MERLIN

CELESTIAL NAVIGATION COMPUTER

INSTRUCTION MANUAL

MERLIN

THIRD EDITION
Reprinted April 1987

PREFACE

The third edition of the Merlin instruction manual has numerous small changes and two major additions: an appendix on land navigation and a substitute sun program.

The interest in land navigation surprised me. Apparently there is no readily available information. I would be pleased to hear comments on the new appendix.

The new sun program means that a complete back-up to Merlin can now be made from any standard EL-512 calculator. Some people look at these programs and think they are complicated. They are not: you merely follow instructions and you do it just once. It's worth it. The resulting machine is only marginally less convenient than Merlin and its accuracy is more than adequate for a back-up.

It is widely held that small boats should carry sight reduction tables for emergencies. I do not agree. Calculator breakdown is a rare event and when it occurs the suitable method will be the one which can be understood and which is still working. That is to say, it should be simple enough to learn at the time and not need a new almanac. That is why this manual lists a permanent sun almanac with precise instructions for noonsights. Traditional tables aren't appropriate.

Another surprise was the number of people who thought that Merlin's almanacs consist of lists of figures. There's a note on page 4 to clear that up. Though Merlin will give sun and Aries positions for 50 years or so, the EL-512 is too small to hold the sun's values from the Nautical Almanac for a single day.

We have expanded a bit over the past two years. Merlin is now on sale in many countries and this manual is available in French. Write if you have any comments. I answer all queries.

Mike Pepperday　　　　Perth, September 1986.

FROM THE PREFACE TO THE SECOND EDITION

If present trends continue computers on board will one day be as common as clocks and printed tables and almanacs will vanish.

It was to replace tables that I bought a Sharp EL-512 in September 1982 during a Pacific cruise. Subsequently it became the basis of several different sight reduction computers but it wasn't until nearly two years later that I found a way to fit a sun almanac in. Merlin evolved from that.

The main part of this manual tells how to operate, care for, and back up, Merlin - there is no need to consult the Sharp booklet. This is followed by appendices to help the learner, the sailor whose electronic equipment fails at sea, and the surveyor. Annexes give reference data necessary for celestial navigation.

Though the manual is not a textbook on celestial navigation, the beginner has been kept very much in mind. With a working knowledge of latitude, longitude and azimuth (bearing) the beginner should be able to manage.

I wish to thank the sailors who tried out prototypes and predecessors. Some of you wrote long letters from remote places. Merlin reflects your comments. Thanks also to the friends who read, criticised, suggested and encouraged. Most of all thanks to my wife, Fran, who believed in it and looked after everything else so that I could get on with it.

Mike Pepperday　　　　Darwin, April 1985.

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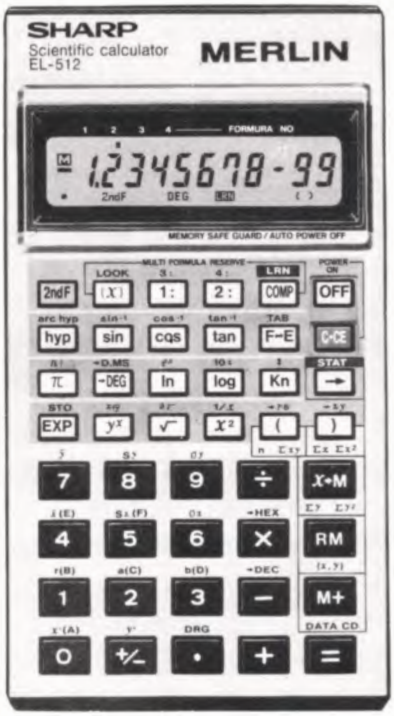
MERLIN DESCRIPTION



Merlin is a Sharp EL-512 calculator programmed to compute Marcq St. Hilaire line of position from celestial observations. It contains sun and Aries almanacs which are valid until early next century.

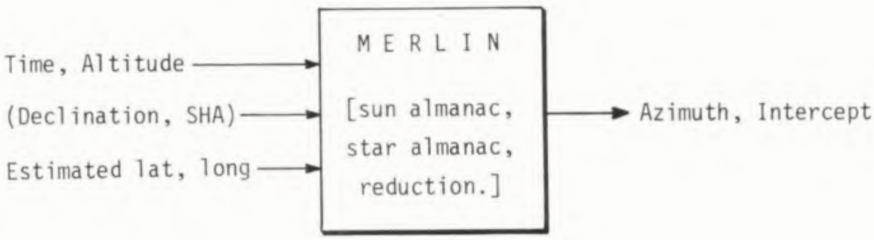
Merlin predicts and identifies stars and computes great circles. It reduces moon and planet sights if an almanac is available.

