channel
Snowhill Creek
New Lipchis Way
Snow Hill
West Wittering
Manhood Peninsula
Havant
Chicheste
mouth
Selsey
500 m
1000 ft
Mapbox
© Mapbox © OpenStreetMap Improve this ma

Layers
Toolbox
Permalink
Kerfourchel
Glévenay
Plouharnel
Cité du Runel
Kergavat
Kercroc
Kerbachic
Alignements
Port en Iliz
Kerhellec
geoportail
IGN



Map view
Sheepwash Lane
B2179
Elms Lane
Chapel Lane
Piggery Hall Lane
West Wittering
Cakeham Road
East Strand
Berry Barn Lane
East Wittering
500 m
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2 Installation

2.1 Description

The system requires a computer with minimum 15.0 Mb spare hard disk capacity and sufficient RAM. The software required is Microsoft Excel 2003 (or later). Excel 2010+ is recommended.

A full pack of files for *Systematic Navigation* could include the following:

Description	File Name	Approximate Size
Excel Application File	SFLNavXX.xls	10,319,000
SysNav manual	SFLNavXX.pdf	5,500
Icon File	SFLNav.ico	766
Read Me Text File	ReadMe.txt	6,978

2.2 Installation

Decompress the files and then set up a directory called *Systematic Navigation*. Copy the files to the directory and set up a link to the Excel file and manual if required.

To start *Systematic Navigation*, click the file icon twice quickly to load *Excel* and the application. A copyright box appears. Click 'OK' and the system displays a description of the information needed. See Section 3.2 for an overview map of the application and Section 4 for detailed instructions.

When you first open the application, click ‘Halt’ at the description dialog box and manually tab along the sheets to the end schedule, ‘Version’. Enter the name and code as given to you on your invoice to register the *Systematic Navigation*.

3 Overview

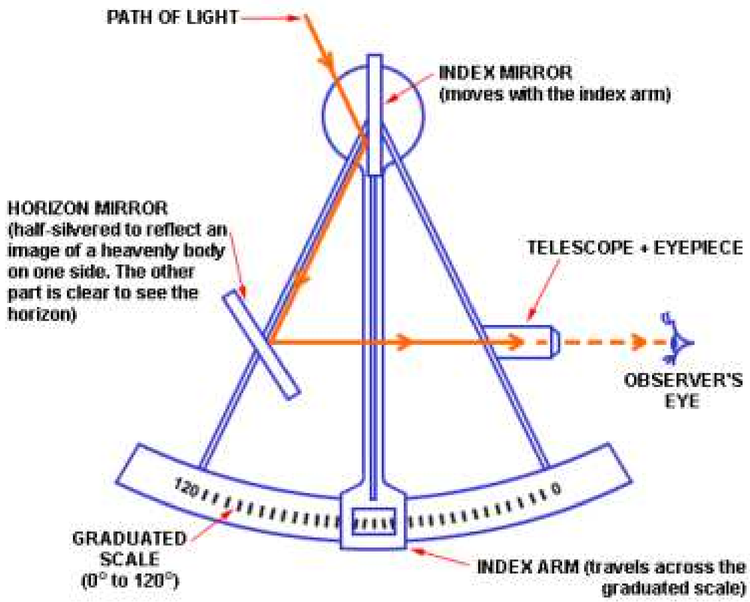
3.1 General Principles

Out of sight of land, there are no landmarks for checking assumed or dead reckoning positions. Similarly, stand-alone GPS or GPS units in mobiles can exhibit problems or run out of battery power. Astro navigation is one method of deriving positions using observations of the Sun, Moon, Stars and Planets. The basic steps in astro navigation are:

- Taking a sight with a marine sextant from an assumed position and noting the exact time.
- Applying correction to the altitude for refraction, instrument error, height etc.
- Computing the position of the body observed (Local and Greenwich Hour Angles and Declination).
- Sight reduction - computation of the altitude and bearing at the time of sight.
- Position lines - comparing the sight reduction with the actual sight and plotting a sight line and distance from the assumed position.
- Entering further sights to derive and plot a statistical fix.

Position lines are generally assumed to be straight over distances up to a few hundred nautical miles. The observer lies along or close to each calculated position line so that the intersection of several position lines increases the accuracy of the 'fix'.

To determine the position line, the altitude of the body is observed above the horizon with a marine sextant. The observer applies corrections to the observed altitude. It can then be compared with the calculated altitude of the centre of the body as if seen from the centre of the earth with no atmosphere. Corrections include instrument or index error, height of the observer's eye above the horizon and the upper or lower limb of the body observed.



The Greenwich Hour Angle and Declination of the body need to be computed. These are equivalent to the latitude and longitude of the body in the heavens. Either tables or the Almanac can be used or this application provides an automatic method needing no input from you.

The normal method of plotting position lines is to use the intercept and azimuth. The intercept is the difference between the observed altitude and the calculated altitude represented as a distance in nautical miles. If the observed altitude is greater than the calculated altitude, the position line lies between the observer and the body. The position line is plotted at right angles to the azimuth of the body at the distance of the intercept from the estimated position - *towards* the body.

When the observed altitude is less than the calculated altitude, the opposite is true. The body lies *away* from the observer at an angle of 180' plus the azimuth.

Further sights of the same body can be added to provide several position lines or alternatively different bodies along a course line. More observations increase the probability of position through the intersection of several lines. The observer can than compute a new assumed position based on the sights as a latitude/longitude position and a distance and bearing from the assumed position.

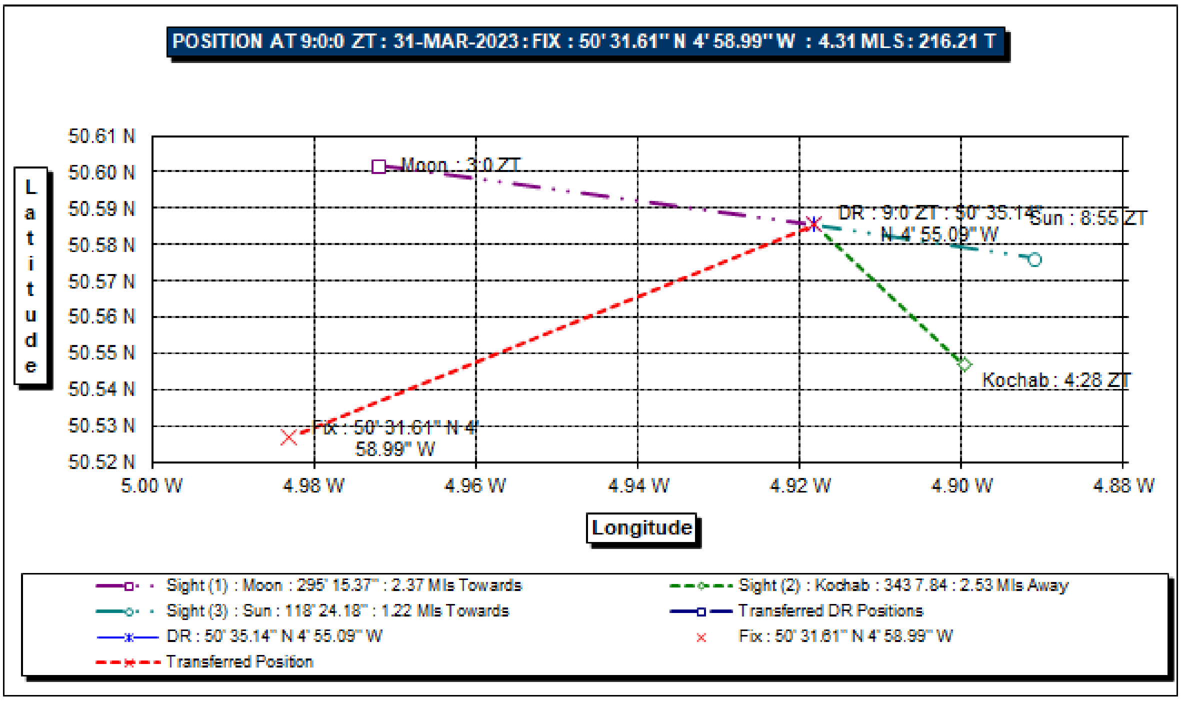
3.2 Systematic Navigation

The methodology described above requires the Almanac and concise mathematics plus plotting instruments to prove a position. These methods are prone to error and time-consuming.

Systematic Navigation is an Excel workbook with groups of separate 'sheets' or 'schedules'. It contains all the base data required and reduces sights and fixes positions for up to three sextant sights of the Sun, 59 navigational Stars, the Moon or the planets of Venus, Mars, Jupiter and Saturn. Data is available from 1991 and is updates in five yearly intervals as new data becomes available. It dispenses with all the manual calculation of corrected altitudes, hour angles and declination from the Almanac and the plotting of position lines on a chart.

Systematic Navigation is not intended as a complete introduction manual of astro navigation[1]. This manual does however contain full explanations of the methods used and lists the algorithms.

Example fix showing the dead reckoning (DR) and calculated fix positions:



[1] See bibliography for *Basic Astro Navigation* by Conrad Dixon.

3.3 Overview of Systematic Navigation

This is a ‘map’ of the application. It identifies the main inputs, choices and flow of information to demonstrate the flexibility between automatic calculation, user choice and manual input.

No	Dialog Box	Comment
1	Copyright	Language A=English, B=German Confirms application directory C:\SFLNav30
2	Information	Summarises information required, HALT here for manual input
3	Options	Keep Dead Reckoning (DR) Position Calculate Greenwich Hour Angle (GHA) and Declination (DEC) automatically (if no, user can choose method)
4	DR Position	Latitude and longitude position Zone time and date Course and speed (if applicable) Temp 'C and pressure Mb (used in sight reduction)
5	Sight No and Method	Sight No (1-3 maximum) Zone Time of Sight Object (Sun, 59 Stars, Moon, Venus, Mars, Jupiter, Saturn) Method chosen under automatic calculation:
6	Stars Subroutine 1 Altitude/Bearing for Identification 2 Star Number to calculate bearing and altitude + star charts 3 Input Star Number directly	(see method table below)
7	Observed Altitude	Sextant Altitude (Hs) Corrections - Index, Height, On/Off Arc, Upper/Lower Limb
8	Sun / 59 Stars / Moon / 4 Planets	(see table below)
9	Information	Displays method only when calculation not set to automatic
10	Options Up to 3 Sights	End of Each Sight: 1 View Sight Result - option to redo or continue 2 Increase number of sights 3 Continue with the next sight - return to 5 above 4 No more - go to end results
11	End Results	Displays result of each sight - intercept and azimuth Statistical fix (if applicable)
12	12 End Options	1 View input sheet and halt for manual input 2 View results summary and chart plot 3 View chart plot and positions of sun, moon etc. 4 Update star chart by bearing or altitude 5 View Stars Charts 6 View positions of sun, moon, planets and star 7 View sun and moon rise and set 8 View background calculations and aries coefficients 9 View polynomial data for date of sights 10 Re-run some or all of the sights 11 Halt for manual input 12 Exit Systematic Navigation with save file options

Method Type No	A Aries/Almanac	B Polynomial Coefficents
1Sun	1991-2025	Calculated 1991-2025
2 Stars	1991-2025	Calculated 1991-2025
3 Moon	1991-2025	Calculated 1991-2025
4 Planets	1991-2025	Calculated 1991-2025

	Sun	59 Stars	Moon	4 Planets
A	Calc *	SHA * DEC	Calc	GHA DEC Variation
B	Calc	Calc	Input Data	Calc

* Calc = Calculated, SHA = Sidereal Hour Angle

For completeness this is a listing of all the schedules in *Systematic Navigation*. When you open the application and choose automatic entry, you enter data to dialog boxes which the system enters directly to the 'Inputs' sheet. This sheet calculates the results and retrieves data from other background schedules.

The system displays the plots on the Results, SightCharts, StarsCharts and Positions schedules.

There are two input methods: you can enter data directly to the 'Inputs' or use the dialog boxes to enter the data in stages. The dialog boxes check your inputs and should remove most input errors.

Task	No	Option
ReadMe	1	On-line notes on *Systematic Navigation*
Overview	2	Useful map of the application (previous page)
Registration	3	'Shareware' registration document
Inputs	4	Main input sheet and results sheet with workings
Results	5	Summary inputs and results with chart plot
SightCharts	6	Chart plot and positions plot of the Sun, Moon and Planets
StarsCharts	7	Star chart plotted in number order or by altitude, bearing or SHA
Positions	8	Calculated position of all bodies at the dead reckoning time
RiseSet	9	Sun and Moon rise and set including Sun transits.
Moon	10	Moon rise and set using Chebyshev or polynomial coefficients.
Altitude	11	Altitude by hour and day for a year for selected object.
Great Circle	12	Terrestrial navigation.
Aries	13	Background calculations.
Data	14	Derived polynomial data for the dead reckoning date
Version	15	Version data on *Systematic Navigation*

3.4 Glossary

All distances are given in (sea/nautical) miles. One nautical mile is:

Metres	1,852.00 metres	(1.85 kilometres)
Yards	2,026.08 yards	(1 metre is 1.094 yards)
English Miles	1.15 miles	(1760 yards to the mile)

A nautical mile corresponds to one minute of latitude and is made up of ten cables; thus, sixty miles is equal to one degree of latitude. Units of longitude vary with latitude and cannot be calculated in this manner.

Term	Explanation
GMT	Greenwich Mean Time. Synonymous in this context with Universal Time (UT).
Lat or B	Latitude (north = positive, south = negative). Shown as 15' N 12.33" or 15.2055.'
Long or L	Longitude (east = positive, west = negative).
GHA	Greenwich Hour Angle = $GHA_{(Aries)}$ + SHA measured in degrees E from 0' to 360'.
SHA	Sidereal Hour Angle = 360 - Right Ascension.
DEC	Declination measured in degrees north (positive) and south (negative).
LHA	Local Hour Angle = GHA + Longitude measured in degrees E from 0' to360'.
Hs	Sextant Altitude measured by the observer's sextant.
I	Instrument or Index Error.
D	Dip of horizon (height of the observer's eye above the horizon).
H	Apparent Altitude = sextant altitude corrected for instrument error and dip. (Hs + I - D).
HP	Horizontal Parallax of Sun, Moon, Venus or Mars.
PA	Parallax in Altitude of Sun, Moon, Venus or Mars. (HP * COS H).
S	Semi-diameter of the Sun or Moon. (Add lower limb and subtract upper limb).
Ho	Observed Altitude = apparent altitude corrected for refraction and if appropriate corrected for parallax and semi-diameter. (H - R + PA + OB ± S).
Hc	Calculated or Computed Altitude - see section 11.
Z	Azimuth (true), measured clockwise around the horizon from 0' to 360'. Defined as the arc of the horizon between the meridian of a place and a vertical circle passing through a celestial body.
P	Intercept of a sight (Ho - Hc). *Towards* = positive, *Away* = negative.
R	Atmospheric Refraction.
T	Course or track, measured as for azimuth from 0' to 360'.
V	Speed in knots.

Latitude and longitude may be written in degrees with decimals or minutes. You usually enter degrees and minutes which the application converts to decimal degrees. Similarly, longitude can be converted to time since 15' is equivalent to one hour.

Local Mean Time is referred to as Zone Time. ZT and GMT are calculated by reference to longitude.

GMT or UT = Zone Time + west longitude or - east longitude (converted into hours i.e. 15'W = plus one hour).

Declination (DEC) is equivalent to the latitude of the body observed and measured in degrees north or south. For example: the Sun moves from the furthest position in the South on 21st December to the 21st June in the North.

Hour Angles are the equivalent of longitude except that longitude is measured up to 180 degrees whereas hour angles have values up to 360 degrees. Three kinds of hour angle are used to calculate positions:

- Sidereal Hour Angle (SHA) is based on a meridian line (c.f. Greenwich for longitude) and in the heavens this is the first point of Aries. The SHA is the degree's difference to Aries (the hour equivalent of the Greenwich meridian).
- Greenwich Hour Angle (GHA) is the addition of the Aries position and the Sidereal Hour Angle.
- Local Hour Angle (LHA) completes the calculation as the addition of the GHA and Longitude (West is subtracted).

Therefore LHA = $GHA_{(Aries)}$ + SHA +/- observer's longitude

4 Using Systematic Navigation

4.1 Method

Systematic Navigation incorporates two different methods of computing the Local Hour Angle and Declination of the observed body. The two methods are denoted as 'A' or 'B' throughout the model.

(A) Almanac / Calculated (A). The model will compute the position of the Sun and Moon automatically and will prompt for Almanac data on the SHA and DEC for Stars and the GHA and DEC Planets. You will find this information on the page in an Almanac containing the day of the observation.

(B) Polynomial Coefficients (B). These are assimilated from *NavPac and Compact Data* produced by Her Majesty's Nautical Almanac Office (HMNAO) and other sources, (referred to in this manual as *Compact Data*). The model calculates the GHA, declination and if applicable the horizontal parallax and semi diameter of the body observed. The model computes the DEC and GHA and adds the longitude to convert to LHA (Local Hour Angle).

The most convenient method for calculating GHA and Declination for each body is shown below. The model will prompt you for the method to be used on all sights. Similar to Methods 'A' and 'B', the celestial bodies are referred to throughout the model by their numbers below:

(1) Sun: Under 'A' GHA and DEC are calculated for 1989-2025, and under Method 'B' the coefficients for 1991-2025 are contained in the model. If you enter an observation for another year, Method 'B' will prompt you to input the coefficients applicable to the month and year.

(2) Stars: The model requires the SHA and DEC under Method 'A' however the data under Method 'B' for the years 1991-2025 are contained in the model. The apparent position of the Stars does not vary month to month and therefore the coefficients are contained on a series of five-year tables.

(3) Moon: Method 'A' and ‘B’ are calculated for 1989-2025. Method ‘B’ uses monthly Chebyshev or polynomial coefficients contained in the model.

(4) Planets: These are denoted as 4 = Venus, 5 = Mars, 6 = Jupiter, 7 = Saturn. Under Method 'A' the Greenwich Hour Angle and the Declination together with hourly corrections must be input. The polynomial coefficients for 1991-2025 are in the model for Method 'B'.

The above provides some flexibility in the model to test the different methods and the results will be very similar. To reduce the complexity of the above, you can decide to compute the GHA and DEC automatically and in this case the routine will choose either 'A' - Calculated / Almanac or 'B' - *Compact Data* as follows:

(1) Sun: Method 'B' for 1991-2025 otherwise Method 'A'. The model derives the coefficients for 1991-2025 and will also calculate the semi-diameter accurately as opposed to using the single figure of 16" used in Method 'A'. This will account for any resulting small differences between the two methods.

(2) Stars: Method 'B' (polynomial coefficients provided for the years 1991-2025).

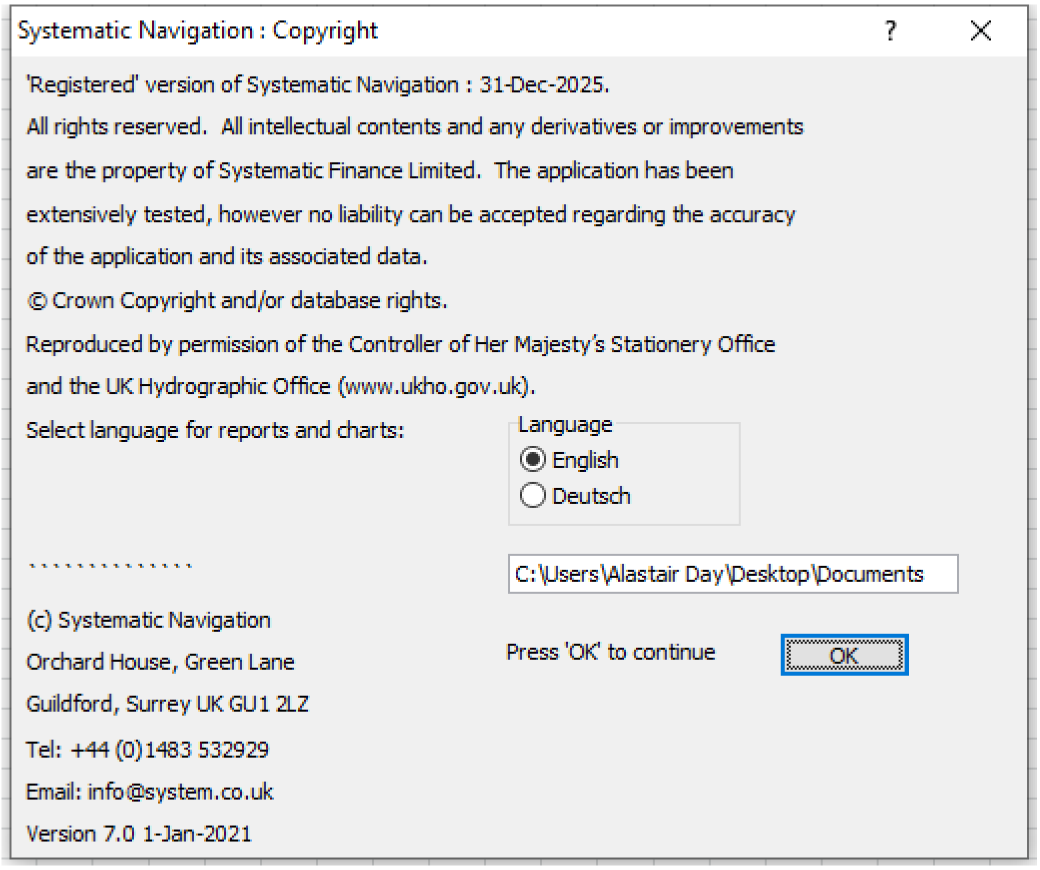
(3) Moon: Method 'A' and ‘B’ with no inputs needed. Method ‘B’ for the years 1991-2025 is more accurate using the Chebyshev coefficients.

(4) Planets: Method 'B' (polynomial coefficients provided for the years 1991-2025).

4.2 Procedure

(1) Double click *Systematic Navigation* in the program group or load **SFLNavXX.xls** and the application displays a copyright box and requests confirmation of the working directory and language for the reports.

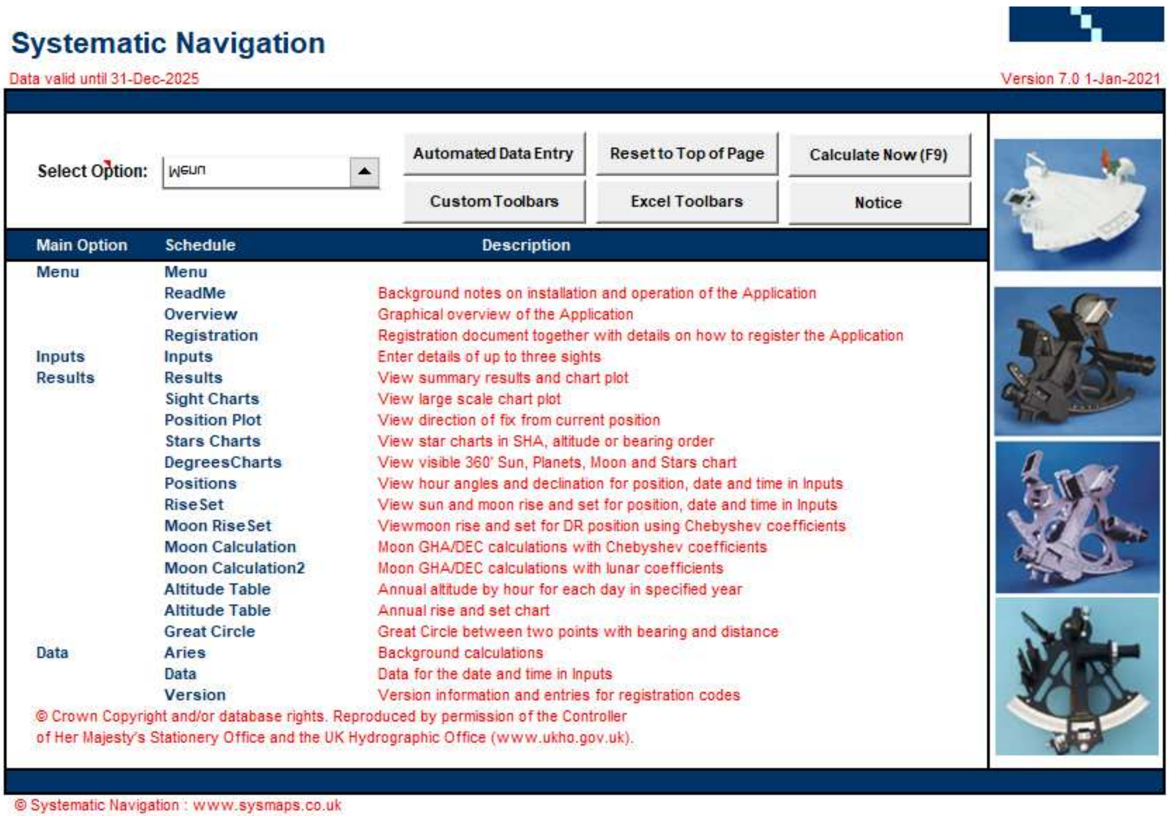
If the system displays the 'circular errors' box, press 'OK' and continue. This is merely informing you that the workbook may contain circular arguments and needs the Excel calculation option set to iteration. If you start the application from an icon, the system should suppress this message. The system sets up the calculation method as it opens so you need take no further action.



(2) Press 'OK' and the system displays the Main Menu showing the data contained in the model. Use the control to select Inputs directly or press 'Automated Data Entry' to enter data via dialogue boxes.

The options are:

ReadMe	Background notes on installation and operation of the Application
Overview	Graphical overview of the Application
Registration	Registration document together with details on how to register the Application
Inputs	Enter details of up to three sights
Results	View summary results and chart plot
Sight Charts	View large scale chart plot
Stars Charts	View star charts in SHA, altitude or bearing order
Positions	View hour angles and declination for position, date and time in Inputs
RiseSet	View sun and moon rise and set for position, date and time in Inputs
Aries	Background calculations
Data	Data for the date and time in Inputs
Version	Version information and entries for registration codes



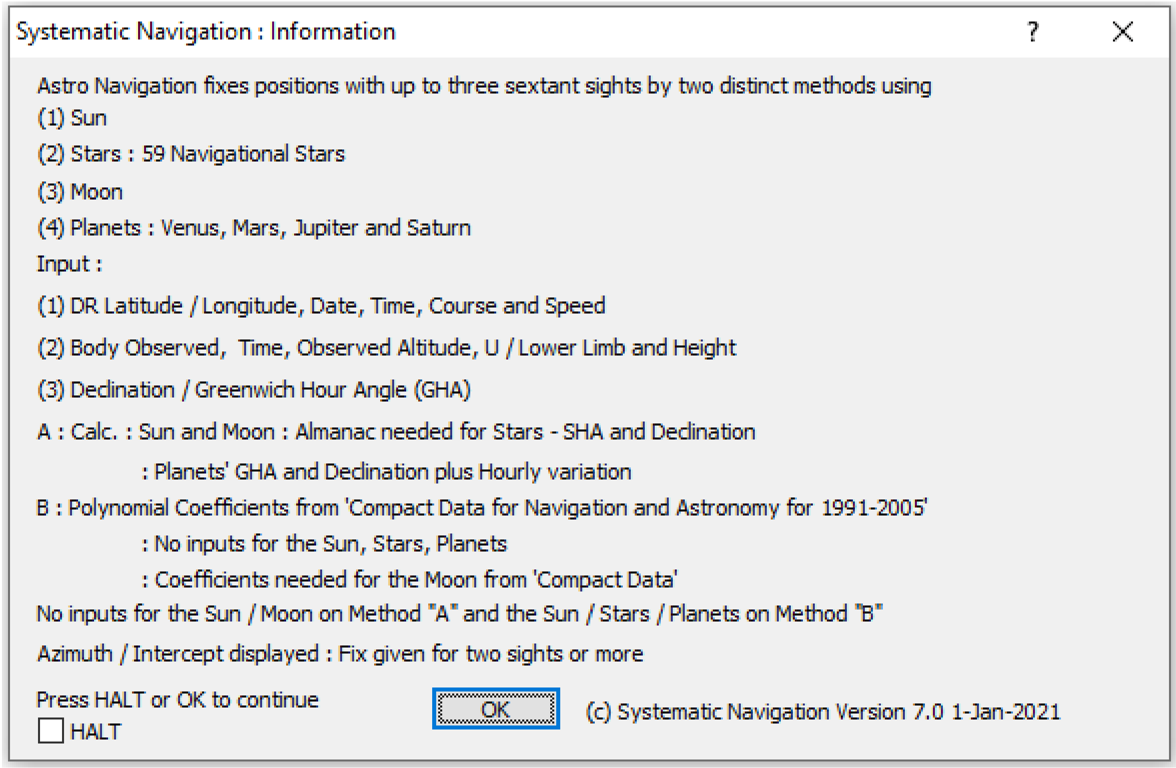
Main Option	Schedule	Description
Menu	Menu	
	ReadMe	Background notes on installation and operation of the Application
	Overview	Graphical overview of the Application
	Registration	Registration document together with details on how to register the Application
Inputs	Inputs	Enter details of up to three sights
Results	Results	View summary results and chart plot
	Sight Charts	View large scale chart plot
	Position Plot	View direction of fix from current position
	Stars Charts	View star charts in SHA, altitude or bearing order
	DegreesCharts	View visible 360' Sun, Planets, Moon and Stars chart
	Positions	View hour angles and declination for position, date and time in Inputs
	RiseSet	View sun and moon rise and set for position, date and time in Inputs
	Moon RiseSet	Viewmoon rise and set for DR position using Chebyshev coefficients
	Moon Calculation	Moon GHA/DEC calculations with Chebyshev coefficients
	Moon Calculation2	Moon GHA/DEC calculations with lunar coefficients
	Altitude Table	Annual altitude by hour for each day in specified year
	Altitude Table	Annual rise and set chart
	Great Circle	Great Circle between two points with bearing and distance
Data	Aries	Background calculations
	Data	Data for the date and time in Inputs
	Version	Version information and entries for registration codes

(3) Press 'Automated Data Entry' and the system displays the Main Menu showing the data contained in the model. Use 'Halt' to stop here and enter all data manually to the Input sheet. If you halt at this point, the system does not recalculate and you should use the button or F9 to update the model.

Automated Data Entry will start a macro described in the following pages with input boxes for the DR position and each of the sights. Any data in the model will be entered in the boxes as they open. If you do not press this button use the combo box to jump to individual sheets or tab along the bottom in Excel. You enter all data on the Inputs sheet and the calculations are used on all the other sheets and charts. The following pages show the automatic sequence.

Reset to top of page resets all sheets to the top ready for saving.

In Excel 2003 you can use Custom Toolbars and Excel Toolbars to toggle between the application and Excel toolbars.



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(4) Press 'OK' and the system requests you to select general options for the sights. These are set to true and they must be clicked to de-select them. The options are:

(a) Keep DR (Dead Reckoning) position and time
(b) Calculate GHA and DEC automatically[2]
(c) Keep existing sight results.

Clicking (a) or (c) will cancel the sights held in the system. If the selection is left untouched, the system will load the currently saved entries into the dialog boxes for cancellation, editing and amendment. Sight Data can be changed and this option does not prevent future editing.

Clicking (b) allows you to choose the method of computing the GHA and DEC.

Select 'OK' to continue or 'Re-Do' to return to the previous screen.

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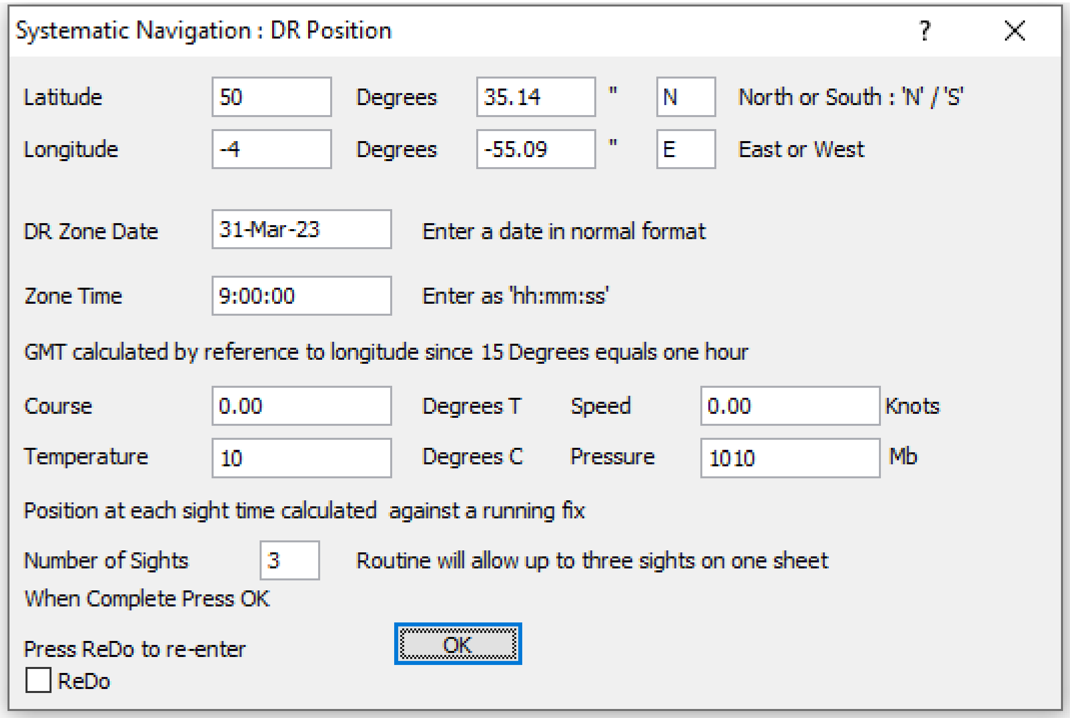
[2] Explained in section 4.1.

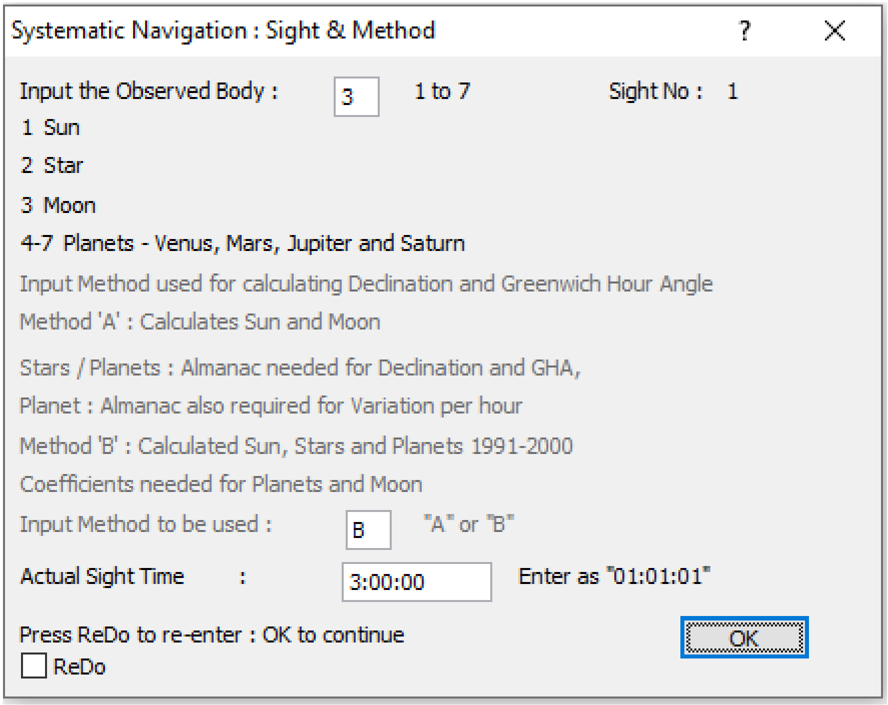
(5) A box requesting the DR position and zone time together with any course and speed between the DR position and the sights (if applicable). You should also enter the number of sights (maximum three). However, if one or two are entered and you chose the retention of current data, any sight numbers above the number of sights chosen will be erased when calculating fixes. Press 'OK' to continue or 'Re-Do' to return to the Main Menu.

Note: the zone time is calculated with reference to longitude and no account is taken of any local time differences e.g. winter and Summer time.

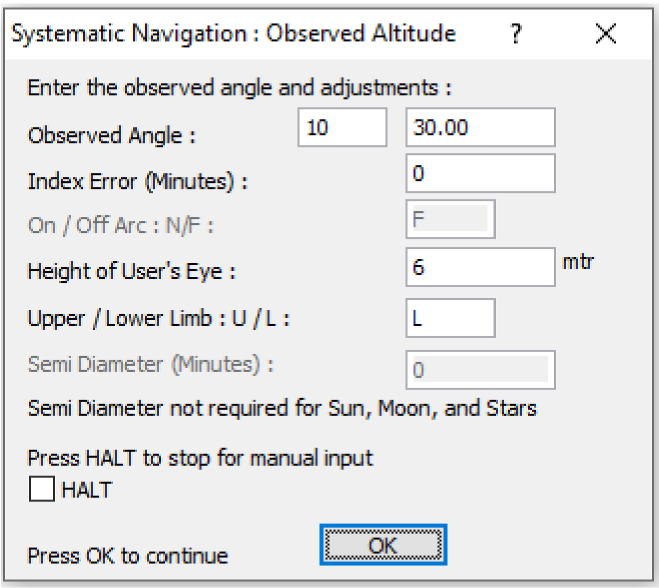
For stars, there is a subroutine for identifying stars or using their number to check the attitude and bearing. See the 'Stars' section 7 below for a full explanation of the three options.



(6) The model prompts you for the body observed and the zone time or local mean time. GMT is calculated by reference to longitude e.g. 100' W = 100' W / (360' per day / 24 hours) = 6.67 hours rounded to 7.0 hours. If the calculation of GHA and DEC is set to automatic, as below, the explanation is dimmed and the relevant method is shown. 'A' for Calculated/Almanac and 'B' for *Compact Data*. Press 'OK' to continue or 'Re-Do' to return to the Main Menu.



(7) Input the Observed Angle. Input the angle in degrees and minutes together with the height of the user's eye i.e. the height above sea level. There are also prompts for the index or instrument error and whether the upper or lower limb was observed. Any items not required for the body observed will be dimmed. Press 'OK' to continue of 'Halt' to stop for manual input. If you select the latter, the system will enter all data so far entered and recalculate the model.

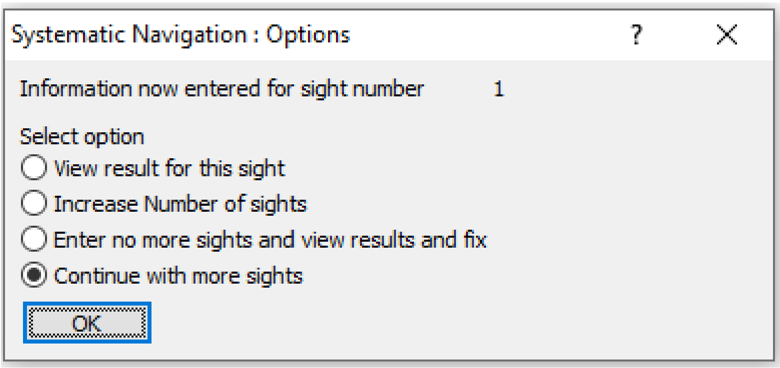


(8) The system now calculates GHA and DEC or prompts you for Almanac data for the day of the sight. If you opted to control the calculation of the GHA and DEC, a box reminds you how the ephemeris is being calculated or alternatively the system asks you for data such as the SHA and DEC.

(9) The information to calculate a position line is now complete and system prompts for:

(a) View result for this sight before continuing with other sights
(b) Increase the number of sights to a maximum of three
(c) Enter no more sights and view final results (and fix if two or more sights entered)
(d) Continue with more sights

The default setting continues with more sights if the sight number is less than the total entered on commencement. If (a) is selected then the system calculates, and the object bearing and azimuth are displayed together with the computed latitude and longitude position of the intercept. The model allows you to re-enter the sight details or press 'OK' to accept this result and continue with the next sight. When all sights have been entered, the options are greyed and the model defaults to calculating a fix.



(10) The system enters all the data on the 'Inputs' sheet as shown on the next page. It is divided into:

- DR Position
- Bodies observed, time and method of ephemeris calculation
- Altitude correction
- GHA, LHA and DEC
- Azimuth and Intercept
- Calculated position and confidence ellipse

Further pages detail the calculations for GHA and LHA, DEC, Observed Altitude (Ho), Computed Altitude (Hc) and the derivation of the statistical fix and error probability.

DR Position:				**Calculated Position:**			English	English
DR Latitude	50 ' N	35.14 "		50 ' N	31.71 "		**Confidence**	**95.00%**
DR Longitude	4 ' W	-55.09 "		4 ' W	58.57 "		**Ellipse**	
DR Zone Date	31-Mar-23	Friday		Distance	4.083 mls		**Latitude**	**3.22 mls**
Zone / GMT	9:00:00	09:00:00 GMT		Bearing	213.83 T		**Longitude**	**8.16 mls**
Course / Speed	0.00 T	0.00 kn					**Bearing**	**40.38 T**
	Sight # 1			**Sight # 2**			**Sight # 3**	
Which Sight	3	Moon		2	Star		1	Sun
Method : 'A' or 'B'	A	Calculated		B	Polynomial		B	Polynomial
Actual Sight Time	3:00:00	03:00:00 GMT		4:28:32	04:28:32 GMT		8:55:00	08:55:00 GMT
Time Diff. / Miles	6:00 hrs	0.00 mls		4:31 hrs	0.00 mls		0:05 hrs	0.00 mls
Revised DR Position	50' 35.1" N	4' 55.1" W		50' 35.1" N	4' 55.1" W		50' 35.1" N	4' 55.1" W
DR Star Altitude '	0.00'	0		0.00'	0		0.00'	0
DR Star Bearing '	0.00 E	0		0.00 E	0		0.00 E	0
Star Number	0	0	Input Star No	40	Kochab		0	0
DR Alt. / Bearing	11' 26.4"	295' 14.78"		63' 46.75"	343' 7.84"		26' 18.62	118' 24.18"
Observed Angle	10 '	30.00 "		63 '	49.00 "		26 '	10.00 "
Index Error : Minutes	0.00 "			0.00 "			0.00 "	
On/Off the Arc : N/F	F	Off Arc		F	Off Arc		F	Off Arc
Height of User's Eye	6.00 mtr			6.00 mtr			6.00 mtr	
Upper / Lower Limb	L	Lower		L	Lower		L	Lower
Moon HP/SD	0.00 "	54.1"/14.7"	Calc. HP/SD	0.00 "	0"	Calc. HP/SD	0.00 "	16"
Corrected Altitude	11' 28.38"			63' 44.21"			26' 19.85"	
Calc Moon DEC	0 ' N	0.00 "	Calc. DEC	0 ' N	0.00 "	Calc. DEC	0 ' N	0.00 "
	0 '	0.00 "		0 '	0.00 "		0 '	0.00 "
	0 '	0.00 "		0 '	0.00 "		0 '	0.00 "
Moon Declination	24' 44.98"	North	Star DEC	74' 3.4"	North	Sun DEC	4' 6.71"	North
Calc Moon GHA	0 ' E	0.00 "	Calc. GHA	0 ' E	0.00 "	Calc. GHA	0 ' E	0.00 "
	0 '	0.00 "		0 '	0.00 "		0 '	0.00 "
	0 '	0.00 "		0 '	0.00 "		0 '	0.00 "
Moon GHA / LHA	107' 26.94"	102' 31.85"	Star LHA	32' 44.58"	27' 49.49"	Sun LHA	312' 40.96"	307' 45.87"
Azimuth / Bearing	**295' 14.78"**	**295' 14.78"**		**343' 7.84"**	**163' 7.84"**		**118' 24.18"**	**118' 24.18"**
Intercept : Miles	**1.99 mls**	**Towards**		**2.53 mls**	**Away**		**1.23 mls**	**Towards**
Calc. Position	**50' 36"N**	**4' 57.8"W**		**50' 32.8"N**	**4' 54"W**		**50' 34.6"N**	**4' 53.5"W**

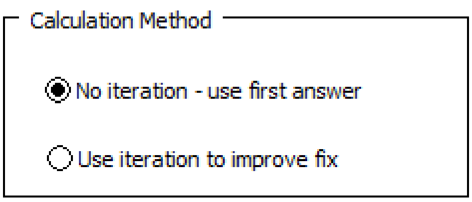
(11) The screen shows a 'best-fit' calculated position with the latitude and longitude and the distance and true bearing from the DR position. The model uses the least squares method from *Compact Data* et al. to produce a most probable position within a confidence ellipse of 95%. To produce an accurate fix, three sights are normally required with some angle between them to provide a 'good cut'. A summary of the position lines for other sights is included.

If any sights are inaccurate such that the intercept is greater than 500 miles, the system will not compute a fix and will display an error message. Similarly, the system will not compute a fix with only one sight although it will derive the latitude longitude position of the observation from a single azimuth and intercept.

Press 'OK' to continue to print, view and 'Re-Do' options. The following show the background calculations on the two other pages on the Inputs schedule.

This is the first page of workings showing the Greenwich Hour Angle, Declination, Polynomial Coefficients (if used) and the corrected altitude. The methodology follows *The Nautical Almanac*. These figures are summarised on the first page and on the Results schedule.

You can improve the position fix by selecting iteration on the Inputs sheet. This will attempt to converge and improve the solution.



(A) GHA and DEC Workings

Sun DEC & GHA	Sight (1)	6.00 hrs	Sight (2)	18.00 hrs	Sight (3)
Sun DEC	0.000'	0.000'	0.000'	0.000'	1.000'
Convert to Radians	0.000	0.000	0.000	0.000	0.017
V	0.000	0.000	0.000	0.000	0.000
DEC : E	0.000	0.000	0.000	0.000	0.000
Declination in Degrees	0.000'	0.000'	0.000'	0.000'	0.000'
X	0.000	0.000	0.000	0.000	0.000
Add to 180'	0.000'	0.000'	0.000'	0.000'	0.000'
Calculated Sun GHA	0.000'	0.000'	0.000'	0.000'	0.000'
LHA Time	0:00:00		0:00:00		0:00:00

Star DEC and GHA

Star	Sight (1)	Sight (2)	Sight (3)
DEC Degrees	0 '	0 '	0 '
Minutes	0.00 "	0.00	0.00
Decimal DEC	0.0000 N	0.0000 N	0.0000 N
SHA	0 E	0 E	0 E
Minutes	0.00 "	0.000	0.000
Decimal SHA	0.0000 E	0.0000 E	0.0000 E
SHA + Calc GHA Aries	0	0	0
Calc Star GHA	0.0000 E	0.0000 E	0.0000 E

Polynomial Coefficients

Sun and Planets	Sight (1)			Sight (2)			Sight (3)	
	GHA	DEC		GHA	DEC		GHA	DEC
Coefficient 0	0.0000000	0.0000000		237.2095000	74.0706000		11.7895100	-8.1488000
Coefficient 1	0.0000000	0.0000000		1.0000017	-0.0000131		0.0956700	12.0737000
Coefficient 2	0.0000000	0.0000000		-0.0162000	-0.0033000		0.0811200	0.9736000
Coefficient 3	0.0000000	0.0000000		0.0117000	-0.0046000		-0.0388300	-0.5207000
Coefficient 4	0.0000000	0.0000000		0.0000000	0.0000000		0.0045100	-0.0228000
Check Sum	0.0000000	0.0000000		238.2050017	74.0626869		11.9319800	4.3550000
Days : X	0.0000	0.0000		0.9746	808.4147		0.9804	808.5971
Calculated	0.0000'	0.0000'		1045.6097'	74.0566'		11.9288'	4.1118'
GHA and DEC	0.0000'	0.0000'		1112.7430'	74.0566'		312.6827'	4.1118'
Coefficient A0	0.00000	Polar Stars onl	0.0000'	0.00000	Polar Stars onl	0.0000'	0.26910	Polar Stars only
Coefficient A1	0.00000	C. Alt.	0.0000'	0.00000	C. Alt.	0.0000'	-0.00230	0.0000'
Check Sum	0.00000		0.0000'	0.00000		0.0000'	0.26680	0.0000'
SemiDiameter	0.0000'		0.0000'	0.0000'		0.0000'	0.2668'	0.0000'
S-D Minutes	0.00 "	Azimuth	0.0000'	0.00 "	Azimuth	0.0000'	16.01 "	0.0000'

(B) Calculated GHA and DEC

GHA	Sight (1)	Sight (2)	Sight (3)
Moon GHA	0.000 E	0.000 E	0.000 E
Mean Variation	0.0000'	0.0000'	0.0000'
Correction	0.0000'	0.0000'	0.0000'
Moon GHA	107.4609'	32.7430'	312.6827'
GHA+Long.	102.5428'	27.8249'	307.7646'
Final LHA	102.5428'	27.8249'	307.7646'
Declination			
Moon DEC	0.000 N	0.000 N	0.000 N
Mean Variation	0.0000'	0.0000'	0.0000'
Variation	0.0000'	0.0000'	0.0000'
Moon Declination	24.7514'	74.0566'	4.1118'

(C) Corrected Altitude (Decimals)

Altitude	Sight (1)		Sight (2)	0	Sight (3)	
Observed (Hs)		10.5000'		63.8167'		26.1667'
Index Error (I)	0.0000'		0.0000'		0.0000'	
DIP - Height (D=0.0293*SqrtH)	-0.0718"		-0.0718"		-0.0718"	
Apparent Altitude (H=Hs+I-D)		10.4282'		63.7449'		26.0949'
Ro=0.0167/tan(H+7.32)/(h+4.32))	0.0865'	0.0880'	0.0082'	0.0080'	0.0337'	0.0331'
f=0.28*Pressure*(Temp+273)	0.9993'		0.9993'		0.9993'	
Refraction (R=Ro*f)		0.0865'		0.0080'		0.0331'
Oblateness of Earth (OB)		-0.0017'		0.0000'		0.0000'
Parallax (HP)	0.9027'		0.0000'		0.0024'	
Parallax Altitude (PA=HP*cosH)		0.8878'		0.0000'		0.0022'
Semi Diameter (S)		0.2459'		0.0000'		0.2668'
Corr. Altitude (Ho=H-R+PA+S)		11.4737'		63.7369'		26.3308'

The third page of workings derive the intercept and azimuth from the computed angle and the fix position using the method of 'least squares'. It also calculates the standard deviation and the estimated position error.

(D) Sight Reduction

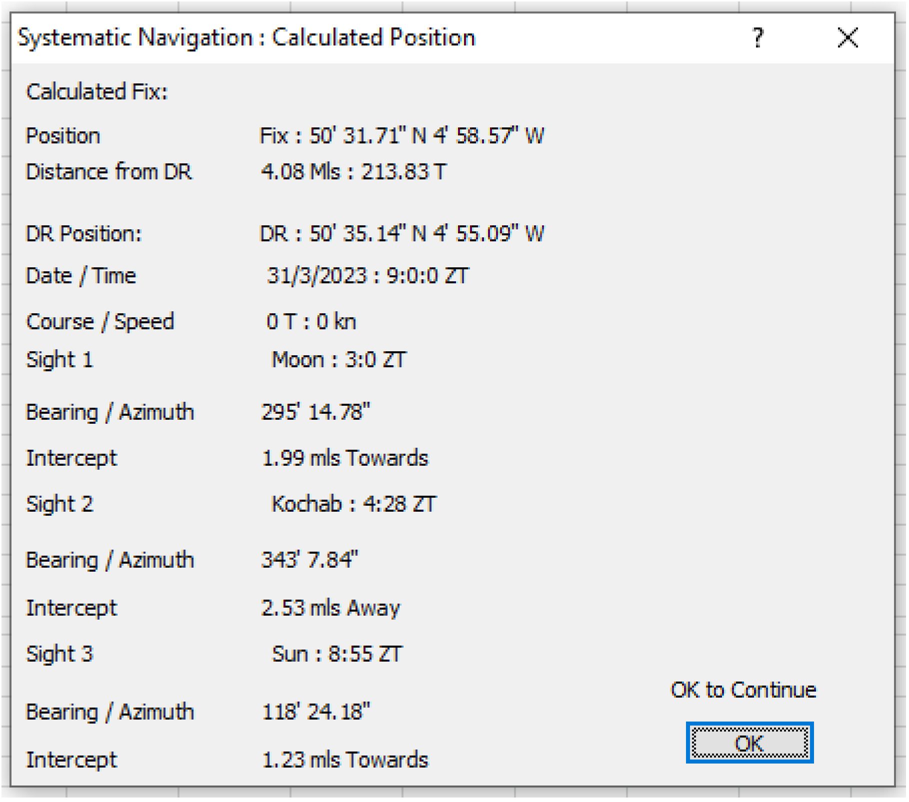
Altitude	Sight (1)	Sight (2)	Sight (3)
Computed Altitude (Hc)	0.1996'	1.1132'	0.4592'
Angle in Degrees	11.4342'	63.7790'	26.3105'
Azimuth Angle	1.1300'	0.2944'	2.0665'
Angle in Degrees	64 ' 44.63"	16 ' 52.16"	118 ' 24.18"
Corrected Azimuth (Z)	295.2561'	343.1306'	118.4031'
Angle in Degrees	295' 15.37"	343' 7.84"	118' 24.18"
Latitude Difference (P)	0.0395'	0.0421'	0.0204'
Latitude as Miles	2.37 mls	2.53 mls	1.22 mls
Towards / Away	Towards	Away	Towards

(E) Computed Position

Position	Sight (1)			Sight (2)		Sight (3)	
Azimuth 1	295.256'	1	295.256'				
Course	0.00 T						
Distance2	0.0000'						
U=90+G	385.256'						
Take out Excess 360	565.256'	205.256'					
U	0.000	0.000'					
W+U	0.040'	0.040'					
Take out Excess 360	475.256	115.256'					
Latitude	50.586 N	50 N	35.14 "				
Longitude	4.918 W	4 W	-55.09 "				
True Azimuth Bearing (Z)	295.256 T	2.37 mls		163.131 T	2.53 mls	118.403 T	1.22 mls
Plot Position / Direction	025.26 T	NW		073.13 T	SE	028.40 T	SE
Distance	-2.14 mls	1.01 mls		0.73 mls	-2.42 mls	1.07 mls	-0.58 mls
Bearing Miles	2.144 W	1.011 N		0.733 E	2.419 S	1.075 E	0.581 S
Latitude/Longitude	0.054 W	0.016 E		0.018 E	0.039 S	0.027 E	0.009 S
Revised Fix Position	4.972 W	50.602 N		4.900 W	50.547 N	4.891 W	50.576 N
Minutes	58.3277	36.1068		53.9770	32.8140	53.4613	34.5782

(F) Fix : Method of Least Squares

				(G) Estimated Position Error	
A	1.32410	A+C = Sights	3.000	Standard Deviation	2.3784 mls
B	-1.08200	No of Sights	3	Deviation Longitude	2.6730 mls
C	1.67590			Deviation Latitude	3.0072 mls
D	-0.03314			2 X Tan	6.151'
E	-0.00559			Atan / 2 = Ellipse Azimuth	40.383'
F	0.00375			Probability P=0.95 Scale Facto	2.4477
G = AC-B^2	1.04834			A : X	9.1617 mls
				B : Y	3.6132 mls



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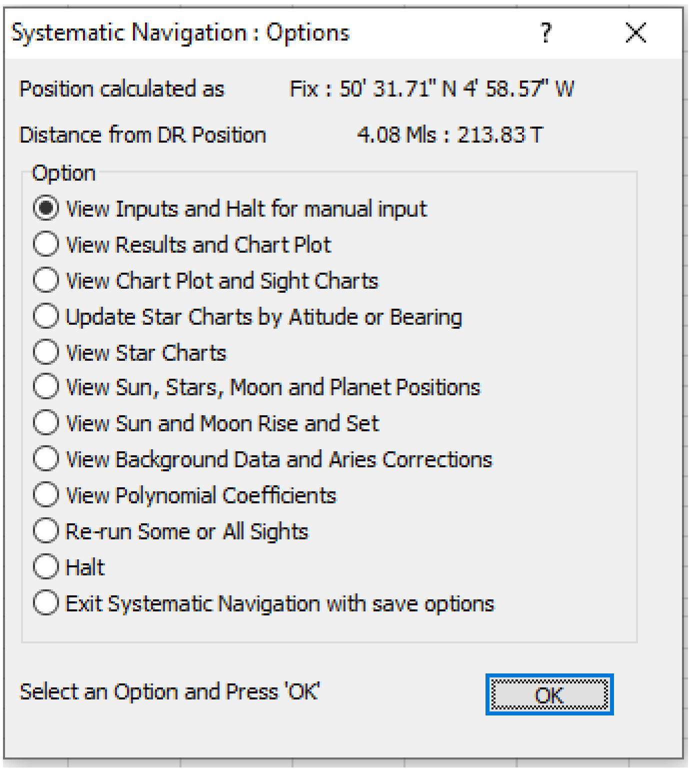
(12) The system displays an options box repeating the Calculated Position and requesting the next action:

1. View input sheet and halt for manual input.
2. View results and chart plot.
3. View chart plot and sights charts.
4. Update and sort stars charts by SHA, altitude or bearing.
5. View stars charts.
6. View Sun, Moon, Planets and Stars positions.
7. View Sun and Moon rise and set and Sun transits.
8. View background data and Aries corrections.
9. View polynomial coefficients for the date of the sights.
10. Re-Run some or all of the sights.
11. Halt for manual input.
12. Quit Astro Navigation and return to Windows with an option to save files.

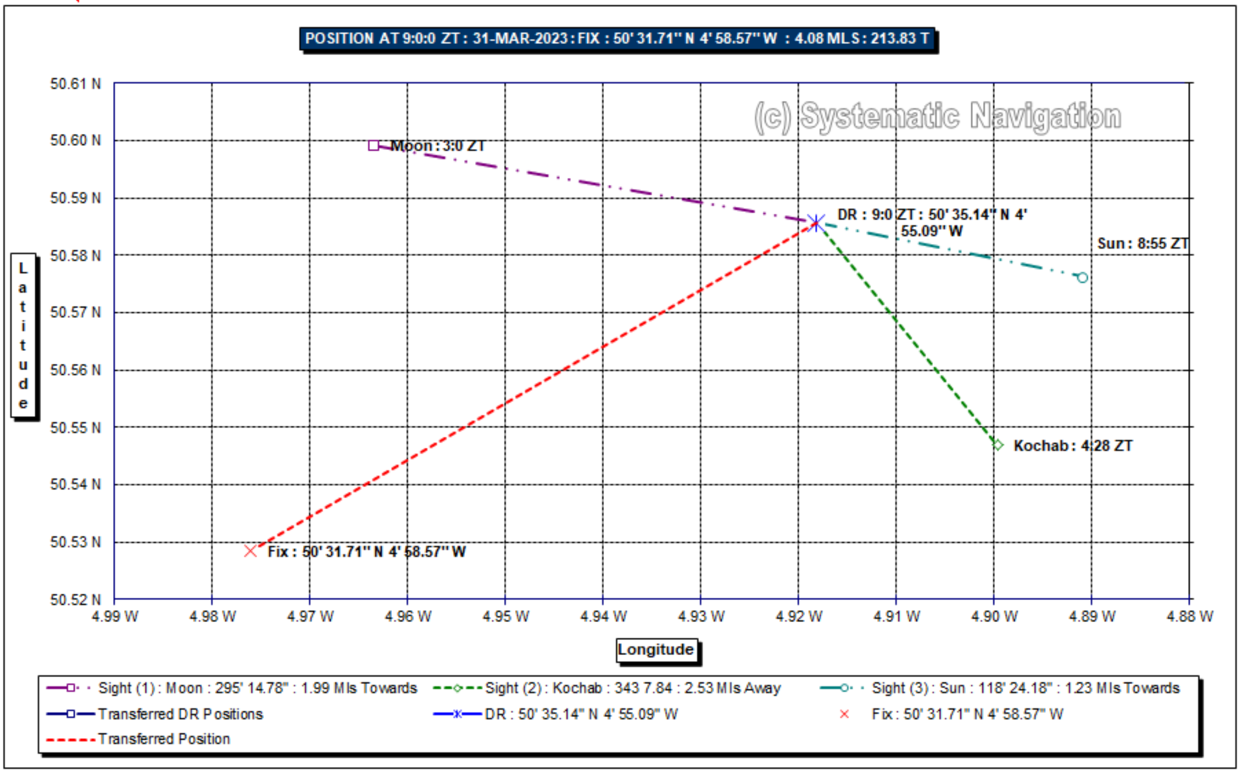
If you press ‘Halt’, then the system displays the Welcome sheet. Use the tabs at the bottom to activate any of the other sheets. You can review all data on the Inputs sheet.



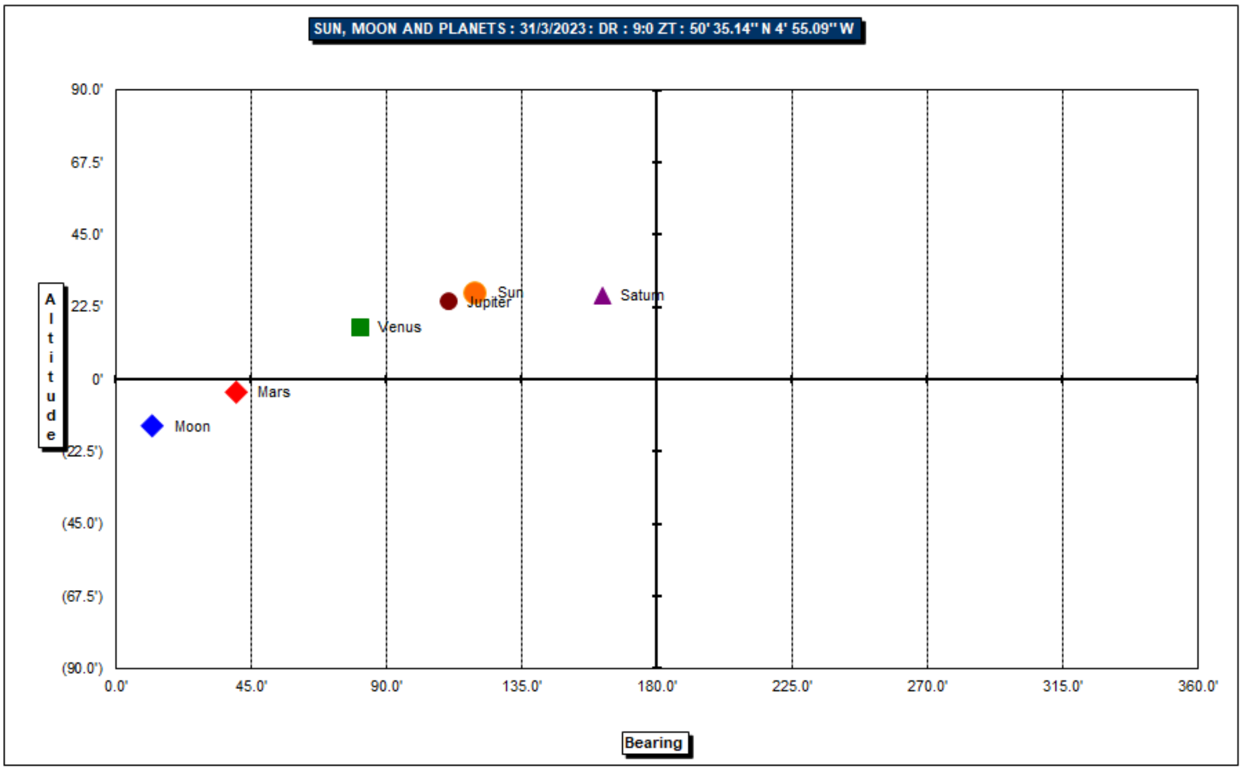
(13) *Systematic Navigation* will halt for you on the chosen schedule for you to review the results. If you want to re-enter the sights, you can press the 'Main Menu' buttons on the schedule or select 'Main Menu' from the pull-down menus.