The net electronic computing time for a sunsight is about 18 seconds. For a star it is about 10 seconds. The usual altitude correction is applied manually; for sun and star sights Merlin does all the rest.

Essential input values are held in memories to be inspected, altered or re-used at will. Merlin is designed for easy reduction of multiple sights: nothing is entered twice.

The almanac programs are general perpetual, not polynomial. The reduction programs are rigorous spherical trigonometry. The programs cannot be corrupted. The batteries last for years and may be replaced without disturbing the programs. A complete set of programs is printed in this manual to enable any EL-512 to be converted into a back-up to Merlin.

This manual gives the coordinates of 59 stars to the year 2000.



MERLIN: A legendary wizard. The name is from the Old Welsh for "of the sea-hill".

A MESSAGE TO NAVIGATORS AND WOULD-BE NAVIGATORS

Merlin calculates according to mathematics that is centuries old. Basically a computer is just a device that does arithmetic very quickly. The principles don't change.*

But the practice does to some extent. In most spheres of activity, when a computer is introduced, procedures usually need some rearranging to exploit it to the full. Merlin is not just an improvement; it opens up new possibilities. Using traditional tables it takes an experienced hand ten or fifteen minutes of concentrated effort to reduce a sight. With Merlin it takes only a few seconds and almost no effort.

With a little practice you can reduce sights on Merlin as fast as altitudes can be read in a seaway. You can give an observer immediate feedback, telling him how consistent his shots are. A very few minutes after taking a long series of sights you can know your position, and you can know how good it is with a confidence previously impossible. Celestial navigation becomes handy for coastal sailing and, in appropriate circumstances, even for harbour navigation.

The following practices (which are nothing exceptional) complement your Merlin and help you get the best out of it:

1. Zero your watch on GMT. Record NO other time.
2. Plot on the chart using a small SQUARE protractor.
3. Keep your sextant in perfect adjustment

You will be reminded of these injunctions again in this manual.

Before doing any sight reductions you have to know the rules for entering numbers into the Sharp EL-512 and Merlin. Practise on your calculator as you read the next few pages.

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* Don't think that Merlin holds a list of numbers like the Nautical Almanac. The Almanac is printed by a computer which uses mathematical formulae to calculate celestial position. Merlin does the same. The time and date you give it are used as a seed from which celestial coordinates are computed, not looked up. The same applies to the sight reduction: the answers which suit the particular circumstances are individually computed, not interpolated from lists of figures.

EL-512 ESSENTIAL FUNCTIONS

The EL-512 is a versatile machine offering 61 functions. The Sharp manual explains them all but for the purposes of sight reduction with Merlin you need to be familiar with only a few. You see the keys labelled 1:, 2: in the very top row? Good. Leave them alone till you have read the following. You may find it helpful to refer to the diagram on page 8.

On-off, Batteries

The red C.CE key switches on; the OFF button is just above it. Switch off is automatic if the calculator is left for a while. If the manufacturer's claims are correct, and you use your Merlin only for navigation, the batteries should last indefinitely, however it would probably be advisable to replace them every few years. Power failure will cause instant loss of programs. A grey dot in the lower left of the display indicates the batteries are in order. Instructions on replacement without power interruption are included in this manual.

Second Function 2ndF. "DEG","RAD","GRAD" 2nd DRG

All the keys have two functions. The primary one is embossed on the surface of the button, the second function is printed above it. The yellow 2ndF key may be regarded like a typewriter's SHIFT key, though you do not hold it down. Example: above the decimal point key is printed DRG. Key 2ndF DRG a few times and watch what happens in the display. Leave the display with DEG showing: it is vitally important. For the meaning of this facility consult the manufacturer's manual. For our purposes DEG must ALWAYS show; NEVER RAD or GRAD. If you press 2ndF then change your mind, press it again and it will disappear.