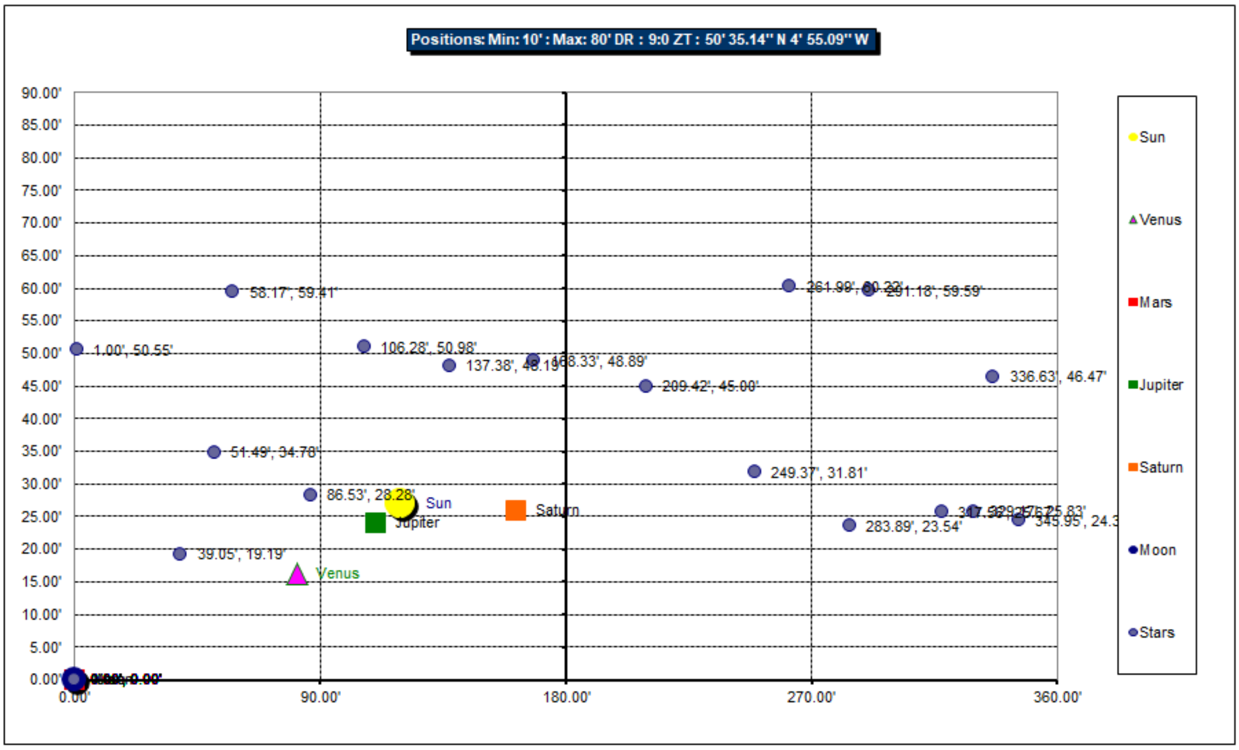
Press the button to save the results sheet with its chart plot to a new file. The system will prompt you for a name, but the default is Year-Month-Day.xls i.e. '23Mar31.xls'. This way you can keep a full record of the inputs, intermediate calculations and results.

(14) You have the choice of chart plots or a combined results and chart plot. Examples of the Results sheet are in the worked examples. These are example chart plots from the SightCharts schedule for 31 March 2023 at GMT 9:0:0 from an assumed position of 50'N 35" 4'W 55.09":

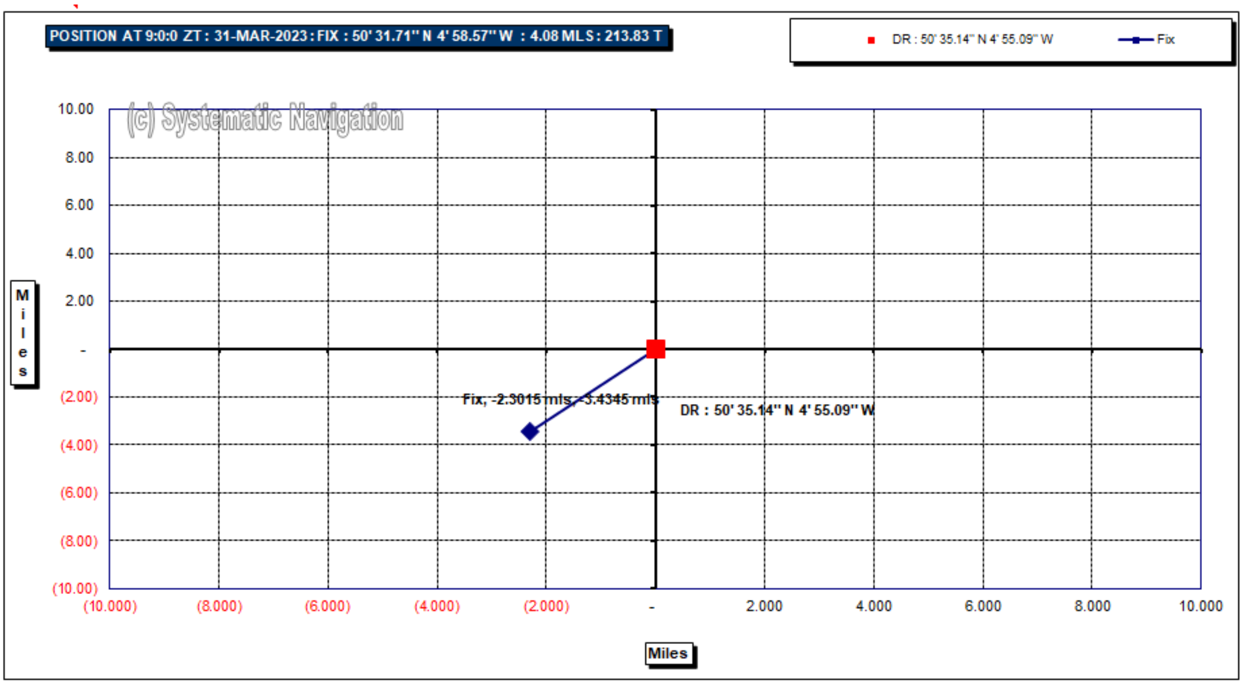


There is also a plot of the Sun, Moon and Planets on the SightCharts schedule:





A further sheet provides a plot of the relative bearing of the fix from the DR position.



The following sections provide an explanation of each body by method with the inputs required and the options available at each stage. If 'Automatic Calculation' is left selected (see Section 4.2) *Systematic Navigation* will compute ephemeris without recourse to you for any data inputs. The following sections assume that you have chosen to select the manual method of derivation of GHA and DEC.

5 Sun

5.1 Method A - Aries

Select 'A' and the routine will move to the Observed Angle and thereafter the system displays a box informing you that the GHA and Declination are automatically calculated. Press 'OK' to continue and the system displays the option box to denote the end of the required inputs for the sight.

Example: The GHA and DEC of the Sun on October 22, 1996 at GMT 21:43:25[3]

Sun GHA and DEC	Calculations
Sun DEC U	288.723'
V	209.770
DEC : E	-0.199
Declination in Degrees	**-11.3920'**
X	0.483
Add to 180'	468.723'
Calculated Sun GHA	509.760'
Sun GHA	**149.7600' (removing multiples of 360')**

The above uses two annual update quantities P and Q which are located on a look-up table on the Aries schedule. These are the mean anomaly on day 0 of the year and the earth's longitude at perihelion. The values for 1996 are -3.9212 and 77.1260 respectively.

A further variable B is the decimal time from day 0 of the year to the GMT sight time where hours of the day are also expressed as decimals.

Example: 22 October 1996 at GMT 21:43:25

22 October 1996 - 0 January 1996 = 296 days

GMT 21:43:25 = (21.723611 / 24) = 0.905150

B = 296 days + 0.905150 hours = 296.905150

The algorithms used by the model are:

(1) DEC

U = (0.9856 * B) + P
V = U + (1.916 * sin U) + (0.02 * sin (2 * U)) - Q
DEC = Asn (0.3978 + sin V)

(2) GHA

X = Atn (0.9175 * tan V)
If sign (sin X) <> sign (sin V) then U = U + 180
GHA = 360 * (B- Integer (B)) + U - X - 180 -Q

If necessary, remove multiples of 360' to place the result in the range 0 to 360'.

(3) Semi-diameter

The model uses a standard semi-diameter for the Sun of 16" (0.266667')

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[3] Example from page 278 of *The Nautical Almanac 1996*. GHA = 149.7604', DEC = 11.3892'S

5.2 Method B - Polynomial Coefficients

The procedure is automatic as 'A' above. Note that the information box on the calculation is not displayed if the user has selected the calculation to automatic ('B'). For years other than 1991-2025, the model will request the polynomial coefficients from for the relevant month from *Compact Data*.

This is the same example as above and the answers are very similar. The coefficients are selected from the tables for the month and year. The semi-diameter is also calculated at 16.11".

Sun GHA and DEC	**GHA**	**DEC**
a_0	12.1661800	-2.8211000
a_1	0.1757000	-12.4213000
a_2	-0.0443100	0.2145000
a_3	-0.0241800	0.5750000
a_4	0.0000700	0.0070000
Check Sum	12.2734600	-14.4459000
Days : X	0.7158	
Calculated	12.2604'	-11.3895'
GHA and DEC	**509.7600'**	**-11.3895'**
GHA (Removing multiples of 360')	**149.7600'**	
a_0	0.26670	
a_1	0.00240	
Sum	0.26910	
Semi-diameter in degrees	0.2684'	
Semi-diameter in Minutes	**16.11"**	

The calculations in the model using the coefficients are:

Time variable x = (d + GMT / 24) / 32.

d is the day in the month and GMT the universal time in hours.

Using the example in the previous section: [22 + (21.7236 / 24)] / 32 = 0.715786

Using x, (GHA - GMT) in hours and DEC in degrees are derived from this expression:

$$a_0 + (a_1 * x) + (a_2 * x^2) + (a_3 * x^3) + (a_4 * x^4)$$

This can be rewritten for use with pocket calculators:

$$(((a_4 * x + a_3) * x + a_2) * x + a_1) * x + a_0$$

You can convert the GHA in hours to degrees by adding GMT and multiplying the result by 15 to convert from hours to degrees.

The semi-diameter is calculated using the expression $S = a_0 + (a_1 * x)$

6 Stars

6.1 Method A - Almanac

The system displays a box requesting the Sidereal Hour Angle and Declination for the day of the sight. Daily/hourly corrections are dimmed since these are only needed for the Planets. The user therefore need only input two numbers for this method. It can be used to check any sight using the *Compact Data* where the result appears to be inaccurate.

Example: The GHA and DEC of *Aldebaran* (10) on 3 February 1996 at GMT 17:23:17[4].

To derive the star's GHA, the system calculates the GHA of Aries as:

$GHA_{(Aries)} = R + (360.985647 * B)$

B is the number of decimal days from day 0 of the year to the time of sight. R is the Aries coefficient constant for the year and gained from a look-up table on the Aries schedule. In this example Aries is 33.9998'.

$GHA_{(Aries)}$ is added to the SHA, 291.0733', to produce the GHA for the star as 325.0732'.

The model uses the Declination you input since this variable changes very slowly. The almanacs contain a list of the 57 navigational stars plus the polar stars *Polaris* (58) and *Octantis* (59). There is usually a list showing the star together with the integer SHA and GHA and then the minutes to be applied for each month.

6.2 Method B - Polynomial Coefficients

The model contains the data for 1991-2025 on five-year tables. Using the example above, the system looks up the coefficients and calculates the GHA and DEC

Star GHA and DEC	GHA	DEC
a_0	30.0283000	-16.4990000
a_1	0.9999605	0.0000058
a_2	0.0028000	-0.0009000
a_3	-0.0052000	0.0005000
a_4	0.0000700	0.0000000
Check Sum	31.0258605	16.4986058
L		34.226'
Calculated	64.2503'	34.226'
GHA and DEC	**325.0712'**	**16.4991'**

The algorithms are similar to the Sun:

Calculate L = 0.9856474 * (D + d + GMT / 24)

D = Number of days from 0:0:0 on 1/1/91 or 1/1/96. d is the day of the month.

For information $GHA_{(Aries)}$ can be derived from 98.9513' + L + (15 * GMT in decimal hours)

The expressions for the GHA and DEC are:

$GHA = a_0 + (a_1 * L) + (a_2 * \sin L) + (a_3 * \cos L) + (15 * \text{GMT in decimal hours})$

$DEC = a_0 + (a_1 * L) + (a_2 * \sin L) + (a_3 * \cos L)$

No semi-diameter is required for stars.

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[4] Example from *Macmillan & Silk Cut Nautical Almanac Astro-Supplement* 1996, Page 39. The answers given are DEC = N 16' 30" and GHA = 324' 34.8" (324.58'). There is an addition error in the text since GHA(Aries) is calculated from the tables as 33.998' and SHA as 291.0733'. These add up to 325.0716' (325' 4.2980") not 324.580' (324' 34.8").

6.3 Polar Stars

You can use the model to calculate latitude with the polar stars e.g. the latitude of the observer when *Polaris* (58) is observed at 50’ 27.82’’ at GMT 17:23:17 on 15 January 1997 at longitude 1’E 15’’[5].

The model provides the answer: Latitude = 49.7170' (49’N 42.57”). Azimuth = 1.250’ (1’E 17.8”).

DR Position:				**Calculated Position:**			A	English
DR Latitude	49 ' N	43.00 "		50 ' N	24.79 "		**Confidence**	**0.00%**
DR Longitude	1 ' E	15.00 "		1 ' E	45.35 "		**Ellipse**	
DR Zone Date	15-Jan-97	Wednesday		Distance	46.164 mls		**Latitude**	**0.00 mls**
Zone / GMT	17:23:17	17:23 GMT		Bearing	25.90 T		**Longitude**	**0.00 mls**
Course / Speed	0.00 T	0.00 kn					**Bearing**	**N/A**
	Sight # 1			**Sight # 2**			**Sight # 3**	
Which Sight/Name	2	Star		2	Star		0	N/K
Method : 'A' or 'B'	B	Polynomial		B	Polynomial		A	Almanac
Actual Sight Time	17:23:17	17:23 GMT		17:23:17	17:23 GMT		0:00:00	00:00 GMT
Time Diff. / Miles	0:00 hrs	0.00 mls		0:00 hrs	0.00 mls		0:00 hrs	0.00 mls
Revised DR Position	49' 43" N	1' 15" E		49' 43" N	1' 15" E		0	0
DR Star Altitude '	0.00'	0		0.00'	0		0.00'	0
DR Star Bearing '	0.00 E	0		0.00 E	0		0.00 E	0
Star Number	58	Polaris	Input Star No	10	Aldebaran		0	0
DR Alt. / Bearing	49 ' 42.59"	0 ' 24.14"		36 ' 57.03"	109 ' 44.49"		0	0 ' 0"
Observed Angle	50 '	27.82 "		37 '	2.70 "		0 '	0.00 "
Index Error : Minutes	0.00 "			0.00 "			0.00 "	
On/Off the Arc : N/F	F	Off Arc		F	Off Arc		F	Off Arc
Height of User's Eye	2.00 mtr			0.00 mtr			6.00 mtr	
Enter 'L'	L	Lower		L	Lower		L	Lower
Calc. HP / SD	0.00 "	0"	Calc. HP/SD	0.00 "	0"	Planet Corr.	0.00 "	0"
Corrected Altitude	50' 24.51"			37' 1.38"			0' 0"	
Calc. Declination	0 ' N	0.00 "	Calc. DEC	0 ' N	0.00 "	Input DEC	0 ' N	0.00 "
	0 '	0.00 "		0 '	0.00 "		0 '	0.00 "
	0 '	0.00 "		0 '	0.00 "		0 '	0.00 "
Star Declination	0' 44.7"	North	Star DEC	16' 30.08"	North	N/K DEC	0' 0"	North
Calc. GHA	0 ' E	0.00 "	Calc. GHA	0 ' E	0.00 "	Input GHA	0 ' E	0.00 "
	0 '	0.00 "		0 '	0.00 "		0 '	0.00 "
	0 '	0.00 "		0 '	0.00 "		0 '	0.00 "
Star GHA / LHA	338' 37.21"	339' 52.21"	Star LHA	307' 4.55"	308' 19.55"	N/K LHA	0' 0"	0' 0"

The model calculates Aries and then GHA and p (polar distance) using polynomial coefficients:

$$L = 0.9856474 * (D + d + GMT / 24)$$

$$GHA = a_0 + (a_1 * L) + (a_2 * \sin L) + (a_3 * \cos L) + (15 * \text{GMT in decimal hours})$$

$$p = a_0 + (a_1 * L) + (a_2 * \sin L) + (a_3 * \cos L)$$

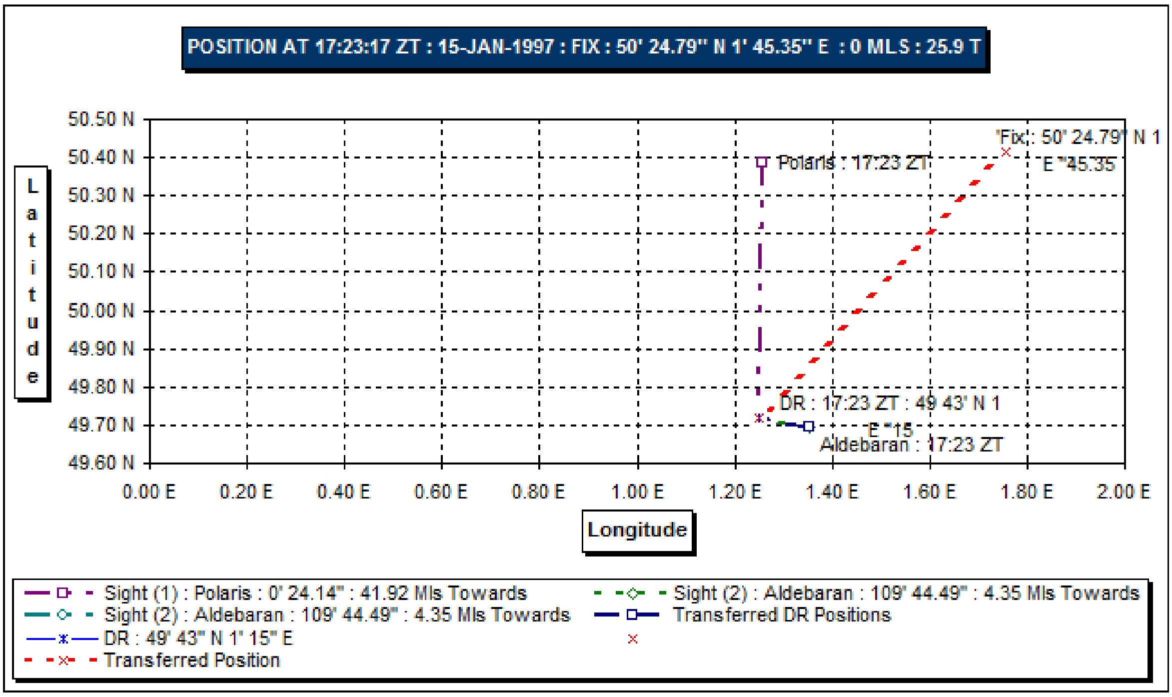
It calculates the LHA = (GHA + longitude in hours). Ho = Observed Altitude

$$\text{Latitude} = Ho - (p * \cos LHA) + 0.0087 * (p * \sin LHA) * (p * \sin LHA) * \tan Ho$$

Azimuth of *Polaris* (58) $= 0 - (p * \sin LHA) / \cos Ho$

Azimuth of *Octantis* (59) $= 180 + (p * \sin LHA) / \cos Ho$

[5] Example from *Macmillan & Silk Cut Nautical Almanac Astro-Supplement* 1997, Page 39. Answer given as 49’N 42” for the latitude and 0’ for the azimuth.



POSITION AT 17:23:17 ZT : 15-JAN-1997 : FIX : 50' 24.79" N 1' 45.35" E : 0 MLS : 25.9 T
Latitude
Longitude
50.50 N
50.40 N
50.30 N
50.20 N
50.10 N
50.00 N
49.90 N
49.80 N
49.70 N
49.60 N
0.00 E
0.20 E
0.40 E
0.60 E
0.80 E
1.00 E
1.20 E
1.40 E
1.60 E
1.80 E
2.00 E
Polaris : 17:23 ZT
Aldebaran : 17:23 ZT
Sight (1) : Polaris : 0' 24.14" : 41.92 Mls Towards
Sight (2) : Aldebaran : 109' 44.49" : 4.35 Mls Towards
Sight (2) : Aldebaran : 109' 44.49" : 4.35 Mls Towards
Transferred DR Positions
DR : 49' 43" N 1' 15" E
Transferred Position

7 Star Charts

7.1 Star Numbers

Systematic Navigation like *The Nautical Almanac* uses this list to identify stars by number. The example above uses star *Aldebaran* (10) which had an SHA of 291' in 1996. This table assumed a date of 1996.

Identification						GHA				DEC
No	Star	Mag	Letter	Constellation	Abreviation	a0	a1	a2	a3	a0
1	Alpheratz	2.2	A	Andromedae	And	97.51430	0.9999645	0.00590	0.00070	29.20420
2	Ankaa	2.4	A	Phoenicis	Phe	93.05250	0.9999650	0.00710	0.00040	(42.19390)
3	Schedar	2.5	A	Cassiopaiae	Cas	89.45700	0.9999613	0.00950	(0.00040)	56.65030
4	Diphda	2.2	B	Ceti	Cet	88.72210	0.9999649	0.00550	(0.00020)	(17.87360)
5	Achernar	0.6	A	Eridani	Eri	75.25720	0.9999736	0.00940	(0.00270)	(57.13220)
6	Hamal	2.2	A	Arietis	Ari	67.79340	0.9999607	0.00530	(0.00240)	23.55950
7	Acamar	3.1	H	Eridani	Eri	55.11700	0.9999739	0.00570	(0.00430)	(40.22220)
8	Menkar	2.8	A	Ceti	Cet	54.03840	0.9999636	0.00430	(0.00340)	4.17010
9	Mirfak	1.9	A	Persei	Per	48.42750	0.9999495	0.00620	(0.00600)	49.93360
10	Aldebaran	1.1	A	Tauri	Tau	30.60180	0.9999598	0.00290	(0.00520)	16.55000
11	Rigel	0.3	B	Orionis	Ori	20.99580	0.9999668	0.00200	(0.00540)	(8.17840)
12	Capella	0.2	A	Aurigae	Aur	20.32440	0.9999473	0.00270	(0.00770)	46.01760
13	Bellatrix	1.7	C	Orionis	Ori	18.31870	0.9999626	0.00170	(0.00550)	6.36770
14	Elnath	1.8	A	Tauri	Tau	17.97900	0.9999554	0.00190	(0.00620)	28.62380
15	Alnilam	1.8	E	Orionis	Ori	15.56300	0.9999648	0.00150	(0.00550)	(1.18940)
16	Betelgeuse	0.5	A	Orionis	Ori	10.80600	0.9999622	0.00110	(0.00560)	7.41020
17	Canopus	-0.9	A	Carinae	Car	3.77590	0.9999866	0.00070	(0.00930)	(52.70670)
18	Sirius	-1.6	A	Canis Majoris	CMa	358.36410	0.9999699	-	(0.00590)	(16.74500)
19	Adhara	1.6	E	Canis Majoris	CMa	355.01920	0.9999736	(0.00040)	(0.00650)	(29.00040)
20	Procyon	0.5	A	Canis Minoris	CMi	344.78330	0.9999635	(0.00120)	(0.00550)	5.17130
21	Pollux	1.2	B	Geminorum	Gem	343.23440	0.9999567	(0.00160)	(0.00610)	27.97560
22	Avior	1.7	E	Carinae	Car	334.14540	0.9999889	(0.00430)	(0.01010)	(59.57560)
23	Suhail	2.2	L	Velorum	Vel	322.69000	0.9999761	(0.00430)	(0.00620)	(43.51600)
24	Miaplacidus	1.8	B	Carinae	Car	321.52570	0.9999975	(0.00920)	(0.01280)	(69.80170)
25	Alphard	2.2	A	Hydrae	Hya	317.72820	0.9999661	(0.00350)	(0.00420)	(8.74830)
26	Regulus	1.3	A	Leonis	Leo	307.51110	0.9999628	(0.00420)	(0.00350)	11.86610
27	Dubhe	2.0	A	Ursae Majoris	UMa	293.63090	0.9999553	(0.01000)	(0.00450)	61.63960
28	Denebola	2.2	B	Leonis	Leo	282.35060	0.9999643	(0.00530)	(0.00120)	14.45680
29	Gienah	2.8	C	Corvi	Crv	275.66120	0.9999645	(0.00550)	(0.00050)	(17.65640)
30	Acrux	1.1	A	Crucis	Cru	272.93910	0.9999626	(0.01160)	(0.00060)	(63.21340)
31	Gacrux	1.6	C	Crucis	Cru	271.79910	0.9999623	(0.00970)	(0.00030)	(57.22860)
32	Alioth	1.7	E	Ursae Majoris	UMa	266.14430	0.9999686	(0.00930)	0.00090	55.84800
33	Spica	1.2	A	Virginis	Vir	258.30790	0.9999634	(0.00530)	0.00120	(11.26870)
34	Alkaid	1.9	G	Ursae Majoris	UMa	252.78950	0.9999723	(0.00770)	0.00280	49.21050
35	Hadar	0.9	B	Centauri	Cen	248.55540	0.9999506	(0.01000)	0.00420	(60.47190)
36	Menkent	2.3	H	Centauri	Cen	247.90310	0.9999590	(0.00610)	0.00270	(36.47100)
37	Arcturus	0.2	A	Bootis	Boo	245.72750	0.9999683	(0.00510)	0.00260	19.07510
38	Rigul Kentaurus	0.1	A	Centauri	Cen	239.62480	0.9999520	(0.00960)	0.00560	(60.91920)
39	Zubenelgenubi	2.9	A	Librae	A2Lib	236.87280	0.9999614	(0.00460)	0.00330	(16.12690)
40	Kochab	2.2	B	Ursae Minoris	UMi	237.20950	1.0000017	(0.01620)	0.01170	74.07060
41	Alphecca	2.3	A	Coronae Bor.	CrB	225.98760	0.9999708	(0.00430)	0.00450	26.64560
42	Antares	1.2	A	Scorpii	Sco	212.20960	0.9999568	(0.00320)	0.00540	(26.47690)
43	Atria	1.9	A	Triang. Aust.	TrA	207.16250	0.9999231	(0.00690)	0.01410	(69.06340)
44	Sabik	2.6	G	Ophiuchi	Oph	201.98770	0.9999598	(0.00210)	0.00550	(15.74960)
45	Shaula	1.7	L	Scorpii	Sco	196.12570	0.9999518	(0.00190)	0.00680	(37.11770)
46	Rasalhague	2.1	A	Ophiuchi	Oph	195.90520	0.9999680	(0.00160)	0.00560	12.54550
47	Eltanin	2.4	C	Draconis	Dra	190.60680	0.9999856	(0.00170)	0.00900	51.48630
48	Kaus Australis	2.0	E	Sagittarii	Sgr	183.49320	0.9999529	(0.00050)	0.00690	(34.37380)
49	Vega	0.1	A	Lyrae	Lyr	180.46900	0.9999777	(0.00020)	0.00730	38.80310
50	Nunki	2.1	S	Sagittarii	Sgr	175.74250	0.9999562	0.00030	0.00630	(26.27020)
51	Altair	0.9	A	Aquilae	Aql	161.93100	0.9999664	0.00150	0.00550	8.92340
52	Peacock	2.1	A	Pavonis	Pav	153.06100	0.9999429	0.00420	0.00920	(56.66790)
53	Deneb	1.3	A	Cygni	Cyg	149.34500	0.9999781	0.00370	0.00690	45.35410
54	Enif	2.5	E	Pegasi	Peg	133.57870	0.9999662	0.00380	0.00390	9.96990
55	Al Na'ir	2.2	A	Gruis	Gru	127.49660	0.9999549	0.00600	0.00500	(46.86070)
56	Fomalhaut	1.3	A	Piscis Aust.	PsA	115.18130	0.9999610	0.00540	0.00280	(29.51280)
57	Markab	2.6	A	Pegasi	Peg	113.43110	0.9999657	0.00500	0.00230	15.31630
58	Polaris	2.1	A	Ursae Minoris	UMi	55.44640	0.9989494	0.38620	(0.30990)	0.64880
59	Octantis	5.5	S	Octantis	Oct	138.42670	0.9993983	0.17260	0.21130	1.13000

7.2 Star Finder

The model allows you three methods of identifying and using stars. The model prompts you in the dialog boxes or you can select stars as one of the options on the End Results box.

Often you have a star sight and need to identify it or alternatively you can check a computed altitude and bearing before using the observation. The options are:

- Star Identification: A box requests the altitude and bearing of a star. Press 'Re-Do' to return to the previous screen or 'OK' to continue. Enter an altitude and bearing and the system calculates the star number and name from the list. Enter the star number and 'OK' to continue or 'Re-Do' to re-enter the altitude and bearing. The model then moves to request the Observed Angle.

Example: *Deneb* (53) at a bearing of 52'E and an altitude of 28.5' at 32'N 45'' 15'W 30'' on 9 February 1996 at GMT 07:03:52[6]. The system performs the mathematics 'backwards' and derives the DEC as 45.3817'N and the LHA as 278.6130'. The GHA is therefore 294.2691'.

Star Identification

Sight (1)				Sight (2)			
Bearing	0.000		0.0000	Bearing	52.000		0.1670
Altitude	0.000	LHA	0.0000 E	Altitude	28.500	LHA	279.6130 E
	0.0000'	GHA	0.0000 E		0.9556'	GHA	294.2691 E
DEC Rads	0.0000'	Aries	0.000	DEC Rads	0.7921'	Aries	14644.636
Declination	0.0000 N	Aries	0.0000 E	Declination	45.3817 N	Aries	244.6356 E
		SHA	0.0000 E			SHA	49.6335 E
		Integer	0			Integer	49
Satr SHA		Match No	0			Match No	53
Star Name		Star	0			Star	53 Deneb

The system calculates GHA(Aries) as 244.6356' and derives the Sidereal Hour Angle as 49.6335'. It then compares this to the list of SHA's and finds number 53 (Deneb) to be the best match.

- Star Finder: You are prompted to enter the star number on the Star Identification box. The identification is dimmed. Press 'OK' to continue or 'Re-Do' to return to the Options box. The altitude and bearing of the star is calculated using the sight reductions calculations below. The system calculates the altitude at 26.3608' and the bearing at 52.218' for *Deneb* (53) at the sight time and position.

(D) Sight Reduction

Altitude	Sight (1)	Sight (2)	Sight (3)
Computed Altitude (Hc)	0.6675'	0.4972'	0.3942'
Angle in Degrees	38.2463'	28.4863'	22.5850'
Azimuth Angle	2.2589'	0.9099'	2.2058'
Angle in Degrees	129 ' 25.4"	52 ' 7.92"	126 ' 23.02"
Corrected Azimuth (Z)	230.5766'	52.1319'	126.3836'
Angle in Degrees	230 ' 34.6"	52 ' 7.92"	126 ' 23.02"
Latitude Difference (P)	0.0774'	0.1053'	0.0388'
Latitude as Miles	4.65 mls	6.32 mls	2.33 mls
Towards / Away	Towards	Away	Towards

The options are then 'OK' to continue, 'Re-Do' to re-enter the Star Options or print preview Stars charts.

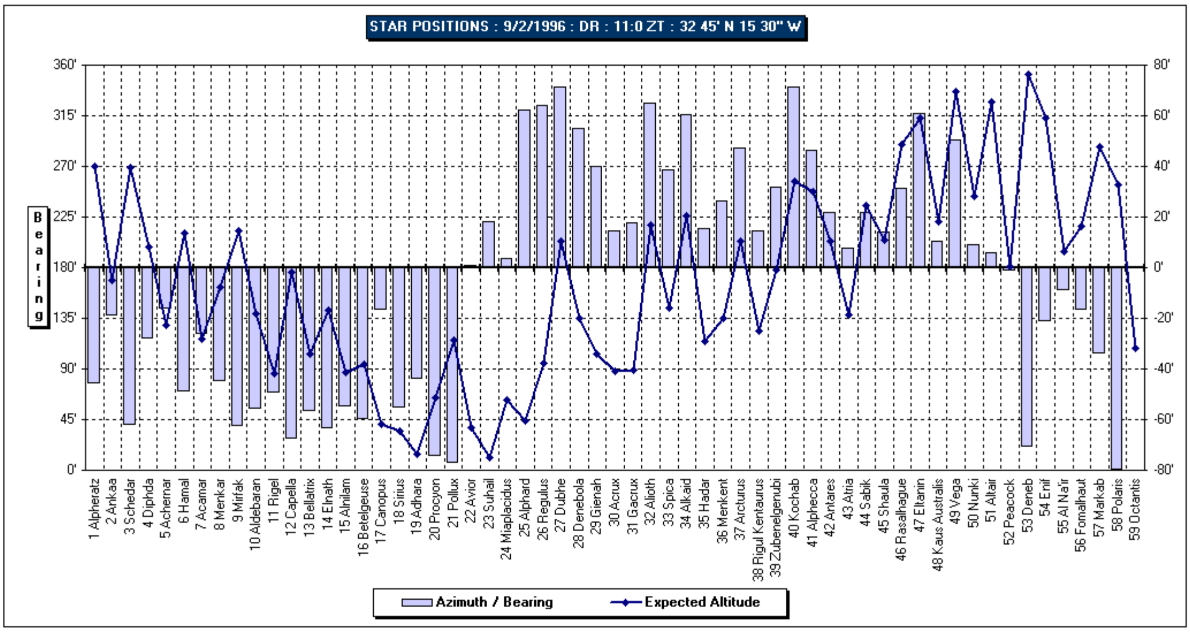
An alternative is to click the Stars Chart which print previews a plot of bearings and altitudes at the DR Time. This is an overlay graph with the bearing on the left-hand Y scale and the altitude on the right-hand scale. This can be reviewed in more detail using the magnification within Print Preview or printed for future reference. This option is repeated in the End Options if missed at this stage.

You then have a further option to sort the stars by SHA, bearing or altitude e.g. to check which stars should be visible. Select a sort order and the system sorts the data and print previews the plot.

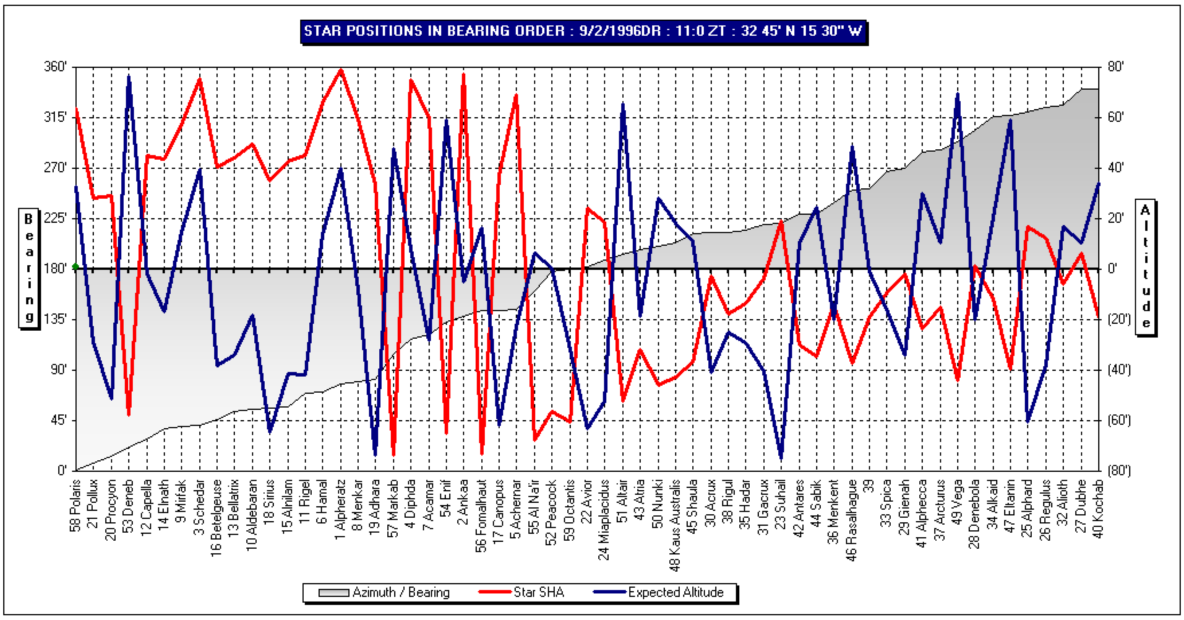
- Input Star Number: You input the star number and the system does not recalculate.

[6] Example from pages 18 and 19 of *Compact Data* 1996.

These are the two types of star charts available. These use the example above for 9 February 1996 at GMT 12:00:00 at position 32’N 45” 15’W 30”.



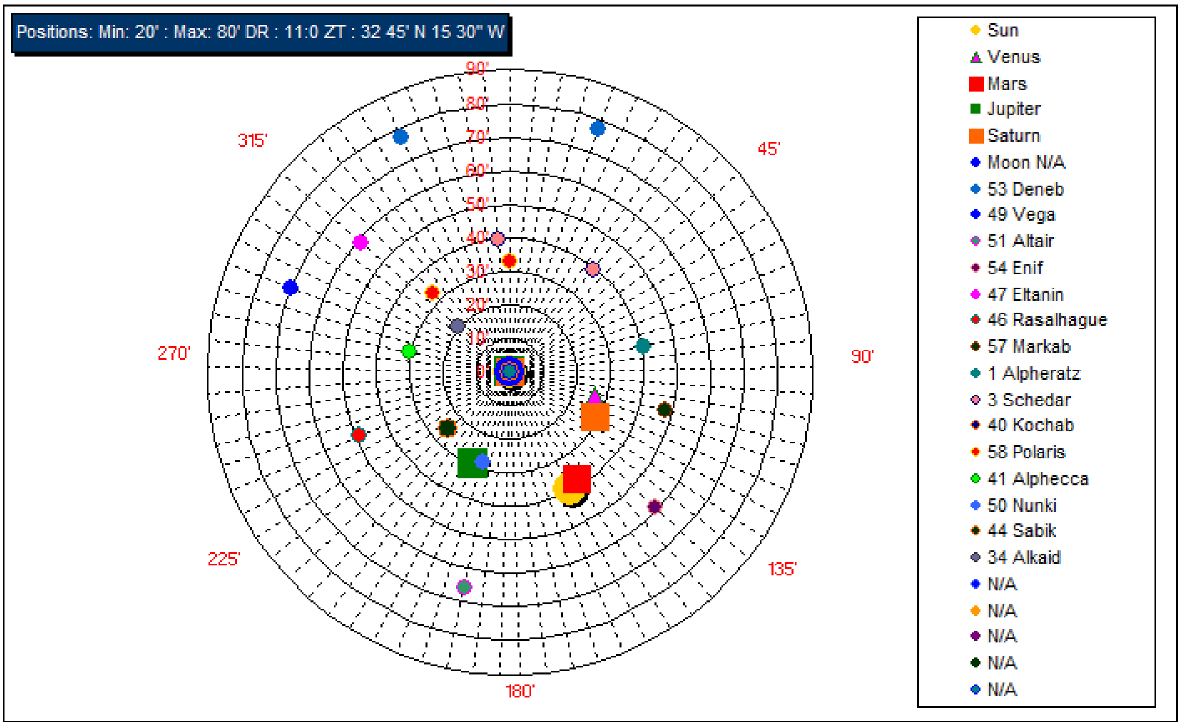
This second plot is sorted as directed in bearing order to show visible stars.



7.3 360' Sun, Planets, Moon and Star Chart

There is an option to plot the visible bodies based on altitude on the DegreesCharts sheet. You can plot up to twenty stars and if a star or planet is not visible, N/A will be displayed.

No	No	Star Name	Mag	C. Altitude	Bearing
1		Sun		39.07'	156.01'
2		Venus		26.86'	109.44'
3		Mars		37.60'	149.45'
4		Jupiter		29.47'	206.21'
5		Saturn		28.92'	117.73'
6		Moon N/A		(21.56')	277.66'
1	53	53 Deneb	1.3	76.38'	21.20'
2	49	49 Vega	0.1	69.55'	293.98'
3	51	51 Altair	0.9	65.53'	193.77'
4	54	54 Enif	2.5	59.03'	132.56'
5	47	47 Eltanin	2.4	58.89'	317.29'
6	46	46 Rasalhague	2.1	48.54'	250.28'
7	57	57 Markab	2.6	47.53'	103.96'
8	1	1 Alpheratz	2.2	40.17'	77.70'
9	3	3 Schedar	2.5	39.40'	40.97'
10	40	40 Kochab	2.2	33.89'	341.07'
11	58	58 Polaris	2.1	32.80'	0.89'
12	41	41 Alphecca	2.3	30.22'	284.13'
13	50	50 Nunki	2.1	28.07'	199.95'
14	44	44 Sabik	2.6	24.68'	229.46'
15	34	34 Alkaid	1.9	20.37'	316.32'
16	N/A	N/A	N/A	N/A	N/A
17	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A
19	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A



8 Moon

8.1 Method A - Aries

Select Method 'A' and no inputs are required. The model uses a complex set of algorithms to derive the GHA, DEC and HP which are outside the scope of this manual[7]. See the second page of the Aries schedule for the workings.

Example: Moon's GHA, DEC and HP on 27 September 1996 at GMT 05:47:22[8]. This is an extract from the 'Inputs' sheet:

	Sight # 1			Sight # 2	
Which Sight	3	Moon		3	Moon
Method : 'A' or 'B'	A	Calculated		B	Polynomial
Actual Sight Time	5:47:22	05:47 GMT		5:47:22	05:47 GMT
Time Diff. / Miles	0:00 hrs	0.00 mls		0:00 hrs	0.00 mls
Revised DR Position	0' 0" S	0' 0" W		0' 0" S	0' 0" W
DR Star Altitude '	0.00'	0		28.00'	0
DR Star Bearing '	0.00 E	0		52.00 E	0
Star Number	0	0		53	
DR Alt. / Bearing	2 ' 20.02"	272 ' 34.62"		2 ' 20.42"	272 ' 34.18"
Observed Angle	3 '	28.00 "		3 '	28.00 "
Index Error : Minutes	0.00 "			0.00 "	
On/Off the Arc : N/F	F	Off Arc		F	Off Arc
Height of User's Eye	6.00 mtr			6.00 mtr	
Upper / Lower Limb	L	Lower		L	Lower
Moon HP/SD	0.00 "	59.7"/16.3"	Calc. HP/SD	0.00 "	0"/16.3"
Corrected Altitude	4' 26.24"			4' 26.33"	
Calc Moon DEC	0 ' N	0.00 "	Calc. DEC	0 ' N	0.00 "
	0 '	0.00 "		0 '	0.00 "
	0 '	0.00 "		0 '	0.00 "
Moon Declination	2' 34.49"	North	Moon DEC	2' 34.05"	North
Calc Moon GHA	0 ' E	0.00 "	Calc. GHA	0 ' E	0.00 "
	0 '	0.00 "		0 '	0.00 "
	0 '	0.00 "		0 '	0.00 "
Moon GHA / LHA	87' 39.84"	87' 39.84"	Moon LHA	87' 39.44"	87' 39.44"

8.2 Method B - Input Polynomial Coefficients

Chebyshev monthly coefficients are available in the model as in the example above (Sight 2).

The Moon's right ascension (RA) and declination (DEC) are derived from trigonometric expressions involving λ, β and the adopted value of the obliquity $\varepsilon = 23°.44$.

The time variable x is calculated from:

$$x = (d + UT^h/24)/32$$

where d is the day of the month and UT^h is the universal time in hours.

Each of the quantities λ, β and HP is derived as follows:

Calculate $y = 2(2x - 1)$
Set $b_{n+1} = b_n = 0$

Use the recurrence relation
$b_i = yb_{i+1} - b_{i+2} + a_i$ for $i = n - 1, n - 2, \ldots, 2, 1, 0$ to calculate b_2 and b_0. Then the required quantity, in degrees, is obtained from the expression: $(b_0 - b_2 + a_0)/2$

The Moon's RA and DEC are calculated from λ and β as follows:

[7] See bibliography for *Astro Navigation by Pocket Computer* by Mike Harris. Algorithms are on page 69.
[8] Example from *Compact Data* 1996 Page 7. Answer given as GHA = 87.6592', DEC = 2.5688', HP = 0.996'

Set $X = \cos\beta \cos\lambda$ $Y = \cos\varepsilon \cos\beta \sin\lambda - \sin\varepsilon \sin\beta$ and $Z = \sin\varepsilon \cos\beta \sin\lambda + \cos\varepsilon \sin\beta$

where $\varepsilon = 23^{\circ}.44$

Then RA° = $\tan^{-1}(Y/X)$ and DEC° = $\sin^{-1} Z$

If $X < 0$ add 180° to RA. If $X > 0$ and $Y < 0$ add 360° to RA.

To obtain the Greenwich hour angle of the Moon (GHA) calculate:

$L^{\circ} = 0.9856474\ (D + d + UT^{h}/24)$

where UTh is the universal time in hours, d is the day of the month and D is the number of days elapsed as per the table January 0 at 0^{h} UT to the beginning of the month on day 0 at 0^{h} UT. Alternatively it may be calculated using the formula in section 4.2.

Then GHA Aries = $99^{\circ}.3133 + L^{\circ} + 15UT^{h}$ and GHA = GHA Aries − RA.

This is a detail from the complex Chebyshev calculations showing the RA, GHA and DEC.

(1) Calculation of Factors

	27-Sep-96
	05:47:22
UT	5.7894
Lookup R	98.9513
Base Year for D	1996
D	244
d	27
x	0.851288339
y	1.405153356
L	267.34821
Data Line No	69

	λ	β	HP
	13	13	8
	0	0	0
	0	0	0
	0	0	0
	0.0017	0.0026	0
	-0.0065	0.0061	0
	-0.0204	0.0063	0
	-0.0066	-0.0025	0
	0.0984	-0.0659	0
	0.1099	-0.1153	0.0025
	0.0129	0.0599	0.0019
	-0.3676	0.9706	0.0038
	-2.5616	1.0056	-0.0052
	1.1953	-3.8168	-0.0434
	5.7793	-2.1718	0.0121
	209.9832	0.635	0.0083
	216.4644	-1.2178	0.9549
Sum	**430.6824**	**(4.7040)**	**0.9349**

(2) Right Ascension and Declination

RA/DEC Calculations			
B15	0	0	0
B14	0	0	0
B13	0	0	0
B12	0.0017	0.0026	0
B11	-0.004111239	0.0097534	0
B10	-0.027876922	0.01740502	0
B9	-0.041660111	0.01220332	0
B8	0.067738077	-0.0661575	0
B7	0.246742497	-0.2204647	0.0025
B6	0.291872971	-0.1837293	0.00541288
B5	-0.204216212	0.93289692	0.00890593
B4	-3.140428067	2.50019251	0.00190132
B3	-3.013266827	-1.236543	-0.0496343
B2	4.685626071	-6.4095251	-0.0595451
B1	219.58049	-7.1348227	-0.0257357
B0	520.3230365	-4.8337949	0.97828248

(3) Remove Multiples and Calculate GHA, DEC, HP and SD

	λ	β	HP
Result	366.0509052	0.17896507	0.99636379
Remove Multiples	6.050905219	0.17896507	0.99636379
Radians	0.105608219	0.00312353	0.01738983
ε Constant	23.44		
ε Constant Radians	0.409105177		
X	0.994423782		
Y	0.095470143		
Z	0.044797247		
RA	0.095712149		
Degrees	5.483902172		
X>180?	5.483902172		
RA: Remove Multiples	5.483902172		
L	267.34821		
GHA Aries	453.1411767		
Remove Multiples	93.14117669		
GHA	87.65727451		
GHA: Remove Multiples	87.65727451		
Minutes	39.43647086		
DEC	0.044812244		
DEC Degrees	2.567552461		
Minutes	34.05314764		
HP	0.996363793		
Minutes	59.78182759		
SD	0.271409497		
Minutes	16.28456983		

9 Planets

9.1 Method A - Input GHA and DEC

The GHA and DEC box requests the Greenwich Hour Angle and Declination for GMT 0:0:0 on the day of the sight. Planets also need the correction per hour and this is also found on the daily page in the Almanac. Press 'Re-Do' to re-enter information or 'OK' to continue to the Options Box at the end of the Sight.

Example: The GHA and DEC of Mars on 28 March 1996 at GMT 12:0:0.

From *The Nautical Almanac*, the GHA and DEC at GMT 0:0:0 is 182’ 57.3” and 0’N 16.6” respectively. The variations per hour are 15.011458’ and 0.791667’ and the model interpolates the data. Publications such as *The Nautical Almanac* provide shorter intervals by displaying data in hourly intervals.

The interpolation formula is:

$GHA_{(day\ 0)}$ at GMT 0:0:0 + decimal hours * [($GHA_{(day\ 1)}$ - $GHA_{(day\ 0)}$) / 24]

In this case: 182.966 + 12 * [(360 + (183.230 - 182.966)) / 24] = 182.966 + (12 * 15.011458) = 363.0925’

Removing multiples of 360’, GHA = 3.0925’ (3’ 5.5”)[9]

Mars GHA and DEC	Sight
Mars GHA	182.955’
Mean Variation	15.0115'
Correction 12 hours	180.1374’
Calculated GHA	273.0237'
Mars GHA	**3.0925’ (3’ 5.549”)**
Mars DEC	0.276667’ N
Daily Variation	0.316663'
Hourly Variation	0.013194'
Variation 12 hours	0.158332’
Mars Declination	**0.434999' (0’N 26.099”)**

This is an extract from the ‘Inputs’ sheet showing both methods. The left hand column shows the results using Method ‘A’ and the right hand column, Method ‘B’ (see next page).

Input Mars DEC	0 ' N	16.60 "	Calc. DEC	0 ' N	0.00 "
Mean Variation/Hour	0 '	0.79 "		0 '	0.00 "
Corr. 12:0:0 GMT	0 '	9.48 "		0 '	0.00 "
Mars Declination	0' 26.08"	North	Mars DEC	0' 26.12"	North
Input Mars GHA	182 ' E	57.30 "	Calc. GHA	0 ' E	0.00 "
Mean Variation/Hour	15 '	0.69 "		0 '	0.00 "
Corr. 12:0:0 GMT	180 '	8.28 "		0 '	0.00 "
Mars GHA / LHA	3' 5.58"	3' 5.58"	Mars LHA	3' 5.5"	3' 5.5"
Azimuth / Bearing	**278' 0.21"**	**278' 0.21"**		**278' 1.09"**	**278' 1.09"**
Intercept : Miles	**123.08 mls**	**Towards**		**123.01 mls**	**Towards**
Calc. Position	**0' 16.5"N**	**1' 57"W**		**0' 16.5"N**	**1' 56.9"W**

[9] Example from the tables on page 68 of *The Nautical Almanac 1996*. GHA = 3.091667 (3’ 5.5”), DEC = 0.4350’ (0’N 26.1”)

9.2 Method B - Polynomial Coefficients

The model contains all the coefficients a_0 to a_4 for GHA and DEC, together with a_0 and a_1 for the semi-diameter.

The system looks up the coefficients from the relevant schedule. There are separate schedules for Venus, Mars, Jupiter and Saturn providing monthly data for each month from January 1991 to December 2025.

Using the example above, the polynomial coefficients are:

Mars GHA and DEC	GHA	DEC
a_0	11.7031500	-8.4901000
a_1	0.5327300	9.7093000
a_2	0.0473400	0.6257000
a_3	-0.0140400	-0.3136000
a_4	0.0013800	0.0052000
Check Sum	12.2705600	1.5365000
Days : X	0.8906	87.230
Calculated	12.2061'	0.4353'
GHA and DEC	**363.0917'**	**0.4353'**
Degrees	**3' 5.502"**	**0'N 26.118"**
HP a_0	0.00100	
HP a_1	0.00000	
Check Sum	0.00100	
Horizontal Parallax	0.0010'	
HP Minutes	**0.06''**	

The answers are very similar to the Almanac results above.

The calculations using the coefficients are the same as for the Sun:

Time variable x = (d + GMT / 24) / 32.

d is the day in the month and GMT the universal time in hours. (GHA - GMT) in hours and DEC in degrees are derived from this expression:

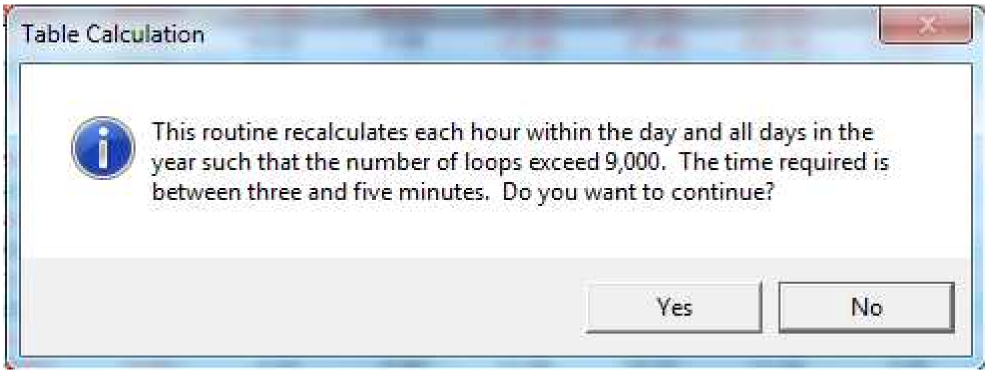
$$a_0 + (a_1 * x) + (a_2 * x^2) + (a_3 * x^3) + (a_4 * x^4)$$

The horizontal parallax is calculated using the expression $HP = a_0 + (a_1 * x)$

10 Annual Altitude Table

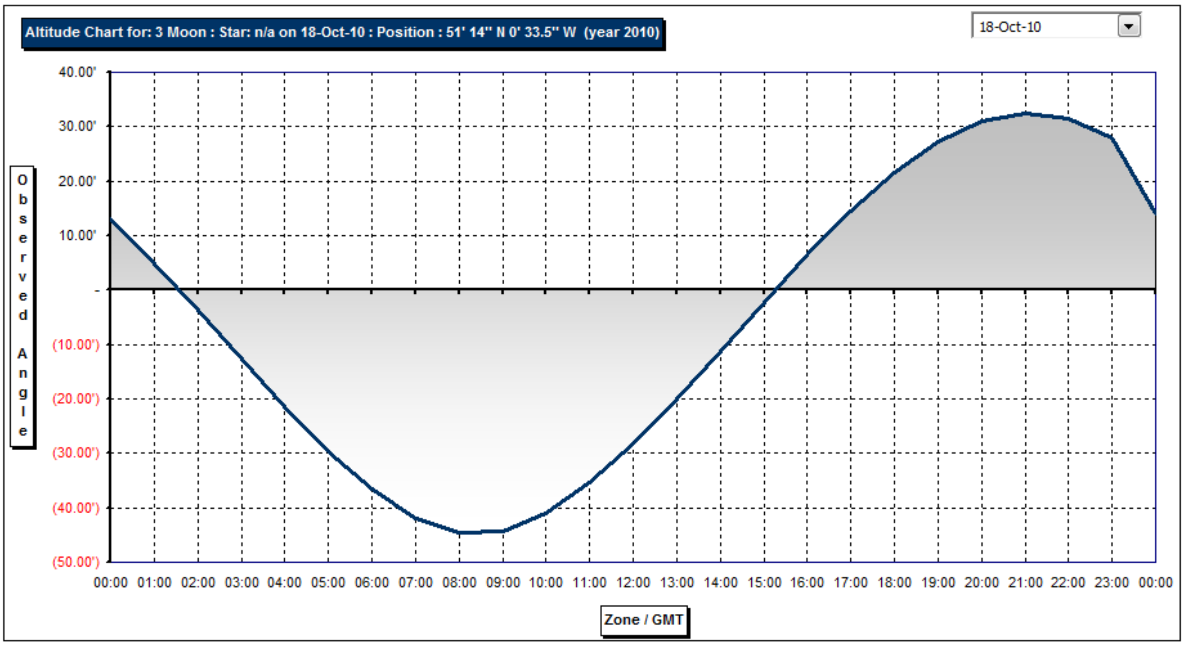
10.1 Method

Select Sun, Stars, Moon etc. and press the button to repopulate the table. This has to recalculate many times and will take about three minutes. The resulting table shows the altitude by day for the selected object:



		00:00 UT 00:00	01:00 UT 01:00	02:00 UT 02:00	03:00 UT 03:00	04:00 UT 04:00	05:00 UT 05:00	06:00 UT 06:00	07:00 UT 07:00
	31-Mar-23	38.58	29.31	20.16	11.43	3.41	(3.59)	(9.24)	(13.19)
001	1-Jan-23	25.81	16.83	7.81	(0.89)	(8.91)	(15.84)	(21.22)	(24.60)
002	2-Jan-23	36.42	27.58	18.51	9.60	1.19	(6.39)	(12.74)	(17.46)
003	3-Jan-23	46.39	37.84	28.81	19.75	11.02	2.90	(4.26)	(10.11)
004	4-Jan-23	55.37	47.43	38.59	29.48	20.49	11.93	4.08	(2.74)
005	5-Jan-23	62.58	55.94	47.62	38.62	29.48	20.56	12.13	4.47
006	6-Jan-23	66.51	62.53	55.44	46.89	37.79	28.63	19.73	11.38
007	7-Jan-23	65.67	65.70	61.14	53.77	45.09	35.92	26.73	17.82
008	8-Jan-23	60.52	64.25	63.42	58.40	50.84	42.08	32.86	23.62
009	9-Jan-23	52.86	58.87	61.51	59.79	54.35	46.66	37.84	28.58
010	10-Jan-23	43.91	51.16	56.12	57.55	54.96	49.14	41.32	32.45
011	11-Jan-23	34.27	42.22	48.57	52.30	52.51	49.12	42.95	35.01
012	12-Jan-23	24.19	32.56	39.77	45.04	47.50	46.60	42.53	36.04
013	13-Jan-23	13.79	22.43	30.21	36.52	40.65	41.91	40.07	35.45
014	14-Jan-23	3.09	11.91	20.09	27.16	32.51	35.54	35.80	33.22
015	15-Jan-23	(7.90)	1.05	9.54	17.17	23.47	27.91	30.01	29.49
016	16-Jan-23	(19.15)	(10.13)	(1.40)	6.68	13.75	19.35	23.04	24.44
017	17-Jan-23	(30.60)	(21.58)	(12.67)	(4.20)	3.51	10.09	15.15	18.32
018	18-Jan-23	(42.05)	(33.15)	(24.13)	(15.34)	(7.08)	0.35	6.62	11.39
019	19-Jan-23	(52.96)	(44.49)	(35.51)	(26.49)	(17.76)	(9.59)	(2.26)	3.93
020	20-Jan-23	(61.95)	(54.75)	(46.23)	(37.21)	(28.16)	(19.38)	(11.14)	(3.71)
021	21-Jan-23	(65.95)	(62.06)	(55.10)	(46.66)	(37.63)	(28.49)	(19.57)	(11.13)
022	22-Jan-23	(62.28)	(63.33)	(59.96)	(53.43)	(45.20)	(36.20)	(26.97)	(17.87)
023	23-Jan-23	(53.14)	(57.77)	(58.74)	(55.70)	(49.58)	(41.61)	(32.71)	(23.44)
024	24-Jan-23	(41.72)	(48.19)	(52.19)	(52.79)	(49.79)	(43.92)	(36.19)	(27.41)
025	25-Jan-23	(29.60)	(37.05)	(42.80)	(46.01)	(46.05)	(42.88)	(37.09)	(29.52)
026	26-Jan-23	(17.44)	(25.47)	(32.27)	(37.20)	(39.58)	(39.01)	(35.56)	(29.75)
027	27-Jan-23	(5.53)	(13.95)	(21.46)	(27.55)	(31.63)	(33.22)	(32.06)	(28.31)
028	28-Jan-23	5.98	(2.72)	(10.74)	(17.66)	(23.02)	(26.32)	(27.20)	(25.54)
029	29-Jan-23	17.04	8.13	(0.28)	(7.86)	(14.20)	(18.89)	(21.51)	(21.81)
030	30-Jan-23	27.60	18.55	9.82	1.71	(5.44)	(11.25)	(15.37)	(17.44)
031	31-Jan-23	37.58	28.48	19.50	10.95	3.13	(3.65)	(9.04)	(12.71)
032	1-Feb-23	46.82	37.81	28.68	19.78	11.38	3.78	(2.72)	(7.80)
033	2-Feb-23	54.91	46.31	37.21	28.07	19.21	10.92	3.46	(2.86)
034	3-Feb-23	61.06	53.54	44.79	35.62	26.45	17.61	9.35	1.96
035	4-Feb-23	63.96	58.67	50.95	42.12	32.90	23.69	14.81	6.55
036	5-Feb-23	62.60	60.64	54.97	47.12	38.24	28.96	19.71	10.78
037	6-Feb-23	57.50	58.83	56.06	50.05	42.10	33.17	23.85	14.55
038	7-Feb-23	50.03	53.79	53.94	50.41	44.08	36.03	27.07	17.71
039	8-Feb-23	41.25	46.60	49.08	48.12	43.93	37.32	29.17	20.17

This is a chart for a selected day in the year. Use the combo box to select a specific day in the year.



Moon phases

11 Corrected Altitude

11.1 Method

All sextant angles (Hs) need to be corrected for index error and altitude to produce the Apparent Altitude (H). The model computes these adjustments automatically and calculates the Observed Altitude (Ho) by subtracting a correction for refraction. For the Sun, Moon, Venus and Mars a correction for parallax is also applied to H and for the Sun and Moon a further correction for semi-diameter is also required.