Decimal Places 2nd TAB [digit]

The EL-512 may be set to display numbers to any desired accuracy. For instance, if you would like the display to show, say, six figures after the decimal point, key 2nd TAB 6 and thereafter whatever the calculator has in the display will be shown to six places. Keying 2nd TAB • will make the display show as many places (up to nine) as that number has. The actual value of the number held by the machine is not affected by this operation - only the number you see is affected. The computations themselves are performed, always, to the full accuracy of the calculator which is about 11 or 12 significant digits, and is some ten thousand times more accurate than navigation actually requires.

Mostly you can leave the machine set to one decimal place (2nd TAB 1). There's always a danger of misreading the display and if you show more figures than you need the danger is increased.

Degrees . Minutes Seconds

On the EL-512 the decimal point is used to separate the degrees from the rest. In navigation, angles are usually expressed in degrees and minutes (° ') there being 60' in 1°. The EL-512, like most scientific calculators, prefers degrees, minutes and seconds (° ' ") there being 60" in 1'.

This is almost a technicality as it only affects one number: the altitude which, even in good conditions, you really can't determine more accurately than one minute - though your sextant may actually read to tenths of a minute. If you do think you can read altitudes to a tenth of a minute then you can convert the tenths into seconds by multiplying mentally by 6. The same goes for almanac values if you use them. For example, to enter a value given as 25° 38'.7 you enter 25.3842 which is 25° 38' 42".

Other examples: 13° 12'.1 = 13° 12' 06"
↑don't forget the zero.
156° 48'.9 = 156° 48' 54"

This is simple enough: there are 60" in 1' thus 6" in 0'.1. For values which are to go into the calculator it's a good idea to write them with their seconds, rather than tenths of minute, so as not to forget. You never ever enter tenths of a minute into the calculator - though the error thus incurred would be almost insignificant.

In the examples in this manual the altitudes were observed to the whole minute and, after corrections are made (see next section), they are computed using values to the nearest 0'.5, ie 30". This is amply accurate for navigation purposes.

Time, which is hours • minutes seconds (h m s) is entered the same way with the decimal point separating the hours from the rest. Incidentally, when time is entered it is always Greenwich time (GMT).

Negative Numbers +/-

A small dash before a value is not for decorative effect. It means the number is a negative one. The Merlin convention is the usual one of indicating SOUTH and WEST with a minus sign. A latitude of -30^{o} means 30^{o}S and -30^{o} is about as different from +30^{o} as Sydney is different from Tokyo. A number that has no sign in front of it is a positive number, the "+" sign being taken for granted. To change the sign of a number in the display use the +/- key. Forgetting to put on a minus sign is by far the most common source of error - a little thing but if you leave it off when it is needed you will compute nonsense. First enter the number, or at least part of it, and then use the change sign key. Repeated keying of the +/- just switches the number in the display alternately positive and negative. Note: Use the +/- key, NOT the - key!

Memories 2nd STO [digit], C.CE Kn [digit], x→M, RM

The calculator has ten data storage registers or "memories". They are numbered (1) to (9) and (M). To store a number in a memory, the number must first be put into the display. For example to store 102.637 into memory (8) first enter 102.637 then key 2nd STO 8 and it is done. To check that (8) really does hold this number key C.CE Kn 8 and whatever is in (8) will be copied into the display. Kn means "recall" but you must key C.CE (clear entry) before Kn. If you don't the recalled value will be automatically multiplied by whatever was in the display already. Try it and see for yourself. After Kn has been used the memory still has the number. A memory retains its contents until you store something else into it. Practise storing and recalling. If you put 0.91747 into (6) and 0.985647 into (7) you won't need to touch these two again. Check them to make sure they are absolutely exactly right.

To use memory (M), keying x→M (not M+) will cause whatever is in the display to be stored in (M). Key RM (Recall Memory) to have a look at what is in (M). Keying RM just shows what is in (M) and does not do the automatic multiplication.

In this manual memories are always indicated in brackets ( ) to distinguish them from other numbers. You do not use the brackets on the calculator.

E for Error

If the machine displays "E" on the left side of the display it means you have asked the impossible of it (such as dividing by zero). Key C.CE to clear it.