The detailed calculations are:

1. dip: D = 0.0293 * SQRT h (where h is the height of the eye above the horizon in metres).

2. I is the instrument or index error.

3. Apparent Altitude H = Hs + I -D.

4. Refraction (R) = 0.0167 / (tan (H + 7.32) / (H + 4.32)). Alternative (R) = 0.0162 / tan H.
   An alternative formula is R = 0.0162 / tan H

5. f = 0.28 * Pressure / (Temperature + 273).

Adjusted Refraction (Ro) = f * R.

6. Calculate the parallax in altitude (PA) from the horizontal parallax (HP) and the apparent altitude (H) for the Sun, Moon Venus and Mars PA = HP * cos H.

Sun HP = 0.0024’. Moon HP is calculated.

7. Oblateness of the Moon. OB = minus 0.0017 * cos H.

8. Semi-diameter for the Sun and Moon. Moon S = 0.2724’ * HP. Sun S is 16” under Method ‘A’ and computed under Method ‘B’. Add lower limb and subtract upper limb.

9. Calculate the Observed Altitude (Ho).

   Ho = H - R + PA + OB ± S.

The model uses the Observed Altitude (Ho) in sight reduction and compares it against the Computed Altitude (Hc) to derive the intercept and azimuth.

This is an extract from the ‘Inputs’ sheet showing workings for the Moon on 9 February 1996 observed at an altitude of 37’ 28.02” (37.4167’)[10].

(C) Corrected Altitude (Decimals)

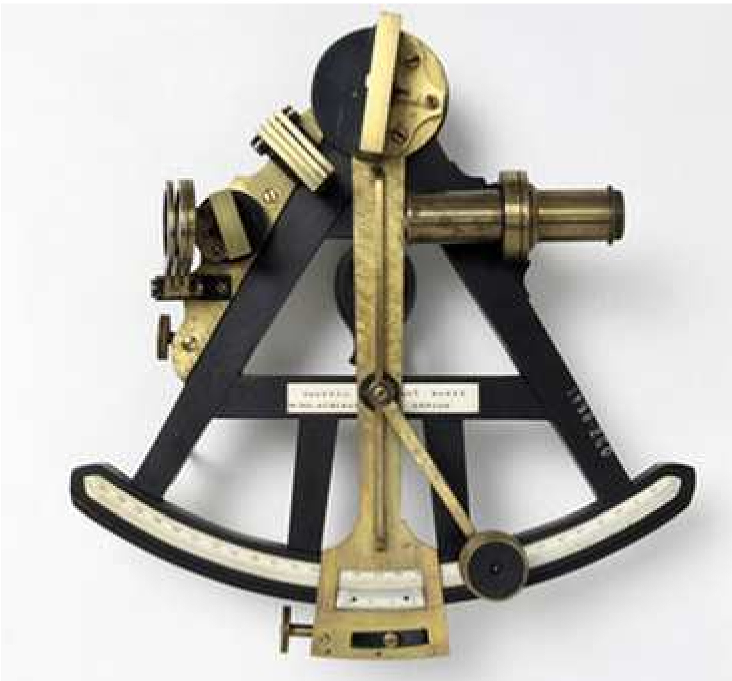
Altitude	Sight (1)	
Observed (Hs)		37.4167'
Index Error (I)	0.0000'	
DIP - Height (D=0.0293*SqrtH)	-0.0718''	
Apparent Altitude (H=Hs+I-D)		37.3449'
Ro=0.0167/tan(H+7.31)/(h+4.4))	0.0217'	
f=0.28*Pressure*(Temp+273)	1.0000'	
Refraction (R=Ro*f)		0.0217'
Oblateness of Earth (OB)		-0.0014'
Parallax (HP)	0.9386'	
Parallax Altitude (PA=HP*cosH)		0.7462'
Semi Diameter (S)		0.2558'
Corr. Altitude (Ho=H-R+PA+S)		38.3238'

[10] Example from page 19 of *Compact Data* 1996.

11.2 Observed Angle

This example from *The Nautical Almanac 1996*[11] assumes a height of 5.4 metres, temperature of -3.0' C, pressure of 982 Mb. The date is 22 October 1996 at GMT 10:0:0.

Altitude	Sun		Moon		Venus	
Observed (Hs)		**21.3283'**		**33.4600'**		**4.5433'**
Index Error (I)	0.0000'		0.0000'		0.0000'	
DIP - Height (D = 0.0293 * Sqrt H)[12]	-0.0681"		-0.0681"		-0.0681"	
Apparent Altitude (H = Hs + I - D)		**21.2602'**		**33.3919'**		**4.4752'**
Ro = 0.0167 / tan [H + 7.31 / (h + 4.4)][13]	0.0423'		0.0251'		0.1801'	
f = 0.28 * Pressure * (Temp + 273)	1.0184'		1.0184'		1.0184'	
Refraction (R = Ro * f)		0.0431'		0.0256'		0.1834'
Oblateness (OB = -0.0017 * cos H))		0.0000'		-0.0014'		0.0000'
Horizontal Parallax (HP)	0.0024'		0.9922'		0.0021'	
Parallax in Altitude (PA = HP * cos H)		0.0022'		0.8284'		0.0021'
Semi Diameter (S) - add lower limb[14]		0.2684'		0.2704'		0.0000'
Corr. Altitude (Ho = H - R + PA + OB ± S)		**21.4878'**		**34.4637'**		**4.2940'**



[11] Example from page 281 of *The Nautical Almanac 1996*. Answers given are 21.4877', 34.4644' and 4.2935'. The slight differences on the Moon and Venus are explained by 0.005' variation in the horizontal parallax. Their example also ignores the oblateness of the Earth which yields a small variation.

[12] Note that with a bubble sextant, no correction for height is needed.

[13] Formula from a paper by G G Bennett, 1982, *Journal of the Institute of Navigation*, volume **35**, page 255. The formula has now been revised to Ro=0.0167/tan(H+7.32)/(h+4.32))

[14] Add lower limb and subtract upper limb.

12 Sight Reduction

12.1 Method

The model uses the classic Marcq Saint Hilaire method to reduce the sights as the mathematical link between the observer and the celestial body. If you know your latitude and longitude, you can predict the true bearing and the height of the object above the horizon. This angle can then be compared to your corrected sextant angle to produce a position line and a measure of distance along this line. With several sights, the model plots a fix through the statistical intersection of these position lines.

The following sight reduction formulae are used:

(1) Computed Altitude (Hc):

Hc = Asin [(sin Latitude * sin Declination) + (cos Latitude * cos Declination * cos LHA)]

(2) Azimuth or True Bearing (Z):

Z = Acos [(sin Declination - (sin Computed Altitude * sin Latitude)) / (cos Hc * cos Latitude)]

If the Local Hour Angle is less than 180' then the Azimuth is 360' less the product of the above expression.

This is an extract from the 'Inputs' sheet showing the workings for the example in the previous section:

(D) Sight Reduction

Altitude	Sight (1)	Sight (2)	Sight (3)
Computed Altitude (Hc)	0.6675'	0.4972'	0.3942'
Angle in Degrees	38.2463'	28.4863'	22.5850'
Azimuth Angle	2.2589'	0.9099'	2.2058'
Angle in Degrees	129 ' 25.4"	52 ' 7.92"	126 ' 23.02"
Corrected Azimuth (Z)	230.5766'	52.1319'	126.3836'
Angle in Degrees	230 ' 34.6"	52 ' 7.92"	126 ' 23.02"
Latitude Difference (P)	0.0774'	0.1053'	0.0388'
Latitude as Miles	4.65 mls	6.32 mls	2.33 mls
Towards / Away	Towards	Away	Towards

13 Calculated Position

13.1 Method

An estimate can be made of the position at the adopted time of fix. The position at the time of the observations can then be easily calculated provided that the course and speed has been constant. Using speed (V) in knots and the track (T) the algorithms are:

Longitude = $L_{(Fix)}$ + t (V / 60) * sin T / cos B_F

Latitude = $B_{(Fix)}$ + t (V / 60) * cos T

$L_{(Fix)}$ and $B_{(Fix)}$ are the estimated longitude and latitude at the time of fix and 't' is the time interval (hours).

Example: DR = 32'N 45" (32.75'N), 15'W 30" (15.50'W) at GMT 12:0:0. A vessel has been on a course of 315'T at 12 knots since GMT 6:58:52[15]. To calculate the start position:

Longitude = -15.50 + -5.0188 * (12 / 60) * sin 315' / cos 32.75'

Longitude = -15.50 + -5.0188 * 0.20 * 0.70711 / 0.841039 = 14.6561'W

Latitude = 32.75 + -5.0188 * (12 / 60) * cos 315'

Longitude = 32.75 +-5.0188 * 0.20 * 0.707107 = 32.0402'N

The position lines for one or more observations can be plotted using the azimuth Z and the intercept p:

p = Ho - Hc

If p is positive the position line is drawn along the azimuth. If p is negative, the position line is away from the assumed position by adding 180' to the azimuth. Provided that there are no observation errors, the observer should be close to or along the position line. Two or more position lines are required to determine a fix.

The model uses the 'Method of Least Squares' to determine a fix from up to three observations. p_1 and Z_1 are the intercept and azimuth for the first observation etc. The model calculates these values:

$A = (\cos^2 * Z_1) + (\cos^2 * Z_2) + \ldots$
$B = (\cos Z_1 * \cos Z_1) + (\cos Z_2 * \cos Z_2) + \ldots$
$C = (\sin^2 * Z_1) + (\sin_2 * Z^2) + \ldots$
$D = (p_1 * \cos Z_1) + (p_2 * \cos Z_2) + \ldots$
$E = (p_1 * \sin Z_1) + (p_2 * \sin Z_2) + \ldots$
$F = p^2_1 + p^2_2 + \ldots$
$G = A * C - B^2$

An improved estimate of the fix is given by:

Longitude $L_I = (A * E - B * D) / (G * \cos B_{(fix)})$

Latitude $B_I = (C * D - B * E) / G$

Departure longitude $dL = L_{(fix)} + L_I$

Departure latitude $dB = B_{(fix)} + B_I$

The model substitutes the DR position with the calculated fix in order to converge on a solution. i.e. $L_I = L_{(fix)}$

The model computes the distance between the assumed position and the improved estimated position in nautical miles from:

$d = 60 * SQRT[(L_I + L_{(fix)})^2 * \cos^2 * B_{(fix)} + (B_I + B_{fix)})^2]$

[15] Example from page 18 and 19 of *Compact Data* 1996 derives the same answers.

The model iterates the result until it converges on an improved estimate. The number of recalculations is set to 5 and you can always recalculate the model by pressing F9 or the 'Calculate' button.

The system also estimates the error in position. n is the number of observations. The standard deviation of the estimated position in nautical miles is given by:

Standard deviation $\sigma = 60 * SQRT (S / (n - 2))$

$S = F - D * dB - E * dL * \cos B_F$

The standard deviations for longitude σ_L and latitude σ_B are given by:

$\sigma_L = \sigma * SQRT (A / G)$: $\sigma_B = \sigma * SQRT (C / G)$

The model assumes a probability of 0.95 and computes the size of a confidence ellipse which means that there is a 95% probability of the revised estimated position lying within the ellipse.

The estimated position has a probability P of being located within a confidence ellipse specified by the axes a and b and the azimuth θ of the a-axis where:

$\tan 2 * \theta = 2 * B / (A - C)$

$a = \sigma * k / SQRT (n / 2 + B / \sin 2 * \theta)$

$b = \sigma * k / SQRT (n / 2 - B / \sin 2 * \theta)$

$k = SQRT [-2 * \log_e * (1 - P)] = 2.448$ at a probability of 95%

13.2 Example

This example applies the theory from the previous sections to bring together the calculation of GHA, LHA, Declination with sight reduction and statistical fixes. This example is taken from *Compact Data*.

On February 9, 1996 at GMT 12:0:0 the DR position is assumed to be 32'N 45" 15'W 30". Three sights have been taken along a course of 315'T at a speed of 12 knots. The temperature is 9.8'C and the atmospheric pressure 1010 Mb. The height of the eye above the horizon is 6.0 metres. Sextant index error is assumed to 0"[16].

	Moon	Star (Deneb 53)	Sun
Time of Sight (GMT)	6:58:52	7:03:52	9:53:45
Difference to DR Time	(5.01 h)	(4.56 h)	(2.06 h)
Observed Angle (Hs)	37' 25"	28' 29"	22' 28"
Adjusted Altitude (Ho)	38' 19.43"	28' 22.86"	22' 37.43"
Declination	5' 24.85" S	45' 16.03' N	14' 50.27" S
GHA	52' 12.08"	294' 18.94"	324' 53.11"
LHA	37' 30.48"	279' 36.5"	309' 42.14''
Azimuth / Bearing	230' 36.38"	52' 4.62"	126' 19.23"
Intercept / Distance	0.88 Miles	0.89 Miles	0.02 Miles
Direction	Away	Away	Towards

[16] This is the complete worked example from pages 18 and 19 of *Compact Data* 1996. The answer given is 32.6554'N (32'N 39.3"), 15.5387'W (15'W 32.3"). a = 1.257 nm, b = 2.485 nm, azimuth θ = 37' using the same methods for four observations.

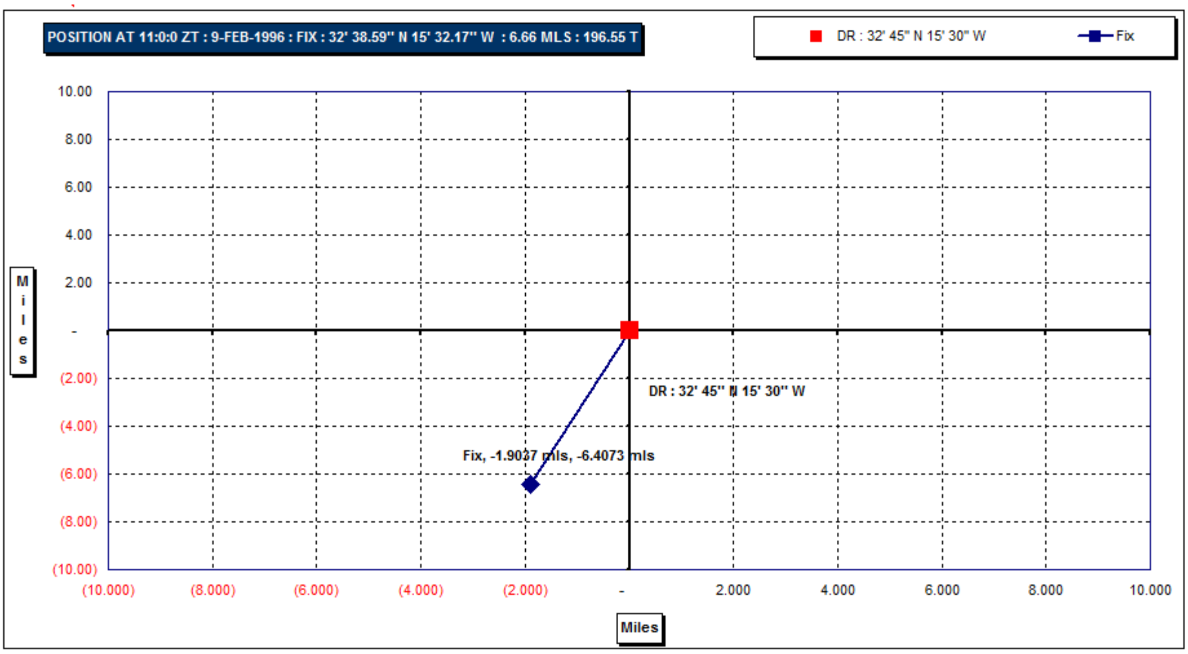
(E) Computed Position

Position	Sight (1)			Sight (2)		Sight (3)	
Azimuth 1	410.606'	-1	50.606'				
Course	315.00 T						
Distance2	1.0038'						
U=90+G	140.606'						
Take out Excess 360	140.606'	140.606'					
U	-0.098	-0.098'					
W+U	-0.083'	0.083'					
Take out Excess 360	230.606	230.606'					
Latitude	32.593 N	32 N	35.59 "				
Longitude	15.489 W	15 W	-29.37 "				
True Azimuth Bearing (Z)	050.606 T	0.89 mls		232.077 T	0.89 mls	126.321 T	0.02 mls
Plot Position / Direction	039.39 T	NE		037.92 T	SW	036.32 T	SE
Distance	0.68 mls	0.56 mls		-0.70 mls	-0.55 mls	0.02 mls	-0.01 mls
Bearing Miles	0.684 E	0.562 N		0.703 W	0.548 S	0.019 E	0.014 S
Latitude/Longitude	0.013 E	0.009 E		0.013 W	0.009 S	0.000 E	0.000 S
Revised Fix Position	14.680 W	31.942 N		14.721 W	31.936 N	15.182 W	32.345 N
Minutes	40.8226	56.5454		43.2376	56.1873	10.9464	20.7249

(F) Fix : Method of Least Squares

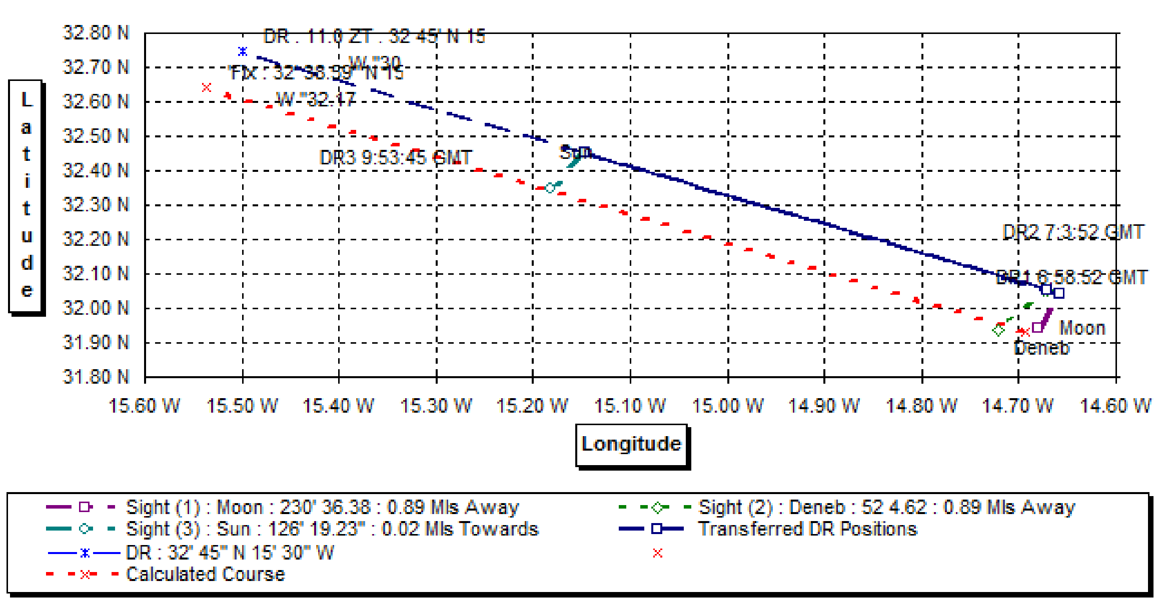
				(G) Estimated Position Error	
A	1.13133	A+C = Sights	3.000	Standard Deviation	1.2564 mls
B	0.49805	No of Sights	3	Deviation Longitude	0.9783 mls
C	1.86867			Deviation Latitude	1.2573 mls
D	0.00000			2 X Tan	-1.351'
E	0.00000			Atan / 2 = Ellipse Azimuth	333.255'
F	0.00044			Probability P=0.95 Scale Fac	2.4477
G = AC-B^2	1.86603			A : X	3.2776 mls
				B : Y	2.1123 mls

The Model uses the 'Method of Least Squares' to compute a fix at the DR Time of 32'N 38.59" 15'W 32.17. This position is on a bearing of 199.45'T 6.66 miles from the DR Position. The confidence ellipse is a = 3.27 nautical miles, b = 2.11 nautical miles and the azimuth θ is 333.25'.



DR Position:			**Calculated Position:**		**Position Error:**	
DR Latitude	32 ' N	45.00"	32 ' N	38.59"	Confidence	
DR Longitude	15 ' W	-30.00"	15 ' W	32.17"	Ellipse	95.00%
DR Zone Date	9-Feb-96	Friday				
Zone / GMT	11:00:00	12:00 GMT	Distance	Bearing	Latitude	2.11 mls
Course / Speed	315.00 T	12.00 kn	6.66 mls	196.55 T	Longitude	3.28 mls
Temperature & Pressure	9.80 'C	1010.00 mb			Bearing	333.25 T
	Sight # 1		**Sight # 2**		**Sight # 3**	
Which Sight	**3 Moon**		**2 Star**		**1 Sun**	
Calc/Almanac/Polynomial	A Calculated		B Polynomial		A Calculated	
Star Number	49		53 Deneb		0	
Actual Sight Time	5:58:52	06:58 GMT	6:03:52	07:03 GMT	8:53:45	09:53 GMT
Time Diff. / Miles	5:01 hrs	60.23 mls	4:56 hrs	59.23 mls	2:06 hrs	25.25 mls
Revised DR Position	31' 56" N	14' 41.6" W	31' 56.7" N	14' 42.4" W	32' 20.7" N	15' 11" W
DR Alt. / Bearing	38 ' 20.31"	230 ' 36.38"	28 ' 23.75"	52 ' 4.62"	22 ' 37.41	126 ' 19.23"
Observed Angle	37' 25.002"		28' 28.998"		22' 28.002"	
Index Error : Minutes	0.00"		0.00"		0.00"	
Height of User's Eye / DIP	-4.31"		-4.31"		-4.31"	
Refraction (R=Ro*f)	1.22"		1.84"		2.40"	
Parallax in Altitude	44.77"		0.00"		0.13"	
Semi-Diameter	15.35"		0.00"		16.00"	
Corrected Altitude	38' 19.43"		28' 22.86"		22' 37.43"	
Calc Moon DEC	-5' 24.85"	South	45' 16.03"	North	-14' 50.27"	South
Moon GHA / LHA	52' 12.07"	37' 30.48"	294' 18.94"	279' 36.5"	324' 53.11"	309' 42.14"
Azimuth / Bearing	**230' 36.38"**	**50' 36.38"**	**52' 4.62"**	**232' 4.62"**	**126' 19.23"**	**126' 19.23"**
Intercept : Miles	**0.89 mls**	**Away**	**0.89 mls**	**Away**	**0.02 mls**	**Towards**
Calc. Position	31' 56.5"N	14' 40.8"W	31' 56.2"N	14' 43.2"W	32' 20.7"N	15' 10.9"W

POSITION AT 11:0:0 ZT : 9-FEB-1996 : FIX : 32' 38.59" N 15' 32.17" W : 6.66 MLS : 196.55 T



14 Sun and Moon Rise and Set

14.1 Description

The model calculates Sun rise and set for the dead reckoning date and position. Set the application to manual and access the RiseSet schedule after entering assumed position data on the Inputs schedule. Press F9 to recalculate the application as this schedule can require more iterations to converge on the results. It uses these expressions:

Calculate t where cos t = sin h - (sin Lat * sin Dec_6) / (cos Lat * cos Dec_6)

h = -0.8333’ for Sun rise or set, -6’ for civil twilight and -12’ for nautical twilight.

Sunrise = (90’ - Longitude - t - GHA_6) / 15

Sunset = (270’ - Longitude - t - GHA_{18}) / 15

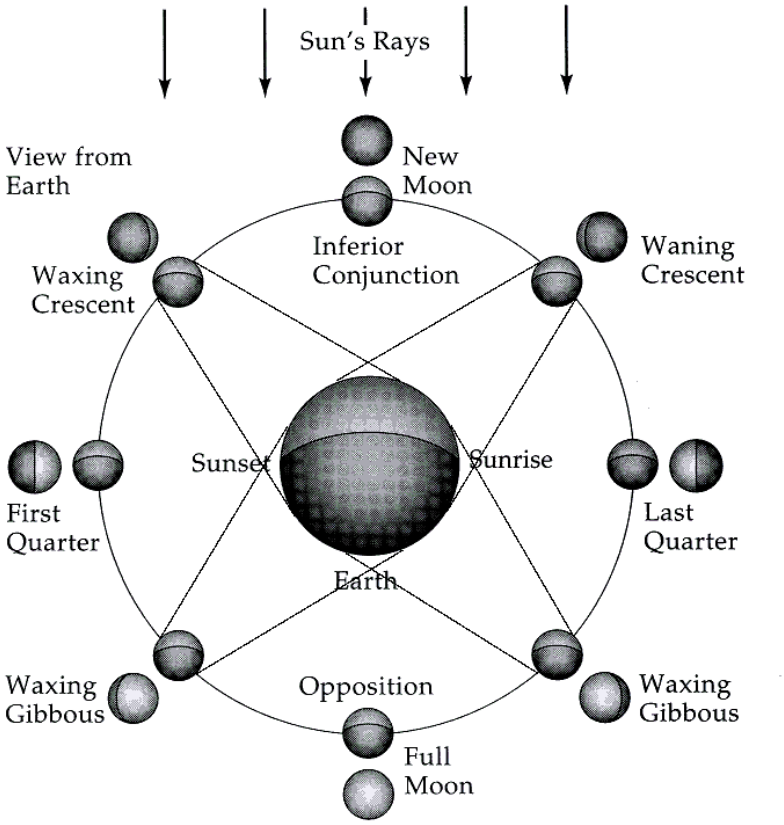
The model uses similar expressions for the Moon however the passage of this body is more complicated. The system iterates an answer despite the possibility of rising and setting on different days.

The model also derives Sun transits.

T_1 = 12 - Longitude converted to hours

Time = 24 - Longitude in hours - y_1 where y_1 is (GHA-GMT) in hours evaluated at time T_1

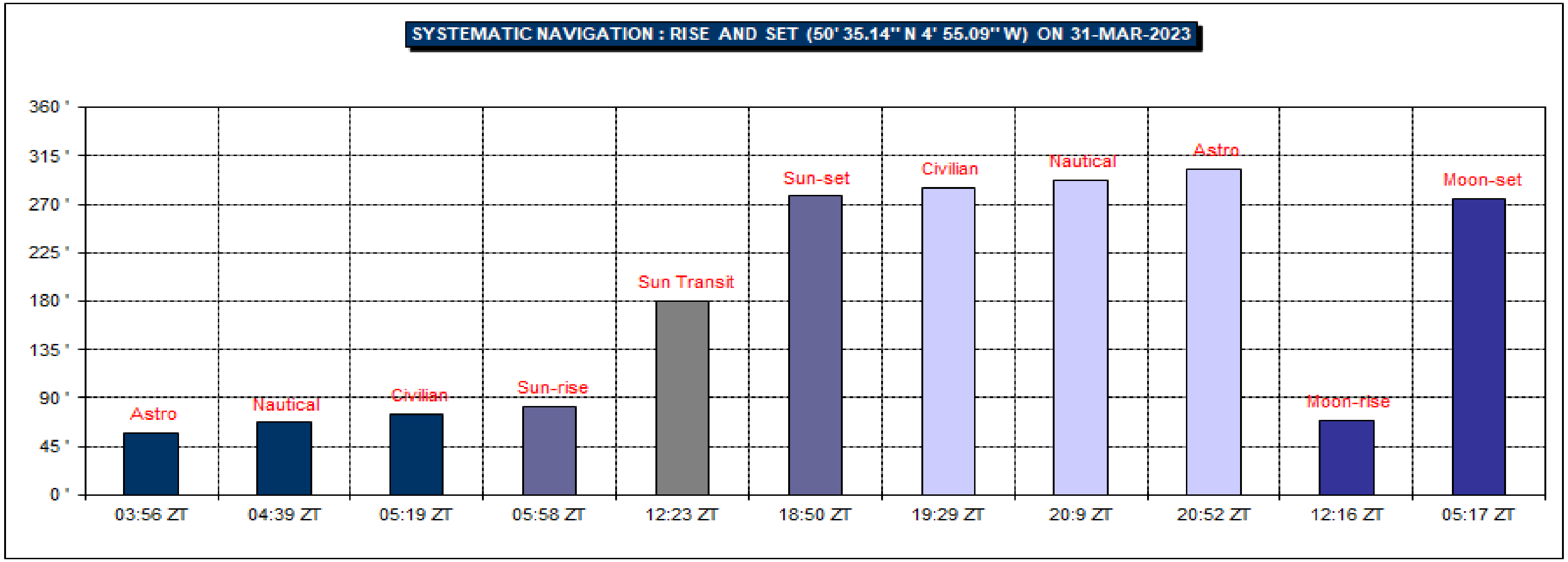
Phases of the Moon



14.2 Example

This example is for March 31, 2023 at 50'N 35.14" 4'W 55.09"

		Rise		Set		Rise and Set Position Data			
		Zonetime	GMT/UT	Zonetime	GMT/UT	Azimuth	Declination	GHA	LHA
1	Sun	05:38 AM	05:58:16	06:30 PM	18:50:32	82' 36.2"	4' 4.32"N	268' 29.21"	263' 34.12"
						277' 23.8"	4' 16.74"N	101' 35.59"	96' 40.5"
2	Sun Transit	12:04 PM	12:23:55	-	-	180' 0"	4' 10.32"N	358' 56.36"	354' 1.27"
3	Civilian	05:00 AM	05:19:41	07:09 PM	19:29:09	75' 4.11	4' 3.66"N	258' 50.45"	253' 55.36"
						284' 55.89	4' 17.4"N	111' 15"	106' 19.91"
4	Nautical	04:19 AM	04:39:39	07:49 PM	20:09:16	66' 58.43	4' 3.06"N	248' 49.75"	243' 54.66"
						293' 1.57	4' 18.06"N	121' 16.93"	116' 21.84"
5	Astro	03:37 AM	03:56:54	08:32 PM	20:52:10	57' 49.54	4' 2.34"N	238' 8.36"	233' 13.27"
						302' 10.46	4' 18.72"N	132' 0.49"	127' 5.4"
6	Moon	11:57 AM	12:16:52	04:57 AM	05:17:00	69' 45.36	23' 22.56"N	268' 5.84"	263' 10.75"
	Chebyshev	11:59 AM	12:19:16	04:08 AM	04:27:57	275' 0.34	21' 39.54"N	82' 27.85"	77' 32.76"
		30-Mar-23		01-Apr-23					



15 Great Circle

The application provides a separate sheet for calculating:

- Destination latitude and longitude given a bearing and distance (as below)
- Bearing and distance from start and destination latitude and longitude positions (next page)

Inputs:

	Degrees	Minutes
Date	31-Mar-23	
Time	10:00:00	
Units	Nautical Miles	
Starting Latitude	32 N	0.00 '
Starting Longitude	14 W	-30.00 '
Destination Latitude	0 N	0.00 '
Destination Longitude	0 E	0.00 '
Bearing	352.20 T	
Distance	181.74	nm
Speed	11.40 kn	

Position:

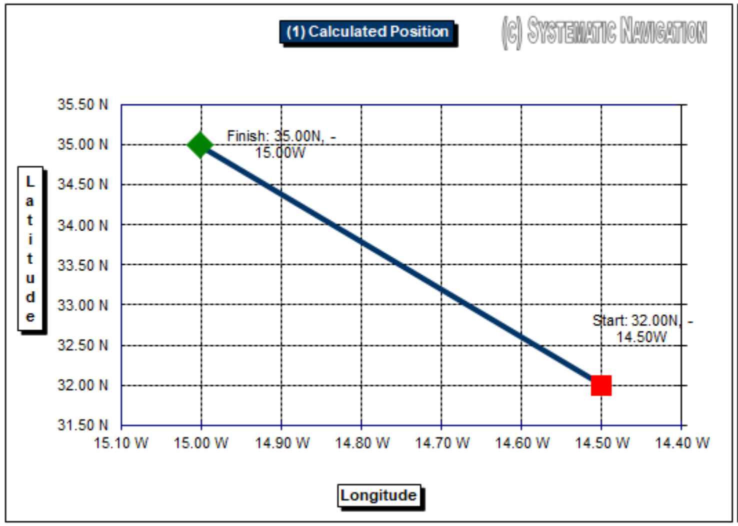
Destination Date	1-Apr-23
ETA Time	1:56:32
Time Taken	15.94 hrs

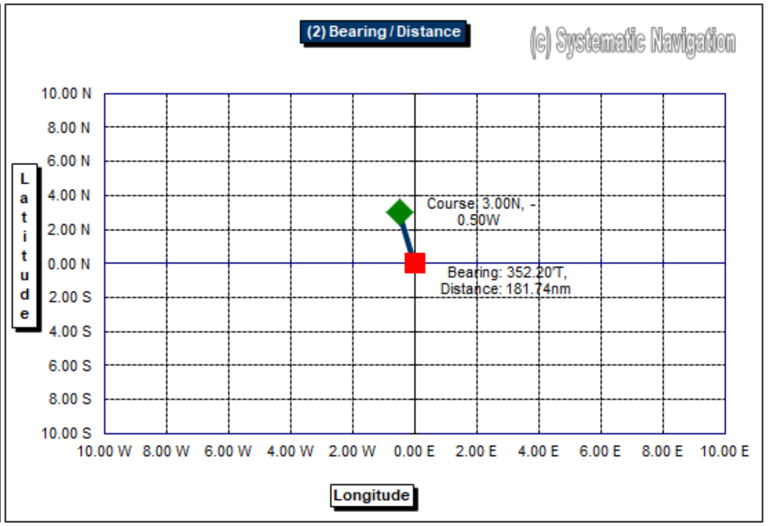
(1) Calculated Position

Destination Latitude	34.9999 N	34 N	59.99"
Destination Longitude	15.0016 W	15 W	-0.10"

(2) Bearing / Distance

Bearing	n/a
Distance	n/a





The units are kilometres, statute miles or nautical miles. The model calculates the item left blank. Enter data to the cells in blue and leave blank the unknown item. The model will calculate either item and leave the known item blank.