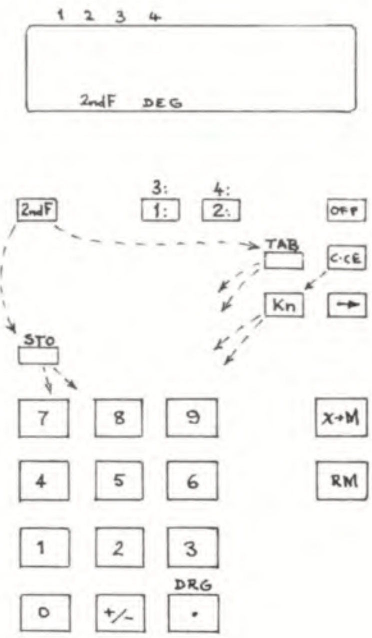
Summary

The functions of the EL-512 you need to be familiar with are:

2nd DRG	DEG must ALWAYS show in the display
2nd TAB [digit]	for setting displayed decimal places
+/-	to change the sign of a number. DON'T use the — key!
2nd STO [digit]	to store a number in a memory
C.CE Kn [digit]	to recall a number from a memory
x→M	to store a number in (M) (not M+)
RM	to recall a number from (M)

Moreover the edit button, →, is useful if you make a mistake when entering a number. The C.CE button clears the display. It is best to confine its use to the instances given above - ie switching on and prior to checking memories (1) to (9).

The sketch below shows all of the functions you need to know about in order to carry out sight reductions with Merlin.



For practice store 1.2345678 in (1)
store -9.87654 in (2)
check that (1) is correct
check that (2) is correct (ensure it is not 9.87654)
store this number in (M) and check it.

You should make sure you can perform these operations with confidence before going any deeper into this manual.

MERLIN FUNCTIONS

Program Keys

Sights are computed using the four Merlin "formulae" (programs) which have been written into the calculator.

The programs are operated (or "run") by using the keys [1:], [2:], 2nd [3:], 2nd [4:] in the top row of the keyboard. In this manual these program keys are always indicated in square brackets to distinguish them from other buttons.

The plastic cap covers the COMP/2nd LRN key. This is the key which begins the process of writing programs and which erases any already installed. The cap prevents this - but do keep your computer away from children. If you are interested in making your own computer there are programs in this manual which you can load into any Sharp EL-512 (or EL-522: it is identical) to make the ideal back-up to Merlin.

It is not possible to read programs which are in the calculator.

Programs Test

The proper functioning of the Merlin programs can be checked any time.

Set the memories with the following numbers:

(1) -20.1
(2) -20.1
(3) 5
(4) doesn't matter
(5) 1111
(6) 0.91747
(7) 0.985647
(8) 102.637
(9) 100

Make quite certain that the memories are correct: in particular that the first two are -20.1 not 20.1.
If they are not correct the check is not going to work.

Ensure DEG is showing in the display. Set the display to four decimal places.

Enter 2			
Key	[1:]	1111.0000	shows
"	[2:]	-22.7456	"
" 2nd	[3:]	168.4536	"
Enter 46			
Key 2nd	[4:]	-16.1682	"
"	RM	46.1610	"

If you don't get these answers either the memories are not set with the above values or you have not pressed the keys exactly as indicated.
You don't need the C.CE key.

Your machine passed this test when it was programmed and it may be said, with a certainty unique to electronic computation, that it cannot fail it. Unless your unit has suffered some trauma it will be in order. Here is a check for such a trauma: When you press those function buttons in the top row the display goes blank while the program runs. Functions [1:], [2:], [3:] and [4:] take about 2, 8, 6 and 3 seconds to run respectively. If they are running for these times (give or take a second) they are certainly running correctly.

If your Merlin really is faulty return it. You are most welcome to contact Meridian Survey Services directly. Customer feedback made this manual and it will make any future improvements.

Fixed Memories

It is essential to the proper functioning of the ephemeris programs that memories (6) (7) (8) (9) contain certain numbers. They are:

(6)	0.91747	(used by program [2:])
(7)	0.985647	(used by program [1:])
(8)	102...	(used by program [2:])
(9)	YM	(used by program [1:])

The values in (6) and (7) never change. Check these memories on your calculator. (Set 2nd TAB• to show all figures.) If they are not right put the values into (6) and (7) and leave them there forever. Do it now.

The value for (8) is a number that should be changed on January 1st every year. For 1984 it is 102.637; for 1985 it is 102.655; the full list is on page 41.

So set memory (8) correctly. This number is a "fine tuner" for the sun ephemeris and is not critical which means you could forget to change it for a year or two and incur only negligible error.