Inputs:

Date	31-Mar-23	
Time	10:00:00	
Units	Nautical Miles	

	Degrees	Minutes
Starting Latitude	32 N	0.00 '
Starting Longitude	14 W	-30.00 '
Destination Latitude	35 N	0.00 '
Destination Longitude	15 W	0.00 '

Bearing	000.00 T	
Distance	-	nm
Speed	11.40 kn	

Position:

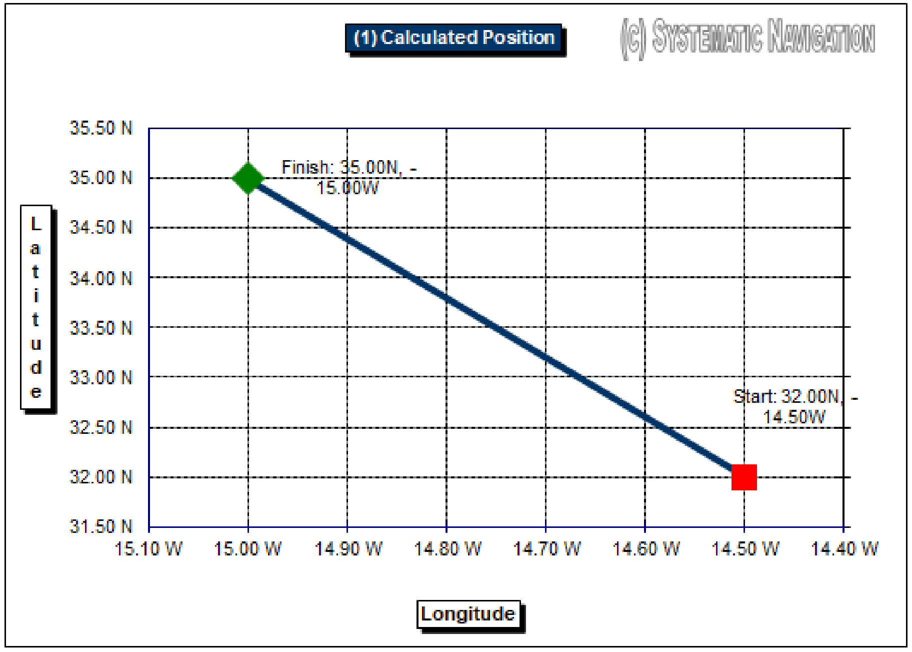
Destination Date	**1-Apr-23**
ETA Time	**1:56:30**
Time Taken	**15.94 hrs**

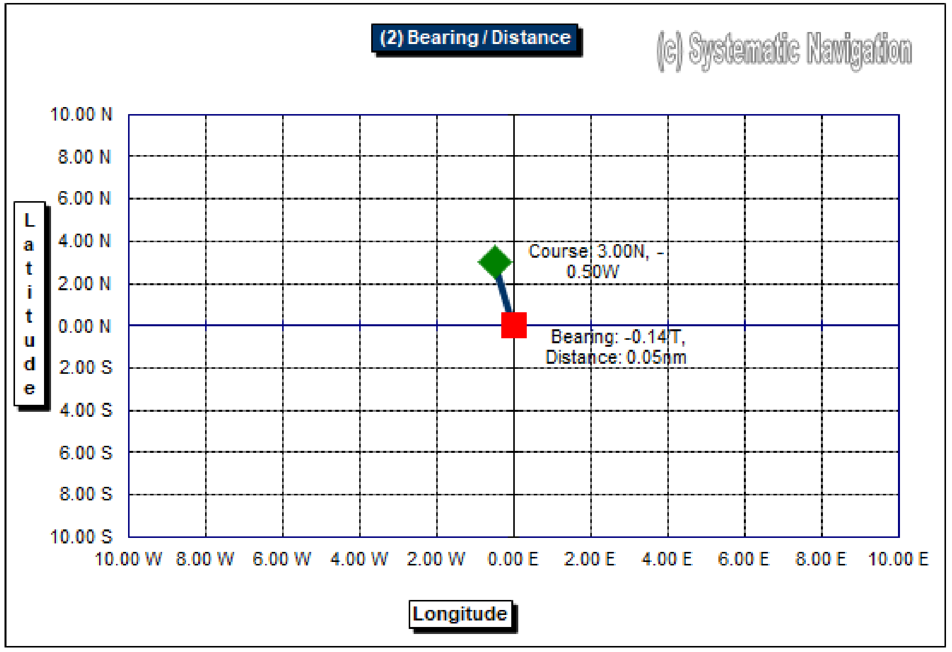
(1) Calculated Position

Destination Latitude	**n/a -**	-
Destination Longitude	**n/a -**	-

(2) Bearing / Distance

Bearing	**352.22 T**
Distance	**181.74 nm**





16 Background Data

16.1 Description

There are three schedules which contain data used by other schedules. These are:

- Aries - Background data for corrections, Stars look-up and Moon calculations.
- Positions - Schedule of SHA, Altitude and Bearing at the DR position, time and date.
- Data - Lookup table of polynomial data for the DR date.

This is an extract from the Aries schedule showing the annual coefficients:

Lookup Table for Annual Update Coefficients

Year	P	Q	R
1988	-3.8470	77.2633	99.8897
1989	-3.1157	77.2461	99.6382
1990	-3.3702	77.2289	99.4008
1991	-3.6251	77.2118	99.1631
1992	-3.8804	77.1946	98.9250
1993	-3.1507	77.1774	99.6719
1994	-3.4071	77.1603	99.4326
1995	-3.6640	77.1431	99.1929
1996	-3.9212	77.1260	98.9529
1997	-3.1930	77.1087	99.6982
1998	-3.4505	77.0916	99.4579
1999	-3.7078	77.0744	99.2177
2000	-3.9523	77.0605	98.9817
2001	-3.2217	77.0411	99.7300
2002	-3.4828	77.0236	99.4887
2003	-3.7354	77.0092	99.2517
2004	-3.9908	76.9909	99.0146
2005	-3.2630	76.9706	99.7608
2006	-3.5156	76.9577	99.5237
2007	-3.7738	76.9424	99.2783
2008	-4.0293	76.9231	99.0413
2009	-3.3014	76.9041	99.7871
2010	-3.5568	76.8858	99.5504
2011	-3.8062	76.8689	99.3020
2012	-4.0772	76.8519	99.0900
2013	-3.3342	76.8350	99.8190
2014	-3.5890	76.8180	99.5810
2015	-3.8445	76.8011	99.3400
2016	-4.1181	76.7841	99.1054
2017	-3.3675	76.7672	99.8380
2018	-3.6248	76.7502	99.6030
2019	-3.8828	76.7333	99.3620
2020	-4.1591	76.7163	99.1600
2021	-3.4063	76.6995	99.8831
2022	-3.6615	76.6826	99.5387
2023	-3.9178	76.6658	99.2978
2024	-4.1954	76.6489	99.1127
2025	-3.4425	76.6320	99.7759

This extract shows the derivation of decimal time for each observation and the revised sight position:

Annual and Basic Decimal Data

Item		Sight 1	Sight 2	Sight 3
N : Year	2023			
P : Sun Ephemeris	-3.9178			
Q : Sun Ephemeris	76.6658			
R : Aries Correction	99.2978			
>Radians	0.017453293			
>Degrees	57.29577951			
Days From 01/01/80	15796.38 dys	15796.13 dys	15796.19 dys	15796.37 dys
Days from 01/01/2023	90.38 dys	90.13 dys	90.19 dys	90.37 dys
Days from 01/3/2023	31.38 dys	31.13 dys	31.19 dys	31.37 dys
Original Latitude	50.5857 N	50.5857 N	50.5857 N	50.5857 N
Original Longitude	4.9182 W	4.9182 W	4.9182 W	4.9182 W
Decimal Latitude	50.5857 N	50.5857 N	50.5857 N	50.5857 N
Decimal Longitude	4.9182 W	4.9182 W	4.9182 W	4.9182 W
Note: No iteration				
Original Latitude-Decimal	0.0000 N	0.0000 N	0.0000 N	0.0000 N
Miles	0.000 mls			
Original Longitude-Decimal	0.0000 E	0.0000 E	0.0000 E	0.0000 E
Miles	0.000 mls			

This displays the Zone or Local Mean Time to GMT conversion table and the calculation of sight times:

Lookup Table for Zone Time / GMT

0	7.50 '	22.50 '	37.50 '	52.50 '	67.50 '	82.50 '	97.50 '
0	1	2	3	4	5	6	7

Transferred DR Positions

	DR Position			Sight (1)		
	Time	Date	Serial	Time	Date	Serial
Longitude	-4.918			-4.918		
Zone	9:00:00	31/3/23	45016.375	3:00:00	31/3/23	45016.125
Adjustment	0.00 hrs	0.000	0.000	0.00 hrs	0.000	0.000
	0.375	31/3/23	45016.375	0.125	31/3/23	45016.125
GMT	9:00:00	31/3/23	45016.375	3:00:00	31/3/23	45016.125

This is the Positions schedule on 31 March 2023 at GMT 9:0:0 from the DR position 50'N 35.14" 5'W 55.09".

Date:	09:00:00 GMT	31-Mar-23	Select:	DR : 9:0 ZT : 50' 35.14" N 4' 55.09" W
Aries:	323.3756'	322.5518'		
L:	808.6005 dys			

No	Star Name	DR Days	GHA	GHA	Aries/SHA	LHA	LHA	DEC	DEC
1	Sun	11.9289'	313.9329'	313' 55.98"	313.9329'	309.0148'	309' 0.89"	4.1132 N	4' 6.79"N
1	Venus	9.5968'	278.9522'	278' 57.13"	278.9522'	274.0340'	274' 2.04"	17.8744 N	17' 52.46"N
2	Mars	6.3522'	230.2824'	230' 16.94"	230.2824'	225.3642'	225' 21.85"	25.4812 N	25' 28.87"N
3	Jupiter	11.3712'	305.5674'	305' 34.04"	305.5674'	300.6492'	300' 38.95"	6.4394 N	6' 26.37"N
4	Saturn	14.2247'	348.3700'	348' 22.2"	348.3700'	343.4518'	343' 27.11"	11.7661 S	11' 45.97"S
1	Moon	323.3756'	197.5916'	197' 35.49"	197.5916'	192.6734'	192' 40.4"	24.7411 N	24' 44.46"N
1	1 Alpheratz	1041.0920'	321.0920'	321' 5.52"	357.7164'	316.1738'	316' 10.43"	29.2155 N	29' 12.93"N
2	2 Ankaa	1036.6318'	316.6318'	316' 37.91"	353.2562'	311.7136'	311' 42.82"	42.1820 S	42' 10.92"S
3	3 Schedar	1033.0357'	313.0357'	313' 2.14"	349.6600'	308.1175'	308' 7.05"	56.6628 N	56' 39.77"N
4	4 Diphda	1032.2997'	312.2997'	312' 17.98"	348.9240'	307.3815'	307' 22.89"	17.8622 S	17' 51.73"S
5	5 Achernar	1018.8457'	298.8457'	298' 50.74"	335.4700'	293.9275'	293' 55.65"	57.1217 S	57' 7.3"S
6	6 Hamal	1011.3673'	291.3673'	291' 22.04"	327.9917'	286.4492'	286' 26.95"	23.5702 N	23' 34.21"N
7	7 Acamar	998.7020'	278.7020'	278' 42.12"	315.3263'	273.7838'	273' 47.03"	40.2155 S	40' 12.93"S
8	8 Menkar	997.6137'	277.6137'	277' 36.82"	314.2380'	272.6955'	272' 41.73"	4.1782 N	4' 10.69"N
9	9 Mirfak	991.9932'	271.9932'	271' 59.59"	308.6176'	267.0750'	267' 4.5"	49.9440 N	49' 56.64"N
10	10 Aldebaran	974.1726'	254.1726'	254' 10.35"	290.7969'	249.2544'	249' 15.26"	16.5546 N	16' 33.28"N
11	11 Rigel	964.5713'	244.5713'	244' 34.28"	281.1957'	239.6531'	239' 39.19"	8.1778 S	8' 10.67"S
12	12 Capella	963.8848'	243.8848'	243' 53.09"	280.5092'	238.9666'	238' 58"	46.0227 N	46' 1.36"N
13	13 Bellatrix	961.8905'	241.8905'	241' 53.43"	278.5149'	236.9723'	236' 58.34"	6.3688 N	6' 22.13"N
14	14 Elnath	961.5452'	241.5452'	241' 32.71"	278.1695'	236.6270'	236' 37.62"	28.6269 N	28' 37.61"N
15	15 Alnilam	959.1364'	239.1364'	239' 8.18"	275.7608'	234.2182'	234' 13.09"	1.1895 S	1' 11.37"S
16	16 Betelgeuse	954.3769'	234.3769'	234' 22.61"	271.0013'	229.4587'	229' 27.52"	7.4097 N	7' 24.58"N
17	17 Canopus	947.3660'	227.3660'	227' 21.96"	263.9904'	222.4479'	222' 26.87"	52.7128 S	52' 42.77"S
18	18 Sirius	1301.9401'	221.9401'	221' 56.41"	258.5645'	217.0219'	217' 1.32"	16.7513 S	16' 45.08"S
19	19 Adhara	1298.5978'	218.5978'	218' 35.87"	255.2221'	213.6796'	213' 40.78"	29.0076 S	29' 0.45"S
20	20 Procyon	1288.3529'	208.3529'	208' 21.18"	244.9773'	203.4348'	203' 26.09"	5.1638 N	5' 9.83"N
21	21 Pollux	1286.7981'	206.7981'	206' 47.89"	243.4225'	201.8800'	201' 52.8"	27.9706 N	27' 58.24"N
22	22 Avior	1277.7324'	197.7324'	197' 43.94"	234.3567'	192.8142'	192' 48.85"	59.5880 S	59' 35.28"S
23	23 Suhail	1266.2667'	186.2667'	186' 16"	222.8911'	181.3485'	181' 20.91"	43.5298 S	43' 31.79"S
24	24 Miaplacidus	1265.1147'	185.1147'	185' 6.88"	221.7390'	180.1965'	180' 11.79"	69.8159 S	69' 48.95"S
25	25 Alphard	1261.2977'	181.2977'	181' 17.86"	217.9220'	176.3795'	176' 22.77"	8.7613 S	8' 45.68"S
26	26 Regulus	1251.0772'	171.0772'	171' 4.63"	207.7016'	166.1591'	166' 9.54"	11.8529 N	11' 51.18"N
27	27 Dubhe	1237.1851'	157.1851'	157' 11.11"	193.8095'	152.2670'	152' 16.02"	61.6272 N	61' 37.63"N
28	28 Denebola	1225.9169'	145.9169'	145' 55.01"	182.5413'	140.9987'	140' 59.92"	14.4412 N	14' 26.47"N
29	29 Gienah	1219.2275'	139.2275'	139' 13.65"	175.8518'	134.3093'	134' 18.56"	17.6723 S	17' 40.34"S
30	30 Acrux	1216.4977'	136.4977'	136' 29.86"	173.1221'	131.5796'	131' 34.77"	63.2282 S	63' 13.69"S
31	31 Gacrux	1215.3594'	135.3594'	135' 21.56"	171.9838'	130.4412'	130' 26.47"	57.2437 S	57' 14.62"S
32	32 Alioth	1209.7101'	129.7101'	129' 42.61"	166.3345'	124.7920'	124' 47.52"	55.8329 N	55' 49.97"N
33	33 Spica	1201.8735'	121.8735'	121' 52.41"	158.4979'	116.9554'	116' 57.32"	11.2837 S	11' 17.02"S
34	34 Alkaid	1196.3600'	116.3600'	116' 21.6"	152.9843'	111.4418'	111' 26.51"	49.1953 N	49' 11.72"N
35	35 Hadar	1192.1060'	112.1060'	112' 6.36"	148.7304'	107.1879'	107' 11.27"	60.4834 S	60' 29.01"S
36	36 Menkent	1191.4644'	111.4644'	111' 27.86"	148.0888'	106.5462'	106' 32.77"	36.4840 S	36' 29.04"S
37	37 Arcturus	1189.2973'	109.2973'	109' 17.84"	145.9217'	104.3792'	104' 22.75"	19.0592 N	19' 3.55"N
38	38 Rigul Kentaurus	1183.1770'	103.1770'	103' 10.62"	139.8014'	98.2588'	98' 15.53"	60.9287 S	60' 55.72"S
39	39 Zubenelgenubi	1180.4376'	100.4376'	100' 26.25"	137.0619'	95.5194'	95' 31.16"	16.1389 S	16' 8.33"S
40	40 Kochab	1180.7955'	100.7955'	100' 47.73"	137.4198'	95.8773'	95' 52.64"	74.0566 N	74' 3.4"N
41	41 Alphecca	1169.5603'	89.5603'	89' 33.62"	126.1847'	84.6421'	84' 38.53"	26.6331 N	26' 37.99"N
42	42 Antares	1155.7721'	75.7721'	75' 46.33"	112.3965'	70.8539'	70' 51.24"	26.4829 S	26' 28.97"S
43	43 Atria	1150.6943'	70.6943'	70' 41.66"	107.3186'	65.7761'	65' 46.57"	69.0648 S	69' 3.89"S
44	44 Sabik	1145.5537'	65.5537'	65' 33.22"	102.1781'	60.6355'	60' 38.13"	15.7540 S	15' 45.24"S
45	45 Shaula	1139.6855'	59.6855'	59' 41.13"	96.3098'	54.7673'	54' 46.04"	37.1188 S	37' 7.13"S
46	46 Rasalhague	1139.4783'	59.4783'	59' 28.7"	96.1027'	54.5602'	54' 33.61"	12.5398 N	12' 32.39"N
47	47 Eltanin	1134.1942'	54.1942'	54' 11.65"	90.8185'	49.2760'	49' 16.56"	51.4798 N	51' 28.79"N
48	48 Kaus Australis	1127.0553'	47.0553'	47' 3.32"	83.6796'	42.1371'	42' 8.23"	34.3721 S	34' 22.33"S
49	49 Vega	1124.0514'	44.0514'	44' 3.09"	80.6758'	39.1333'	39' 8"	38.7996 N	38' 47.98"N

17 Data Schedules

17.1 Description

There are several schedules used to calculate the GHA and DEC. These are for:

Sun	1 = Sun
Star	2 = Star
Moon	3 = Moon
Planet	4 = Venus, 5 = Mars, 6 = Jupiter, 7 = Saturn

This data is for the period 1991-2025. If the model is used outside these dates, it will prompt you for Almanac or revised polynomial data. This is an extract from the Stars schedule:

Identification					
No	Star	Mag	Letter	Constellation	Abreviation
1	Alpheratz	2.2	A	Andromedae	And
2	Ankaa	2.4	A	Phoenicis	Phe
3	Schedar	2.5	A	Cassiopaiae	Cas
4	Diphda	2.2	B	Ceti	Cet
5	Achernar	0.6	A	Eridani	Eri
6	Hamal	2.2	A	Arietis	Ari
7	Acamar	3.1	H	Eridani	Eri
8	Menkar	2.8	A	Ceti	Cet
9	Mirfak	1.9	A	Persei	Per
10	Aldebaran	1.1	A	Tauri	Tau
11	Rigel	0.3	B	Orionis	Ori
12	Capella	0.2	A	Aurigae	Aur
13	Bellatrix	1.7	C	Orionis	Ori
14	Elnath	1.8	A	Tauri	Tau
15	Alnilam	1.8	E	Orionis	Ori
16	Betelgeuse	0.5	A	Orionis	Ori
17	Canopus	-0.9	A	Carinae	Car
18	Sirius	-1.6	A	Canis Majoris	CMa
19	Adhara	1.6	E	Canis Majoris	CMa
20	Procyon	0.5	A	Canis Minoris	CMi
21	Pollux	1.2	B	Geminorum	Gem
22	Avior	1.7	E	Carinae	Car
23	Suhail	2.2	L	Velorum	Vel
24	Miaplacidus	1.8	B	Carinae	Car
25	Alphard	2.2	A	Hydrae	Hya
26	Regulus	1.3	A	Leonis	Leo
27	Dubhe	2.0	A	Ursae Majoris	UMa
28	Denebola	2.2	B	Leonis	Leo
29	Gienah	2.8	C	Corvi	Crv
30	Acrux	1.1	A	Crucis	Cru
31	Gacrux	1.6	C	Crucis	Cru
32	Alioth	1.7	E	Ursae Majoris	UMa
33	Spica	1.2	A	Virginis	Vir
34	Alkaid	1.9	G	Ursae Majoris	UMa
35	Hadar	0.9	B	Centauri	Cen
36	Menkent	2.3	H	Centauri	Cen
37	Arcturus	0.2	A	Bootis	Boo
38	Rigul Kentaurus	0.1	A	Centauri	Cen
39	Zubenelgenubi	2.9	A	Librae	A2Lib
40	Kochab	2.2	B	Ursae Minoris	UMi

18 Worked Examples

18.1 Sun, Moon and a Star on 21 June 1994

Check the Scenarios in the application (2003: Tools Scenarios, 2007+: Data, What-if, Scenarios) as all the examples are included in the model.

A ship at ZT 22:0:0 (GMT 23:0:0) on 21 June 1994 calculated its DR Position as 32' 0" N 15' 0" W and has followed a course of 325.00' T at a speed of 8 knots per hour for several hours. Three sights have been taken and a fix is now sought to check the transferred positions.

The individual sights are :

(1) Sun at ZT 18:0:0 (GMT 19:0:0) at an altitude of 11' 57.0"
(2) Moon at ZT 18:23:30 at an altitude of 11' 34.0"
(3) Star thought to be *Kochab* (40) at ZT 21:23:20 at an altitude of 46' 31.0" and a bearing of 356' 0.0".

At 15' W the model calculates the local time as:

GMT + 15' W / (360 / 24) = GMT - 1 hour (the usual convention for West and South is negative).

The star finder and identification routines are used to ensure the accurate selection of the star. A following page shows the location of all Navigational Stars for the DR time and position in this example. Summary of results:

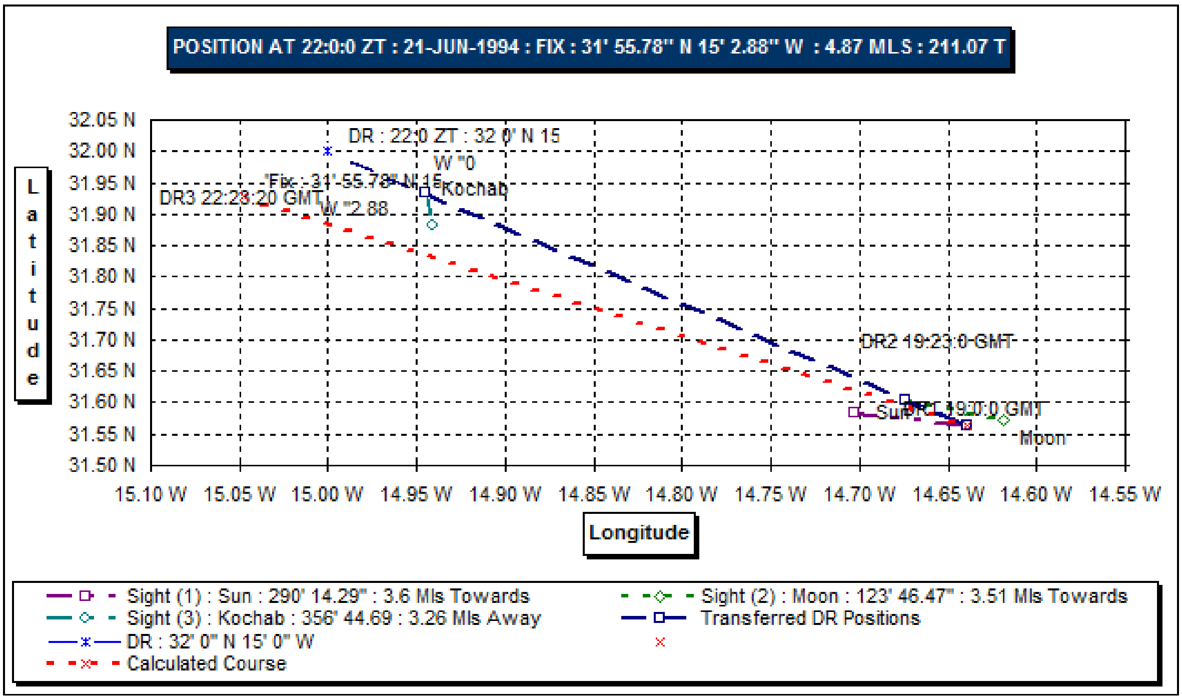
	Sun	Moon	Star (Kochab 40)
Time of Sight (GMT)	19:00:00	19:23:00	22:23:20
Difference to DR Time	(4 h 00 m)	(3 h 36 m)	(0 h 36 m)
Observed Angle	11' 57.0"	11' 34.0"	47' 31.0"
Adjusted Altitude	12' 8.35"	12' 44.94"	47' 30.09"
Declination	23' 26.29" N	20' 17.28" S	74' 10.93" N
GHA	104' 33.7"	314' 48.56"	23' 1.61"
LHA	89' 53"	300' 5.79"	8' 2.59"
Azimuth /Bearing	290' 14.09"	123' 42.94"	356' 45.86"
Intercept / Distance	3.60 Miles	3.51 Miles	3.26 Miles
Direction	Towards	Towards	Away

The Model uses the 'Method of Least Squares' to compute a fix at the DR Time of 31'N 55.78" 15'W 2.88". This position is on a bearing of 211.07' T 4.87 miles from the DR Position.

The results also show the confidence ellipse using standard deviation at 95% with its angle bearing 42.48' T. The length of the ellipse is 6.88 miles and its width 13.03 miles.

DR Position:			Calculated Position:		Position Error:	
DR Latitude	32 ' N	0.00"	31 ' N	55.78"	Confidence	
DR Longitude	15 ' W	0.00"	15 ' W	2.88"	Ellipse	95.00%
DR Zone Date	21-Jun-94	Tuesday				
Zone / GMT	22:00:00	23:00 GMT	Distance	Bearing	Latitude	6.88 mls
Course / Speed	325.00 T	8.00 kn	4.87 mls	211.07 T	Longitude	13.03 mls
Temperature & Pressure	9.80 'C	1010.00 mb			Bearing	042.48 T

	Sight # 1		Sight # 2		Sight # 3	
Which Sight	**1 Sun**		**3 Moon**		**2 Star**	
Calc/Almanac/Polynomial	B Polynomial		B Polynomial		B Polynomial	
Star Number	49		0		40 Kochab	
Actual Sight Time	18:00:00	19:00 GMT	18:23:00	19:23 GMT	21:23:20	22:23 GMT
Time Diff. / Miles	4:00 hrs	32.00 mls	3:37 hrs	28.93 mls	0:36 hrs	4.89 mls
Revised DR Position	31' 33.8" N	14' 38.4" W	31' 36.3" N	14' 40.4" W	31' 56" N	14' 56.7" W
DR Alt. / Bearing	12 ' 4.74"	290 ' 14.29"	12 ' 41.1"	123 ' 46.47"	47 ' 33.34	356 ' 44.69"
Observed Angle	11' 57"		11' 34"		47' 31"	
Index Error : Minutes	0.00"		0.00"		0.00"	
Height of User's Eye / DIP	0.00"		0.00"		0.00"	
Refraction (R=Ro*f)	4.56"		4.60"		0.91"	
Parallax in Altitude	0.14"		59.00"		0.00"	
Semi-Diameter	15.76"		16.41"		0.00"	
Corrected Altitude	12' 8.35"		12' 44.6"		47' 30.09"	
Calc. Declination	23' 26.29"	North	-20' 17.64"	South	74' 10.93"	North
Sun GHA / LHA	104' 33.7"	89' 55.34"	314' 50.11"	300' 9.68"	23' 1.61"	8' 4.91"
Azimuth / Bearing	**290' 14.29"**	**290' 14.29"**	**123' 46.47"**	**123' 46.47"**	**356' 44.69"**	**176' 44.69"**
Intercept : Miles	**3.60 mls**	**Towards**	**3.51 mls**	**Towards**	**3.26 mls**	**Away**
Calc. Position	31' 35"N	14' 42.2"W	31' 34.4"N	14' 37.1"W	31' 52.9"N	14' 56.5"W



18.2 Regulus, Antares and Kochab on 4 July 1994

This example is taken from *The Nautical Almanac 1994* (HMSO)[17].

Required: calculate the position of a ship on 4 July 1994 at GMT 21:0:0 which has been travelling on a constant course of 325' T for several hours at a speed of 20 knots.

Three observations have been taken:

Sight No	Number/Star	GMT / Universal Time	Adjusted Altitude
Sight (1)	(26) Regulus	GMT 20:39:23	27.0109'
Sight (2)	(42) Antares	GMT 20:45:47	26.0764'
Sight (3)	(40) Kochab	GMT 21:10:34	47.4449'

The time is GMT 21:0:0 and the estimated position (DR) is 32' N 15' W.

No Hour Angle, Declination and corrections to the Observed Angle are needed with *Systematic Navigation* and the intermediate results using the same format as *The Nautical Almanac 1994* (HMSO) are:

Star:	Regulus	Antares	Kochab
Star Number:	26	42	40
Time of Observation	20:39:23 UT	20:45:47 UT	21:10:34 UT
Adjusted Altitude (H_o)	27.0109'	26.0764'	47.4449'
Greenwich Hour Angle	80.4516'	346.7984'	17.6023'
Local Hour Angle	65.5084'	331.8312'	2.5424'
Time Difference to DR	-0.3436 hours	-0.2369 hours	+0.1761 hours
Revised Latitude	31.5250' N	31.5730' N	31.6480' N
Revised Longitude	14.9320' W	14.9790' W	15.0590' W
Azimuth (Z)	267.7551'	151.9161'	358.9752'
Calculated Altitude (H_c)	27.0210'	26.0983'	47.4647'
Distance (p)	+0.0100'	+0.0220'	+0.0198'
Intercept (I)	0.60 miles	1.32 miles	1.19 miles
Direction	Away	Away	Away

The Almanac calculates a final estimated position of 31.6193' N 15.0204' W (31' N 37.158" 15' W 1.224").

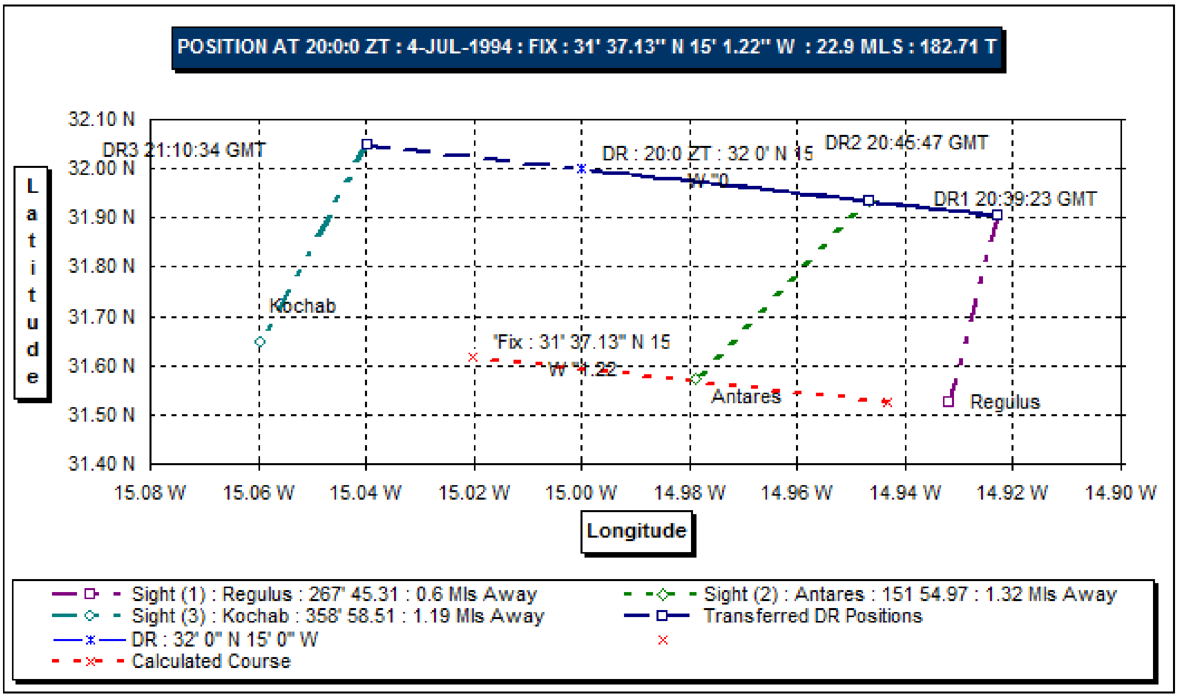
The fix using the model is 31'N 37.13" 15'W 1.22" at a distance from the DR position of 22.90 miles on a bearing of 182.71' T.

The system print-out is on the next page.

[17] Example from pages 282 and 283. Position calculated as 31.6193' (31'N' 37.158"), 15.0204'W (15'W 1.224")

DR Position:			Calculated Position:		Position Error:	
DR Latitude	32 ' N	0.00"	31 ' N	37.13"	Confidence	
DR Longitude	15 ' W	0.00"	15 ' W	1.22"	Ellipse	95.00%
DR Zone Date	4-Jul-94	Monday				
Zone / GMT	20:00:00	21:00 GMT	Distance	Bearing	Latitude	4.55 mls
Course / Speed	325.00 T	20.00 kn	22.90 mls	182.71 T	Longitude	3.26 mls
Temperature & Pressure	9.80 'C	1010.00 mb			Bearing	332.68 T

	Sight # 1		Sight # 2		Sight # 3	
Which Sight/Name	**2 Star**		**2 Star**		**2 Star**	
Calc/Almanac/Polynomial	B Polynomial		B Polynomial		B Polynomial	
Star Number	26 Regulus		42 Antares		40 Kochab	
Actual Sight Time	19:39:23	20:39 GMT	19:45:47	20:45 GMT	20:10:34	21:10 GMT
Time Diff. / Miles	0:20 hrs	6.87 mls	0:14 hrs	4.74 mls	0:10 hrs	3.52 mls
Revised DR Position	31' 31.5" N	14' 56.6" W	31' 33.2" N	14' 58" W	31' 40" N	15' 3.6" W
DR Alt. / Bearing	27 ' 1.26"	267 ' 45.31"	26 ' 5.9"	151 ' 54.97"	47 ' 27.88	358 ' 58.51"
Observed Angle	27' 2.6"		26' 6.6"		47' 27.61"	
Index Error : Minutes	0.00"		0.00"		0.00"	
Height of User's Eye / DIP	0.00"		0.00"		0.00"	
Refraction (R=Ro*f)	1.94"		2.02"		0.91"	
Parallax in Altitude	0.00"		0.00"		0.00"	
Semi-Diameter	0.00"		0.00"		0.00"	
Corrected Altitude	27' 0.66"		26' 4.58"		47' 26.7"	
Calc. Declination	11' 59.62"	North	-26' 25.22"	South	74' 10.97"	North
Star GHA / LHA	80' 27.1"	65' 30.5"	346' 47.9"	331' 49.87"	17' 36.14"	2' 32.54"
Azimuth / Bearing	**267' 45.31"**	**87' 45.31"**	**151' 54.97"**	**331' 54.97"**	**358' 58.51"**	**178' 58.51"**
Intercept : Miles	**0.60 mls**	**Away**	**1.32 mls**	**Away**	**1.19 mls**	**Away**
Calc. Position	31' 31.5"N	14' 55.9"W	31' 34.4"N	14' 58.7"W	31' 38.9"N	15' 3.6"W



18.3 Sun, Moon and Star on 19 June 1991

This example appears on page xxii of *Compact Data* 1991. On 19/6/91 at GMT 21:00 the DR position of a ship is 32' 45" N 15' 30" W and it has followed a course of 325' T at a constant speed of 12 knots for several hours.

Sight	Time	Altitude	Height
(1) Sun	18:15:24 GMT	21' 25.398"	6.0 metres
(2) Moon	20:30:45 GMT	46' 32.700"	6.0 metres
(3) *Vega* (49)	20:42:23 GMT	29' 27.132"	6.0 metres

Using a further sight of *Dubhe* (27) the fix gained by *Compact Data* is 32' 39.1" N 15' 34.2" W and this compares well with the answer below, given that the Moon is calculated using Method 'A with Aries coefficients.

DR Position:			Calculated Position:		Position Error:	
DR Latitude	32 ' N	45.00"	32 ' N	35.92"	Confidence	
DR Longitude	15 ' W	-30.00"	15 ' W	29.33"	Ellipse	95.00%
DR Zone Date	19-Jun-91	Wednesday				
Zone / GMT	20:00:00	21:00 GMT	Distance	Bearing	Latitude	3.09 mls
Course / Speed	325.00 T	12.00 kn	9.10 mls	176.27 T	Longitude	4.95 mls
Temperature & Pressure	9.80 'C	1010.00 mb			Bearing	331.42 T

	Sight # 1		Sight # 2		Sight # 3	
Which Sight	**1 Sun**		**3 Moon**		**2 Star**	
Calc/Almanac/Polynomial	B Polynomial		A Calculated		B Polynomial	
Star Number	0		0		49 Vega	
Actual Sight Time	17:15:24	18:15 GMT	19:30:45	20:30 GMT	19:42:23	20:42 GMT
Time Diff. / Miles	2:44 hrs	32.92 mls	0:29 hrs	5.85 mls	0:17 hrs	3.52 mls
Revised DR Position	32' 9" N	15' 6.9" W	32' 31.1" N	15' 25.3" W	32' 33" N	15' 26.9" W
DR Alt. / Bearing	21 ' 33.65"	284 ' 51.89"	47 ' 25.2"	204 ' 2.47"	29 ' 24.01	60 ' 27.27"
Observed Angle	21' 25.4"		46' 32.7"		29' 27.13"	
Index Error : Minutes	0.00"		0.00"		0.00"	
Height of User's Eye / DIP	-4.31"		0.00"		0.00"	
Refraction (R=Ro*f)	2.53"		0.87"		1.76"	
Parallax in Altitude	0.13"		39.02"		0.00"	
Semi-Diameter	15.77"		15.46"		0.00"	
Corrected Altitude	21' 34.47"		47' 26.17"		29' 25.37"	
Calc. Declination	23' 25.53"	North	-7' 11.56"	South	38' 46.45"	North
Sun GHA / LHA	93' 32.15"	78' 25.24"	31' 33.21"	16' 7.87"	298' 59.86"	283' 32.94"
Azimuth / Bearing	**284' 51.89"**	**284' 51.89"**	**204' 2.47"**	**204' 2.47"**	**60' 27.27"**	**60' 27.27"**
Intercept : Miles	**0.82 mls**	**Towards**	**0.96 mls**	**Towards**	**1.36 mls**	**Towards**
Calc. Position	32' 9.2"N	15' 7.8"W	32' 30.3"N	15' 25.8"W	32' 33.7"N	15' 25.6"W

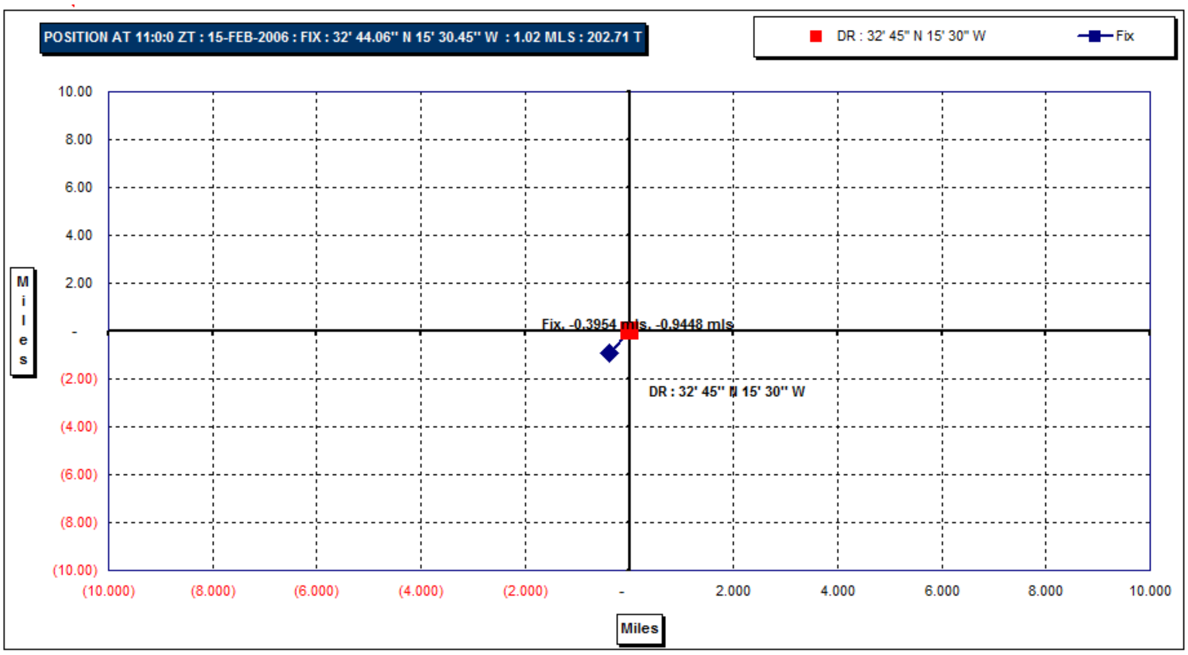
18.4 Vega, Moon and Sun on 15 February 2006

This example applies the theory from the previous sections to bring together the calculation of GHA, LHA, Declination with sight reduction and statistical fixes. This example is taken from *Compact Data*.

On February 15, 2006 at GMT 11:0:0 the DR position is assumed to be 32’N 45” 15’W 30”. Three sights have been taken along a course of 315’T at a speed of 12 knots. The temperature is 9.8’C and the atmospheric pressure 1010 Mb. The height of the eye above the horizon is 6.0 metres. Sextant index error is assumed to 0”[18].

	Star (Vega 49)	Moon	Sun
Time of Sight (GMT)	6:28:52	6:33:52	9:53:45
Difference to DR Time	(5.32 h)	(5.26 h)	(2.06 h)
Observed Angle (Hs)	48' 5.2"	28' 26"	23' 58.9"
Adjusted Altitude (Ho)	47' 60"	29' 26.33"	24' 8.68"
Declination	38' 46.99" N	5' 43.04' N	12' 39.53" S
GHA	323' 3.758"	73' 17.12"	324’ 54.23"
LHA	308' 30.9"	56' 41.5"	308’ 45.01’’
Azimuth / Bearing	65' 45.64"	257' 27.11"	126' 42.51"
Intercept / Distance	0.34 Miles	0.39 Miles	0.09 Miles
Direction	Towards	Towards	Towards

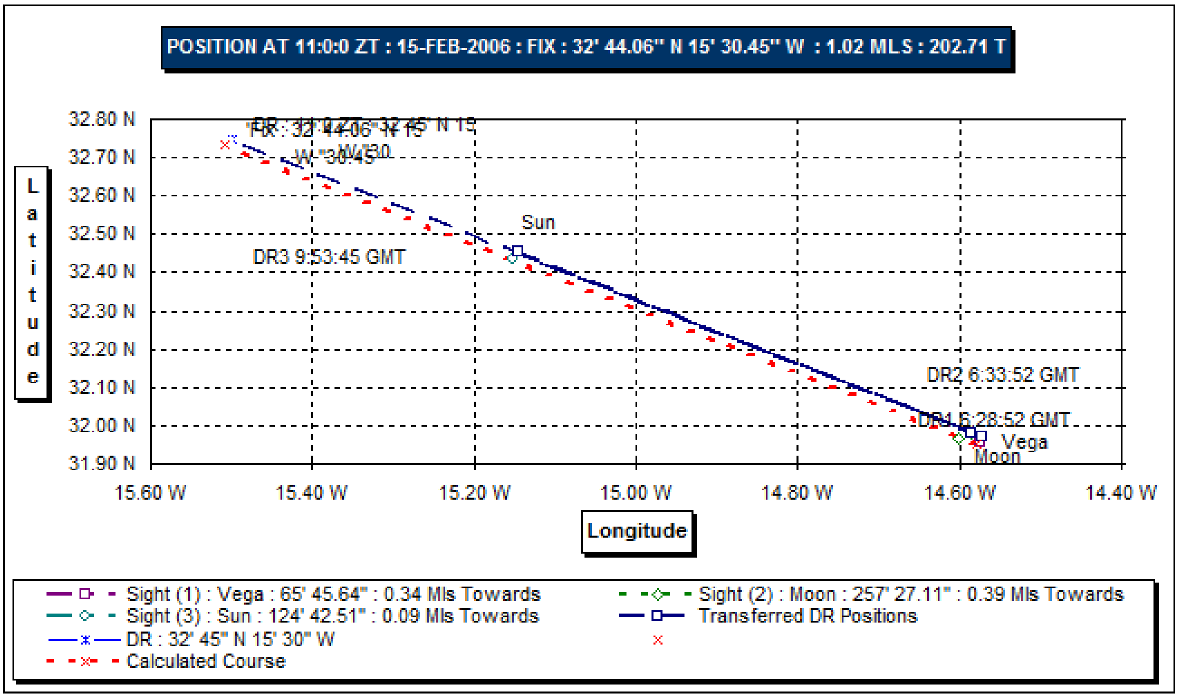
The calculated position after several iterations is 32 ' N 44.06", 15 ' W 30.45" a distance 1.02 miles and a bearing of 202.71 degrees from the DR position.



[18] This is the complete worked example from pages 60 and 61 of *Compact Data* 2006. The answer given is 32.7211’N (32’N 43.266”), 15.4707’W (15’W 28.2420”). a = 5.089 nm, b = 3.959 nm, azimuth θ = 350’ using the same methods for four rather than three observations.

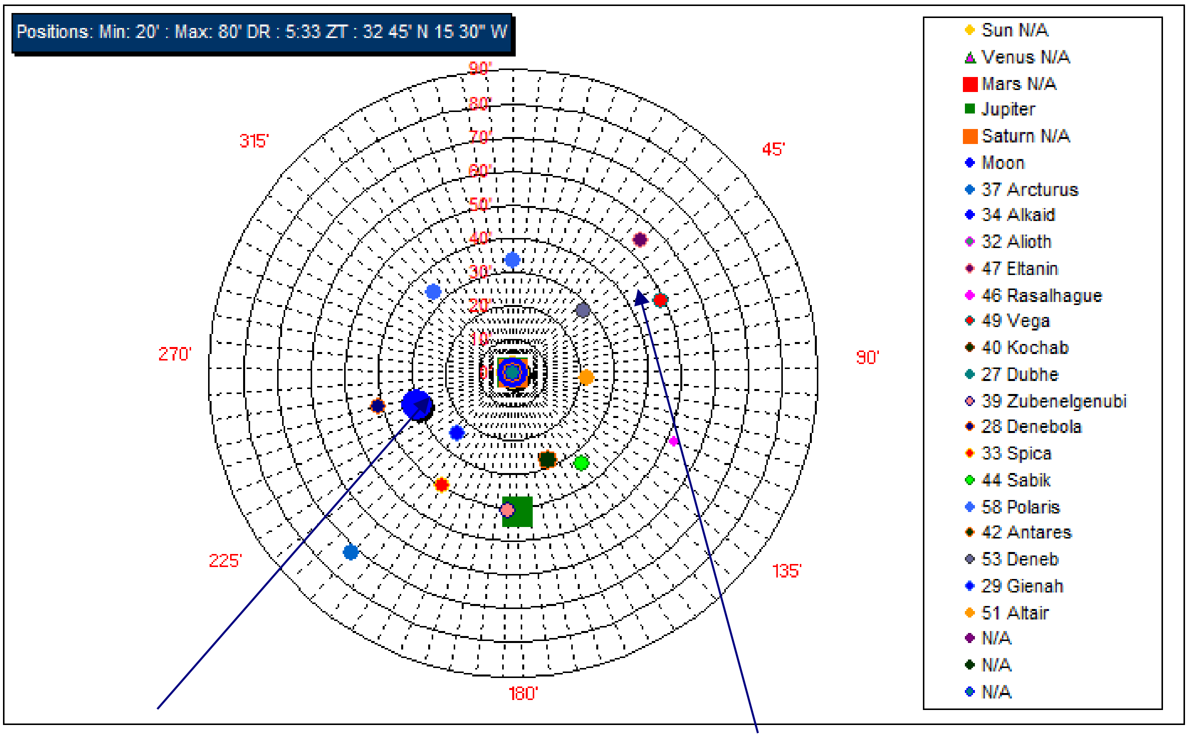
DR Position:			Calculated Position:		Position Error:	
DR Latitude	32 ' N	45.00"	32 ' N	44.06"	Confidence	
DR Longitude	15 ' W	-30.00"	15 ' W	30.45"	Ellipse	95.00%
DR Zone Date	15-Feb-06	Wednesday				
Zone / GMT	11:00:00	12:00 GMT	Distance	Bearing	Latitude	0.82 mls
Course / Speed	315.00 T	12.00 kn	1.02 mls	202.71 T	Longitude	1.76 mls
Temperature & Pressure	9.80 'C	1010.00 mb			Bearing	356.49 T

	Sight # 1		Sight # 2		Sight # 3	
Which Sight/Name	**2 Star**		**3 Moon**		**1 Sun**	
Calc/Almanac/Polynomial	B Polynomial		A Calculated		B Polynomial	
Star Number	49 Vega		0		0	
Actual Sight Time	5:28:52	06:28 GMT	5:33:52	06:33 GMT	8:53:45	09:53 GMT
Time Diff. / Miles	5:31 hrs	66.23 mls	5:26 hrs	65.23 mls	2:06 hrs	25.25 mls
Revised DR Position	31' 57.2" N	14' 34.8" W	31' 57.9" N	14' 35.6" W	32' 26.2" N	15' 9.2" W
DR Alt. / Bearing	47 ' 59.66"	65 ' 45.64"	29 ' 25.94"	257 ' 27.11"	24 ' 8.59	124 ' 42.51"
Observed Angle	48' 5.2"		28' 25.998"		23' 58.902"	
Index Error : Minutes	0.00"		0.00"		0.00"	
Height of User's Eye / DIP	-4.31"		0.00"		-4.31"	
Refraction (R=Ro*f)	0.90"		1.74"		2.23"	
Parallax in Altitude	0.00"		47.53"		0.13"	
Semi-Diameter	0.00"		14.73"		16.18"	
Corrected Altitude	47' 60"		29' 26.33"		24' 8.68"	
Calc. Declination	38' 46.99"	North	5' 43.04"	North	-12' 39.53"	South
Star GHA / LHA	323' 3.75"	308' 28.97"	73' 17.12"	58' 41.5"	324' 54.23"	309' 45.01"
Azimuth / Bearing	**65' 45.64"**	**65' 45.64"**	**257' 27.11"**	**257' 27.11"**	**124' 42.51"**	**124' 42.51"**
Intercept : Miles	**0.34 mls**	**Towards**	**0.39 mls**	**Towards**	**0.09 mls**	**Towards**
Calc. Position	31' 57.4"N	14' 34.4"W	31' 57.9"N	14' 36.1"W	32' 26.2"N	15' 9.1"W



This is a listing of the visible planets and stars at the DR position at 6:30:0 GMT based on a minimum of 20’ and a maximum of 80’. This sheet can be used to ascertain the potential bodies and show the approximate altitude and bearing.

No	No	Star Name	Mag	C. Altitude	Bearing
1		Sun N/A		(15.63')	95.25'
2		Venus N/A		13.88'	119.82'
3		Mars N/A		(35.10')	350.98'
4		Jupiter		41.08'	182.32'
5		Saturn N/A		3.07'	291.11'
6		Moon		29.98'	256.47'
1	37	37 Arcturus	0.2	71.44'	226.34'
2	34	34 Alkaid	1.9	67.18'	322.64'
3	32	32 Alioth	1.7	56.76'	324.61'
4	47	47 Eltanin	2.4	54.89'	45.36'
5	46	46 Rasalhague	2.1	51.65'	113.36'
6	49	49 Vega	0.1	48.57'	66.63'
7	40	40 Kochab	2.2	48.54'	357.77'
8	27	27 Dubhe	2	41.54'	326.00'
9	39	39 Zubenelgenu	2.9	40.92'	186.74'
10	28	28 Denebola	2.2	40.61'	260.89'
11	33	33 Spica	1.2	39.19'	214.68'
12	44	44 Sabik	2.6	33.87'	145.09'
13	58	58 Polaris	2.1	33.44'	0.13'
14	42	42 Antares	1.2	28.01'	160.37'
15	53	53 Deneb	1.3	27.63'	51.89'
16	29	29 Gienah	2.8	24.38'	226.71'
17	51	51 Altair	0.9	21.85'	93.45'
18	N/A	N/A	N/A	N/A	256.47'
19	N/A	N/A	N/A	N/A	256.47'
20	N/A	N/A	N/A	N/A	256.47'



Moon Vega

18.5 Moon, Star (18 Sirius) and Mars on 11 September 2014

On September 11, 2014 at GMT 06:30:0 the DR position is assumed to be 32'N 1" 15'W 38". Three sights have been taken along a course of 315'T at a speed of 12 knots. The temperature is 9.8'C and the atmospheric pressure 1010 Mb. The height of the eye above the horizon is 6.0 metres. Sextant index error is assumed to 0"[19].

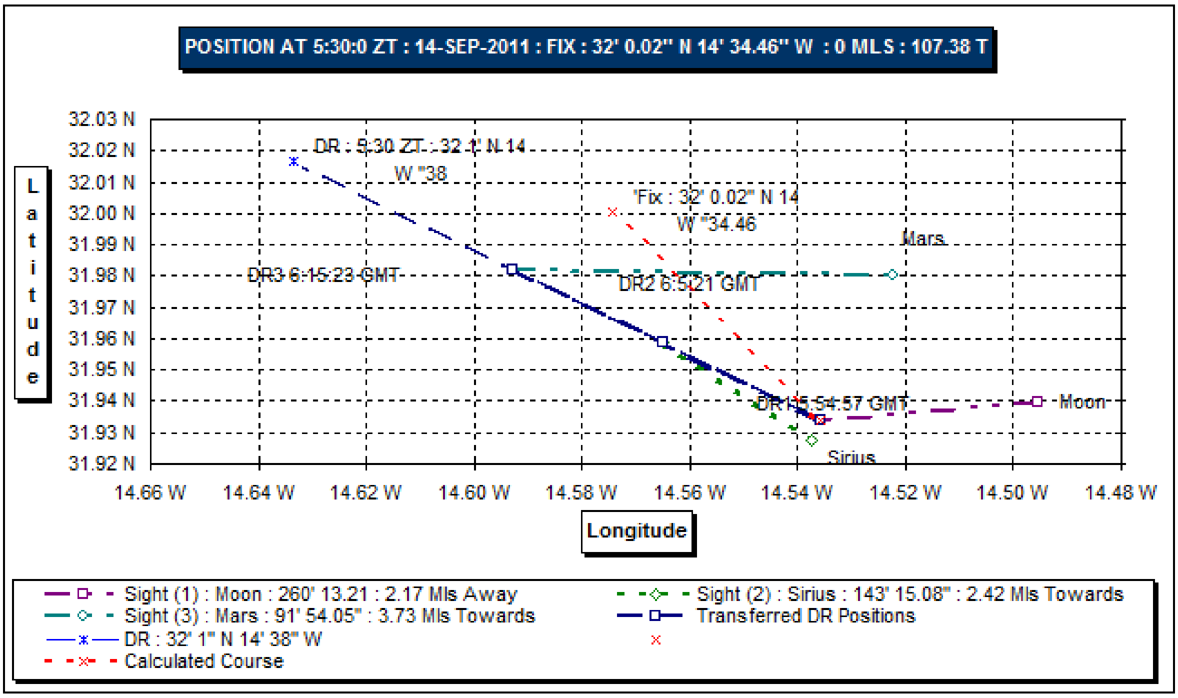
	Moon	Star	Mars
Time of Sight (GMT)	5:54:52	6:05:21	6:15:235
Difference to DR Time	(0.35 h)	(0.24 h)	(0.14 h)
Observed Angle (Hs)	30' 26.6"	32' 42.9"	47' 10.4"
Adjusted Altitude (Ho)	31' 21.82"	32' 37.04"	47'5.22"
Declination	8' 46.45" N	16 43.82' S	21' 36.81" N
GHA	72' 52.1"	342' 47.9"	327' 28.1"
LHA	58' 19.94"	328 14.01"	312' 52.54''
Azimuth / Bearing	260' 13.21"	143' 15.08"	91' 54.05"
Intercept / Distance	2.17 Miles	2.42 Miles	3.73 Miles
Direction	Away	Towards	Towards

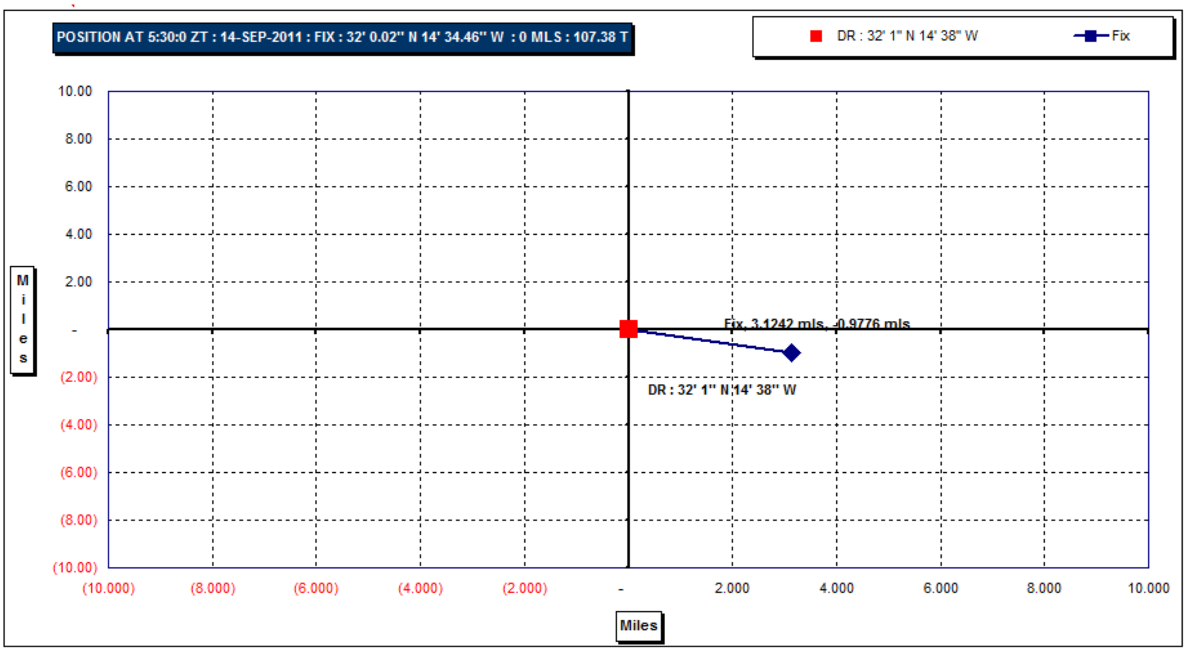
The calculated position after several iterations is 32 ' N 0.02", 14 ' W 34.46" a distance 3.154 miles and a bearing of 107.38 degrees from the DR position.

DR Position:			Calculated Position:		Position Error:	
DR Latitude	32 ' N	1.00"	32 ' N	0.02"	Confidence	
DR Longitude	14 ' W	-38.00"	14 ' W	34.46"	Ellipse	95.00%
DR Zone Date	14-Sep-11	Wednesday				
Zone / GMT	5:30:00	06:30 GMT	Distance	Bearing	Latitude	1.50 mls
Course / Speed	315.00 T	12.00 kn	3.15 mls	107.38 T	Longitude	2.99 mls
Temperature & Pressure	9.80 'C	1010.00 mb			Bearing	011.31 T

	Sight # 1		Sight # 2		Sight # 3	
Which Sight	**3 Moon**		**2 Star**		**5 Mars**	
Calc/Almanac/Polynomial	B Polynomial		B Polynomial		B Polynomial	
Star Number	49		18 Sirius		0	
Actual Sight Time	4:54:57	05:54 GMT	5:05:21	06:05 GMT	5:15:23	06:15 GMT
Time Diff. / Miles	0:35 hrs	7.01 mls	0:24 hrs	4.93 mls	0:14 hrs	2.92 mls
Revised DR Position	31' 56" N	14' 32.2" W	31' 57.5" N	14' 33.9" W	31' 58.9" N	14' 35.6" W
DR Alt. / Bearing	31 ' 24"	260 ' 13.21"	32 ' 34.62"	143 ' 15.08"	47 ' 1.49	91 ' 54.05"
Observed Angle	30' 26.598"		32' 42.9"		47' 10.4"	
Index Error : Minutes	0.00"		0.00"		0.00"	
Height of User's Eye / DIP	-4.31"		-4.31"		-4.31"	
Refraction (R=Ro*f)	1.61"		1.55"		0.93"	
Parallax in Altitude	46.60"		0.00"		0.05"	
Semi-Diameter	14.71"		0.00"		0.00"	
Corrected Altitude	31' 21.82"		32' 37.04"		47' 5.22"	
Calc. Declination	8' 46.45"	North	-16' 43.82"	South	21' 36.81"	North
Moon GHA / LHA	72' 52.1"	58' 19.94"	342' 47.9"	328' 14.01"	327' 28.1"	312' 52.54"
Azimuth / Bearing	**260' 13.21"**	**80' 13.21"**	**143' 15.08"**	**143' 15.08"**	**91' 54.05"**	**91' 54.05"**
Intercept : Miles	**2.17 mls**	**Away**	**2.42 mls**	**Towards**	**3.73 mls**	**Towards**
Calc. Position	31' 56.4"N	14' 29.7"W	31' 55.7"N	14' 32.3"W	31' 58.8"N	14' 31.3"W

[19] This adapted from the examplei from pages 18 and 19 of *Compact Data* 2010. The answer given for different times and positions is 32.788'N (32'N 47.3"), 15.508'W (15'W 30.5"). a = 4.177 nm, b = 1.816 nm, azimuth θ = 16' using the same methods for four rather than three observations.


POSITION AT 5:30:0 ZT : 14-SEP-2011 : FIX : 32' 0.02" N 14' 34.46" W : 0 MLS : 107.38 T
Latitude
Longitude
DR : 5:30 ZT : 32 1' N 14 W "38
'Fix : 32' 0.02" N 14 W "34.46
Mars
DR3 6:15:23 GMT
DR2 6:5:21 GMT
DR1 5:54:57 GMT
Moon
Sirius
Sight (1) : Moon : 260' 13.21 : 2.17 Mls Away
Sight (2) : Sirius : 143' 15.08" : 2.42 Mls Towards
Sight (3) : Mars : 91' 54.05" : 3.73 Mls Towards
Transferred DR Positions
DR : 32' 1" N 14' 38" W
Calculated Course


POSITION AT 5:30:0 ZT : 14-SEP-2011 : FIX : 32' 0.02" N 14' 34.46" W : 0 MLS : 107.38 T
DR : 32' 1" N 14' 38" W
Fix
Miles
Fix, 3.1242 mls, -0.9776 mls
DR : 32' 1" N 14' 38" W

18.6 Moon, Star (37 Acturus) and Mars on 2 April 2016

On April 2, 2016 at GMT 12:00:0 the DR position is assumed to be 33’N 24” 15’W 42”. Three sights have been taken along a course of 315’T at a speed of 12 knots. The temperature is 9.8’C and the atmospheric pressure 1010 Mb. The height of the eye above the horizon is 6.0 metres. Sextant index error is assumed to 0”[20].

	Moon	Star	Mars
Time of Sight (GMT)	6:04:27	6:14:17	5:19:43
Difference to DR Time	(5.55 h)	(5:45 h)	(5.4 h)
Observed Angle (Hs)	29' 30.4"	38' 42.1"	31' 28.8"
Adjusted Altitude (Ho)	30' 30.19"	38' 36.55"	31' 22.03"
Declination	15' 43.01" S	19 5.86' N	20' 43.71" S
GHA	338' 18.83"	70' 29.54"	40’ 2.08"
LHA	323' 39.17"	55' 48.22"	25’ 19.83’’
Azimuth / Bearing	138' 32.77"	269' 12.84"	207' 57.43"
Intercept / Distance	1.27 Miles	1.36 Miles	1.10 Miles
Direction	Towards	Towards	Away

22.03

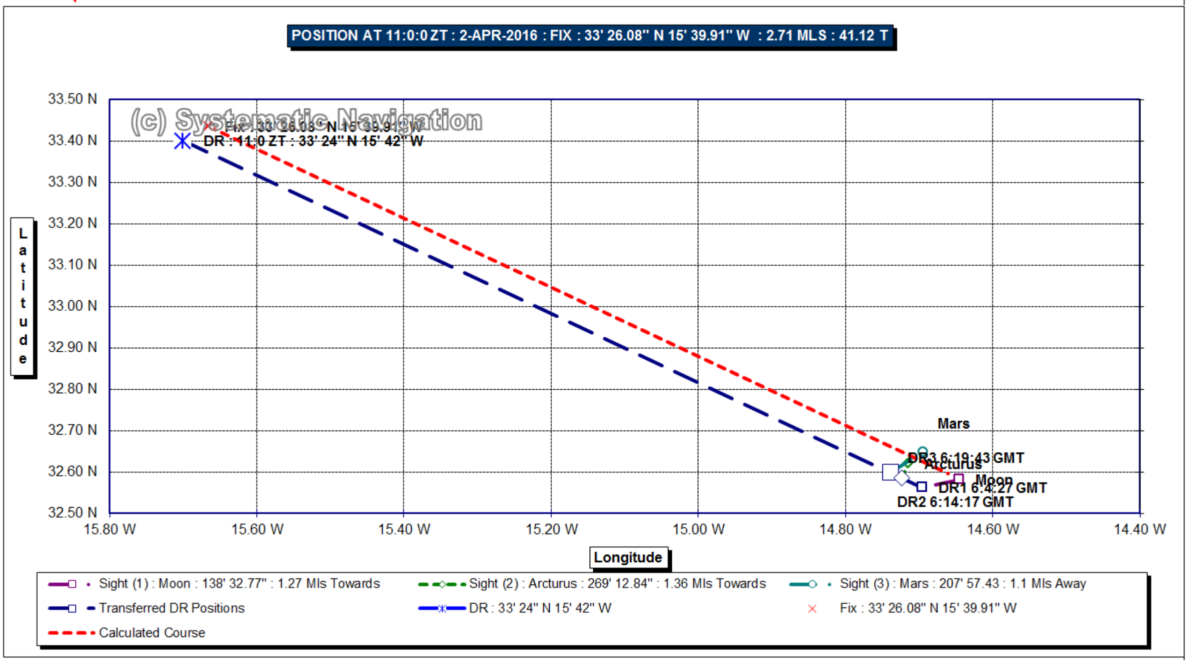
The calculated position after several iterations using the switch on the right of the Inputs sheet is 33 ' N 26.08", 15 ' W 39.91" a distance 2.713 miles and a bearing of 41.12 degrees from the DR position.

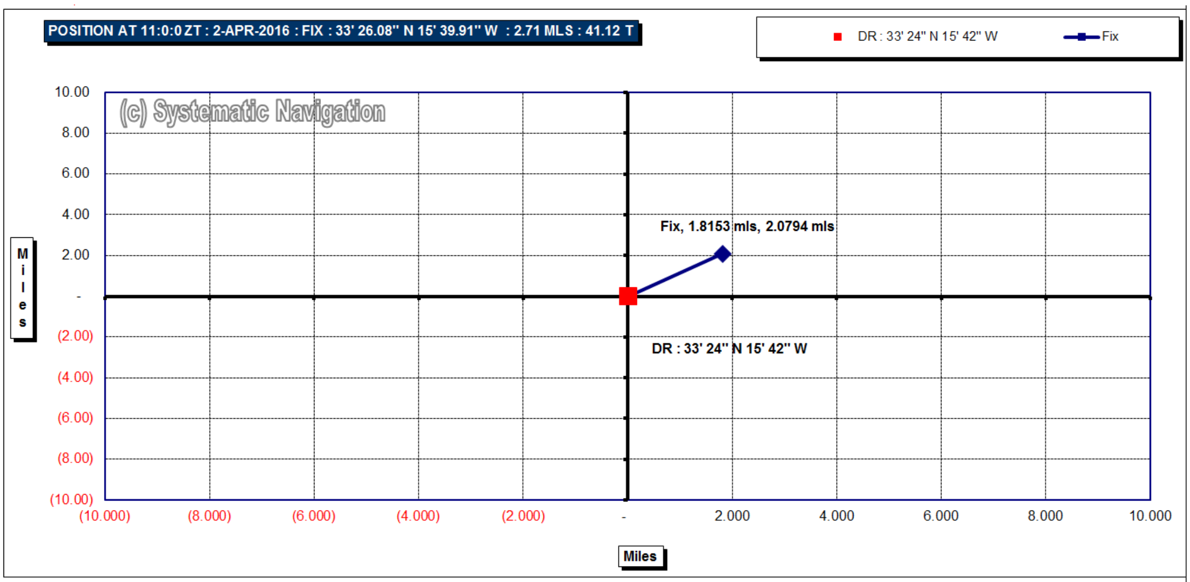
Systematic Navigation: Inputs | Main Menu | Calculate (F9) | Copy Results | Clear Results | Version 6.0 1-Jan-2016

DR Position:			**Calculated Position:**		English	English
DR Latitude	33 ' N	24.00 "	33 ' N	26.08 "	**Confidence**	**95.00%**
DR Longitude	15 ' W	-42.00 "	15 ' W	39.91 "	**Ellipse**	
DR Zone Date	2-Apr-16	Saturday	Distance	2.713 mls	**Latitude**	**4.08 mls**
Zone / GMT	11:00:00	12:00 GMT	Bearing	41.12 T	**Longitude**	**4.58 mls**
Course / Speed	315.00 T	12.00 kn			**Bearing**	**11.71 T**

	Sight # 1			Sight # 2			Sight # 3	
Which Sight	3	Moon		2	Star		5	Mars
Method : 'A' or 'B'	B	Polynomial		B	Polynomial		B	Polynomial
Actual Sight Time	5:04:27	06:04 GMT		5:14:17	06:14 GMT		5:19:43	06:19 GMT
Time Diff. / Miles	5:55 hrs	71.11 mls		5:45 hrs	69.14 mls		5:40 hrs	68.06 mls
Revised DR Position	32' 35.8" N	14' 39.7" W		32' 37.2" N	14' 41.3" W		32' 38" N	14' 42.2" W
DR Star Altitude '	0.00'	0		0.00'	0		0.00'	0
DR Star Bearing '	0.00 E	0		0.00 E	0		0.00 E	0
Star Number	0	0	Input Star No	37	Arcturus		0	0
DR Alt. / Bearing	30' 28.93"	138' 32.77"		38' 35.19"	269' 12.84"		31' 24.13	207' 57.43"
Observed Angle	29 '	30.40 "		38 '	42.10 "		31 '	28.80 "
Index Error : Minutes	0.00 "			0.00 "			0.00 "	
On/Off the Arc : N/F	F	Off Arc		F	Off Arc		F	Off Arc
Height of User's Eye	6.00 mtr			6.00 mtr			6.00 mtr	
Upper / Lower Limb	L	Lower		L	Lower		L	Lower
Calc. HP / SD	0.00 "	0"/15.7"	Calc. HP/SD	0.00 "	0"	Calc. HP/SD	0.00 "	0"
Corrected Altitude	30' 30.2"			38' 36.55"			31' 23.03"	
Calc. Declination	0 ' N	0.00 "	Calc. DEC	0 ' N	0.00 "	Calc. DEC	0 ' N	0.00 "
	0 '	0.00 "		0 '	0.00 "		0 '	0.00 "
	0 '	0.00 "		0 '	0.00 "		0 '	0.00 "
Moon Declination	-15' 43.01"	South	Star DEC	19' 5.86"	North	Mars DEC	-20' 43.71"	South
Calc. GHA	0 ' E	0.00 "	Calc. GHA	0 ' E	0.00 "	Calc. GHA	0 ' E	0.00 "
	0 '	0.00 "		0 '	0.00 "		0 '	0.00 "
	0 '	0.00 "		0 '	0.00 "		0 '	0.00 "
Moon GHA / LHA	338' 18.83"	323' 39.17"	Star LHA	70' 29.54"	55' 48.22"	Mars LHA	40' 2.08"	25' 19.83"
Azimuth / Bearing	**138' 32.77"**	**138' 32.77"**		**269' 12.84"**	**269' 12.84"**		**207' 57.43"**	**27' 57.43"**
Intercept : Miles	**1.27 mls**	**Towards**		**1.36 mls**	**Towards**		**1.10 mls**	**Away**
Calc. Position	**32' 34.9"N**	**14' 38.7"W**		**32' 37.2"N**	**14' 42.9"W**		**32' 38.9"N**	**14' 41.7"W**

[20] This is the complete worked example from pages 18 and 19 of *Compact Data* 2016-2020. The answer given is 33.4466’N (33’N 26.8”), 15.6593’W (15’W 39.6”). a = 5.089 nm, b = 3.959 nm, azimuth θ = 19’ using the same methods for four rather than three observations.


POSITION AT 11:0:0 ZT : 2-APR-2016 : FIX : 33' 26.08" N 15' 39.91" W : 2.71 MLS : 41.12 T
(c) Systematic Navigation
DR : 11:0 ZT : 33' 24" N 15' 42" W
Mars
DR3 6:19:43 GMT
Arcturus
Moon
DR1 6:4:27 GMT
DR2 6:14:17 GMT
Latitude
Longitude
Sight (1) : Moon : 138' 32.77" : 1.27 Mls Towards
Sight (2) : Arcturus : 269' 12.84" : 1.36 Mls Towards
Sight (3) : Mars : 207' 57.43 : 1.1 Mls Away
Transferred DR Positions
DR : 33' 24" N 15' 42" W
Fix : 33' 26.08" N 15' 39.91" W
Calculated Course


POSITION AT 11:0:0 ZT : 2-APR-2016 : FIX : 33' 26.08" N 15' 39.91" W : 2.71 MLS : 41.12 T
DR : 33' 24" N 15' 42" W
Fix
(c) Systematic Navigation
Fix, 1.8153 mls, 2.0794 mls
DR : 33' 24" N 15' 42" W
Miles

18.7 Moon, Star (34 Alkaid) and Sun on 1 May 2021

On May 1, 2021 at GMT 12:00:0 the DR position is assumed to be 32'N 45" 15'W 30". Three sights have been taken along a course of 315'T at a speed of 12 knots. The temperature is 10'C and the atmospheric pressure 1010 Mb. The height of the eye above the horizon is 6.0 metres. Sextant index error is assumed to 0"[21].

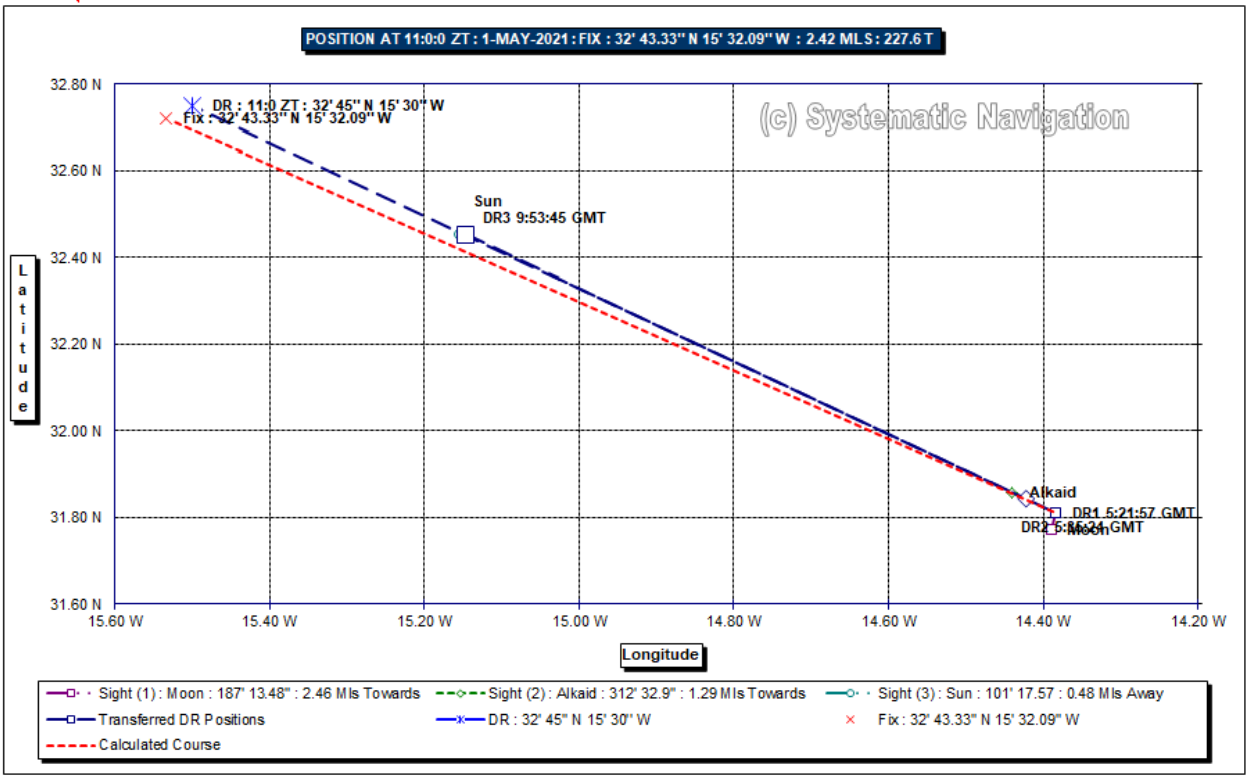
	Moon	Star	Mars
Time of Sight (GMT)	5:21:57	5:35:24	9:53:45
Difference to DR Time	(6.38 h)	(6:24 h)	(2.06 h)
Observed Angle (Hs)	31' 16.9"	28' 46.8"	44' 46.4"
Adjusted Altitude (Ho)	32' 18.08"	28' 40.72"	44' 57.08"
Declination	25' 33.9" S	49 12.51' N	15' 12.17" S
GHA	21' 9.29"	96' 7.26"	329' 10.08"
LHA	6' 46.22"	81' 41.93"	314' 1.31''
Azimuth / Bearing	187' 13.48"	312' 32.9"	101' 17.57"
Intercept / Distance	2.46 Miles	1.29 Miles	0.48 Miles
Direction	Towards	Towards	Away

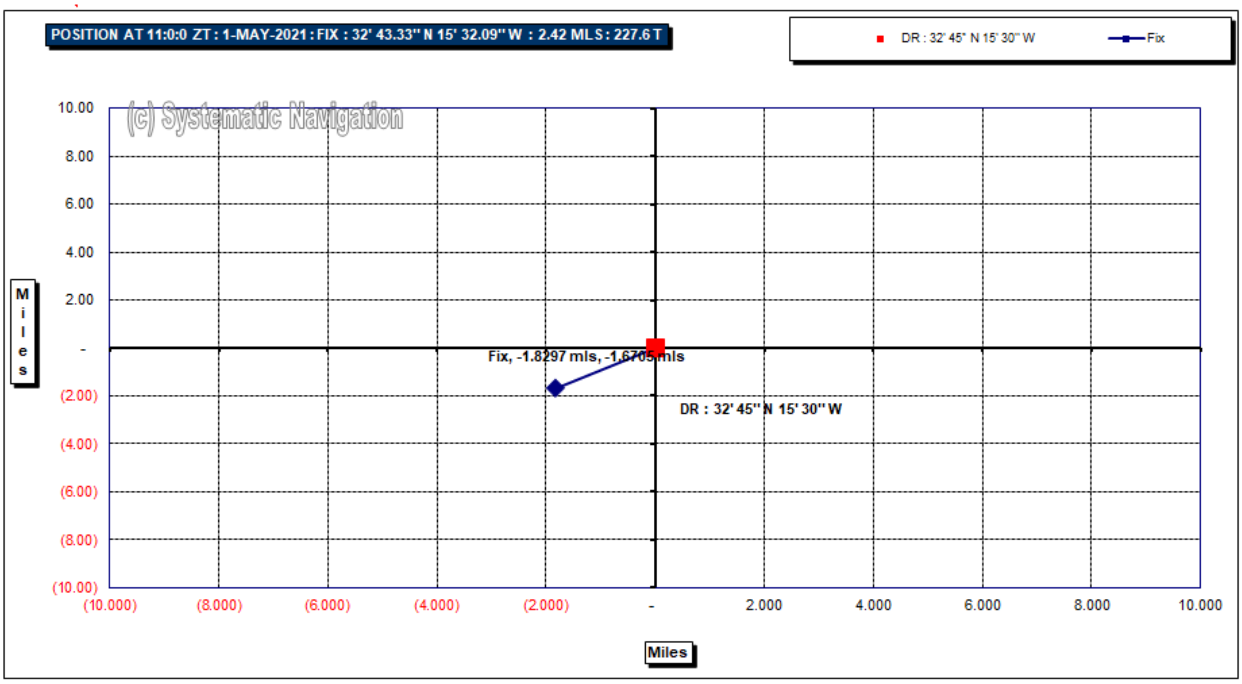
22.03

The calculated position after several iterations using the switch on the right of the Inputs sheet is 33 ' N 26.08", 15 ' W 39.91" a distance 2.713 miles and a bearing of 41.12 degrees from the DR position.

DR Position:				**Calculated Position:**			**English**	**English**
DR Latitude	32 ' N	45.00 "		32 ' N	43.33 "		**Confidence**	**95.00%**
DR Longitude	15 ' W	-30.00 "		15 ' W	32.09 "		**Ellipse**	
DR Zone Date	1-May-21	Saturday		Distance	2.424 mls		**Latitude**	**2.66 mls**
Zone / GMT	11:00:00	12:00:00 GMT		Bearing	227.60 T		**Longitude**	**3.96 mls**
Course / Speed	315.00 T	12.00 kn					**Bearing**	**43.98 T**
	Sight # 1			**Sight # 2**			**Sight # 3**	
Which Sight	3	Moon		2	Star		1	Sun
Method : 'A' or 'B'	B	Polynomial		B	Polynomial		B	Polynomial
Actual Sight Time	4:21:57	05:21:57 GMT		4:35:24	05:35:24 GMT		8:53:45	09:53:45 GMT
Time Diff. / Miles	6:38 hrs	79.61 mls		6:24 hrs	76.92 mls		2:06 hrs	25.25 mls
Revised DR Position	31' 48.7" N	14' 23.1" W		31' 50.6" N	14' 25.3" W		32' 27.1" N	15' 8.8" W
DR Star Altitude '	0.00'	0		0.00'	0		0.00'	0
DR Star Bearing '	0.00 E	0		0.00 E	0		0.00 E	0
Star Number	0	0	Input Star No	34	Alkaid		0	0
DR Alt. / Bearing	32' 15.62"	187' 13.48"		28' 39.43"	312' 32.9"		44' 57.55	101' 17.57"
Observed Angle	31 '	16.90 "		28 '	46.80 "		44 '	46.40 "
Index Error : Minutes	0.00 "			0.00 "			0.00 "	
On/Off the Arc : N/F	F	Off Arc		F	Off Arc		F	Off Arc
Height of User's Eye	6.00 mtr			6.00 mtr			6.00 mtr	
Upper / Lower Limb	L	Lower		L	Lower		L	Lower
Calc. HP / SD	0.00 "	0"/16.2"	Calc. HP/SD	0.00 "	0"	Calc. HP/SD	0.00 "	15.9"
Corrected Altitude	32' 18.08"			28' 40.72"			44' 57.08"	
Calc. Declination	0 ' N	0.00 "	Calc. DEC	0 ' N	0.00 "	Calc. DEC	0 ' N	0.00 "
	0 '	0.00 "		0 '	0.00 "		0 '	0.00 "
	0 '	0.00 "		0 '	0.00 "		0 '	0.00 "
Moon Declination	-25' 33.9"	South	Star DEC	49' 12.51"	North	Sun DEC	15' 12.17"	North
Calc. GHA	0 ' E	0.00 "	Calc. GHA	0 ' E	0.00 "	Calc. GHA	0 ' E	0.00 "
	0 '	0.00 "		0 '	0.00 "		0 '	0.00 "
	0 '	0.00 "		0 '	0.00 "		0 '	0.00 "
Moon GHA / LHA	21' 9.29"	6' 46.22"	Star LHA	96' 7.26"	81' 41.93"	Sun LHA	329' 10.08"	314' 1.31"
Azimuth / Bearing	**187' 13.48"**	**187' 13.48"**		**312' 32.9"**	**312' 32.9"**		**101' 17.57"**	**281' 17.57"**
Intercept : Miles	**2.46 mls**	**Towards**		**1.29 mls**	**Towards**		**0.48 mls**	**Away**
Calc. Position	**31' 46.4"N**	**14' 23.4"W**		**31' 51.4"N**	**14' 26.4"W**		**32' 27.2"N**	**15' 9.3"W**

[21] This is the complete worked example from *Compact Data* 2011-2025. The answer given is 32.7309'N (32'N 43.9"), 15.5365'W (15'W 32.2"). a = 1.874 nm, b = 3.335 nm, azimuth θ = 320' using the same methods for four rather than three observations.


POSITION AT 11:0:0 ZT : 1-MAY-2021 : FIX : 32' 43.33" N 15' 32.09" W : 2.42 MLS : 227.6 T
(c) Systematic Navigation
DR : 11:0 ZT : 32' 45" N 15' 30" W
Fix : 32' 43.33" N 15' 32.09" W
Sun
DR3 9:53:45 GMT
Alkaid
DR1 5:21:57 GMT
Latitude
Longitude
32.80 N
32.60 N
32.40 N
32.20 N
32.00 N
31.80 N
31.60 N
15.60 W
15.40 W
15.20 W
15.00 W
14.80 W
14.60 W
14.40 W
14.20 W
Sight (1) : Moon : 187' 13.48" : 2.46 Mls Towards
Sight (2) : Alkaid : 312' 32.9" : 1.29 Mls Towards
Sight (3) : Sun : 101' 17.57 : 0.48 Mls Away
Transferred DR Positions
DR : 32' 45" N 15' 30" W
Fix : 32' 43.33" N 15' 32.09" W
Calculated Course


POSITION AT 11:0:0 ZT : 1-MAY-2021 : FIX : 32' 43.33" N 15' 32.09" W : 2.42 MLS : 227.6 T
DR : 32' 45" N 15' 30" W
Fix
(c) Systematic Navigation
Fix, -1.8297 mls, -1.6705 mls
DR : 32' 45" N 15' 30" W
Miles
10.00
8.00
6.00
4.00
2.00
-
(2.00)
(4.00)
(6.00)
(8.00)
(10.00)
(10.000)
(8.000)
(6.000)
(4.000)
(2.000)
2.000
4.000
6.000
8.000
10.000

19 Information

19.1 Read Me Notes

Systematic Navigation - Version 7.0 1-Jan-2021 : 'Registered' Copy

CONTENTS

Unless registered, this is an 'Evaluation' version which is valid for a 21 day evaluation period for a single position. The software is not free and after 21 days, you should register it and keep your conscience clear!

Introduction

Systematic Navigation comprises a complete application in Microsoft Excel for astro navigation without tables or an almanac. It has been full revised and updated for the period 1991-2025 and should be of interest to navigators, astonomers and students particularly those studying for the yachtmaster examinations.

The model accepts up to three sextant sights taken from one position or along a course line. It then reduces the sights and derives an azimuth/bearing plot and an intercept in miles from the DR position. With two or more sights, Systematic Navigation will statistically calculate a fix position in latitude and longitude.

The results sheet summarises the results for each sight and draws a plot of the revised position.

The table below shows the extent of automatic calculation of the Greenwich Hour Angle and Declination. You can always use the model as a training aid and opt to enter all data and check your answers against the model.

Systematic Navigation uses both Method 'A' (Aries coefficents) or Method 'B' (Polynomial coefficients):

	Method A	Method B
Sun	Yes	1991-2025
Stars	Enter Almanac Data	1991-2025
Moon	Yes	1991-2025
Planets	Enter Almanac Data	1991-2025

Systematic Navigation contains these separate schedules within the file:

(1) Input form for up to three sights of the sun, moon, stars and planets
(2) Results with a chart plot and fix
(3) Chart Plot and sun, moon and planetary positions
(4) Star charts at the DR time
(5) Positions schedule of the sun, moon, stars and planets
(6) Sun and moon rise and set
(7) Great Circle navigation
(8) Background calculations and aries coefficients
(9) Read Me and Registration

Please contact Alastair Day if you would like assistance or further information on this or any other of our products. We welcome suggestions and look forward to hearing from you.

The program has been extensively tested. However no liability can be accepted regarding the use or accuracy of the programs whatsoever. We will make every effort to rectify any errors reported to us at the address below.

19.2 Installation

You need to install Systematic Navigation on a hard disk. Follow the instructions below:

The system requirements are an IBM compatible computer with minimum 3.0 Mb spare disk capacity. The software requirements are Windows and Excel 2003+..

The package contains all the files for this application.

(A) Unzip the files to a new directory C:\SFLNavXX

(B) The complete package contains the Excel file, pdf manual and ReadMe text

(C) Click the icon twice to start the application - Systematic Navigation.

19.3 Starting the Application

After installing Systematic Navigation, open it following the instructions below:

(A) Click the icon twice and the system will load Excel and Systematic Navigation.

(B) When you first open the system, it will display copyright information. Press to agree.

(C) The system opens Systematic Navigation.

(D) Press 'Halt' and tab to 'Version' to enter any licencing information.

Save this file with your results whenever you exit Systematic Navigation.

All reports were prepared with an HP 5 laser printer: if you have problems adjust the magnification in Print Preview. Keep all files in the same sub-directory - they will not work correctly if split between different directories.

19.4 Version and File Information

This is the Version sheet which is the last schedule on *Systematic Navigation.* The system displays this information at the bottom of each schedule.

A complete copy of *Systematic Navigation* is valid until 31 December 2025. After this date, the application will not work properly and will display error messages.

Installation:	1/1/2021 07:00:00	Original installation date
Serial No:	14197-121-7.0	Licence serial number
Licence Type:	'Registered' Copy	'Shareware' or 'Registered' licence
Application:	Systematic Navigation	Initial macro screen
BoxName:	Systematic Navigation	Title of the macro dialog boxes
Version:	Version 7.0 1-Jan-2021	Appears on all sheets to identify the version
Expiry Date:	31 Dec 2025	Data valid until 31-Dec-2025
Price:	na	Normal price for Systematic Navigation
Contact:	© Systematic Navigation : www.sysmaps.co.uk	Copyright holder displayed on all schedules
Author:	Alastair Day	Author and copyright holder
Company:	Systematic Navigation	Company name and address
Address1:	Orchard House	
Address2:	Green Lane	
Town:	Guildford	
County:	Surrey UK	
Postcode:	GU1 2LZ	
Telephone:	+44 (0)1483 532929	
Fax:	na	
Email:	info@system.co.uk	
Web:	www.sysmaps.co.uk	

Enter the name or company name and password sent to you after registration:

Name:

Password

If you enter the name and code correctly and press F9, the licence type and expiry date above will be updated to "Registered Copy" and a later expiry date.

Licence: Data valid until 31-Dec-2025

IMPORTANT: DO NOT DELETE OR MOVE THIS FILE
THIS INFORMATION IS USED BY ALL FILES IN SYSTEMATIC NAVIGATION

If you have any problems or would like more information about this product or any of our other activities, please contact Systematic Finance Ltd as above. Similarly, if you have any suggestions regarding this product, please let us know. We will try to incorporate your improvements into the next version.

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21 Bibliography

We would like to thank the authors of these publications which proved to be invaluable reference guides in the preparation of *Systematic Navigation*.

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Guildford, 27 August 2020