The number in (9) is the Year-Month number. This YM number must be updated on the 1st of every month (Greenwich date). It <u>is</u> critical. It is obtained by adding the year number to the month number from the lists on page 41. Note that in leap years the month number is one less for January and February. The other months never change.

In sum then, (6) and (7) are permanent; (8) is changed on the first of January annually; (9) gets a new YM number on the first of the month.

ALTITUDE CORRECTIONS

Before altitude is used by Merlin the usual corrections must be made to the sextant readings. They are two: dip, which depends on the height of the observer's eye above sea level, and so-called "main correction" which depends on the altitude of the body. Both can be found from the quick reference card. If your sextant has an index error you must apply it too. It is generally more satisfactory to adjust the sextant, but see note below.

Example

Observed alt: 25° 34', SUN lower limb. Ht of eye: 2.6 metres.

dip corr. = -2'.8 (dip is always negative)
main corr. = +14'.1 (L.L. sun usually positive)

total corr. = +11'.3 = 11'.5, near enough

Corrected alt is therefore 25° 45'.5, ie. 25° 45' 30"

Of course you could first take the dip from the sextant altitude and then add the lower limb alt correction. But if you first find the total correction as above you can then apply it to each of a series of readings.

The tables give the corrections for intervals of 0'.5. When interpolating the in-between values there's no need for great precision: near enough is (more than) good enough.

Note that the card carries three columns of main corrections:
stars - a correction for atmospheric refraction
sun's lower limb - corrects for refraction and semi-diameter
sun's upper limb - corrects for refraction and semi-diameter

Refraction is uncertain for altitudes lower than 10° or 15° but the navigator may be compelled to use such observations. For correction of altitudes lower than 6° use Annex C but for observations on the horizon (ie 0°) use Annex D.

Note on index corrections: On a small vessel the dip correction is usually always the same. It is feasible to introduce to the sextant an index error which precisely compensates for the dip. For artificial horizon, bubble sextant and theodolite sights there is no dip correction.

SIGHT REDUCTION

General Advice

Given the Greenwich time Merlin computes the position of the sun or star then, given the other usual information, it computes azimuth and intercept after the standard Marcq St. Hilaire manner.

Apart from its speed and ease there are a couple of other fine consequences that old salts in particular should note:

1. For your "assumed position" you can use your DR position. This is because there's no need to make up any whole numbers. Naturally you may use any "assumed position" within reason but you should use your DR (ie. your best estimate of position) for then the intercepts will tend to be small and are, in effect, corrections to your DR. Not only are the intercepts short but for all bodies of a group they radiate from the same point. Plotting is therefore both easier and more accurate than traditionally. For efficient plotting it is almost essential that you have a small square protractor.

2. As a rule you should take multiple observations of each body and then compute out each sight to position line. If you take, say, four sights one after the other to a particular body, don't do any averaging. Just compute all four intercepts. If you could observe perfectly the intercepts would all be exactly the same (neglecting movement of the vessel). But you can't and they won't be, so you get an impression of the quality of your observations. If there is a mistake it will show as an anomolous value and can be rejected. For plotting average the intercepts (which is much easier than averaging times and angles too).

3. There's so little writing to be done that you can put down the answers on the same sheet as you booked the readings. You don't have to use the worksheet enclosed (make photocopies) but it is recommended. It is not advisable to try to use computation sheets from other reduction methods. It is handy to have a plastic clipboard. No working on any other paper (except the chart) is needed, and if you find yourself making notes elsewhere, you are doing something wrong. Notice that the worksheet has no space for time conversions. None are required if you record your readings directly in Greenwich mean time. This is an important point. See page 34 for a discussion of it.

Reading the Quick Reference Card

The quick reference card tells you everything that concerns a Merlin sight reduction. There are no wasted words and when you are new to it, it might look somewhat cryptic. We will soon clear that up.

Actually it is so straight forward that there is a tendency to rely on memory to reduce sights and so you are herewith warned that that is an easy way to slip up. At least in the beginning, keep the card with the calculator and use it.

Compare the card with the following instructions for a sun sight.

In memory (1) store your estimated latitude. This is in degrees and minutes. If it is south you must make it negative. Example: your estimated latitude is 35^o 27' South so key 3 5 · 2 7 +/-, check the display holds -35.27 then key 2nd STO 1 and it's done. In memory (2) store your estimated longitude. This is also in degrees and minutes and is negative if it is west. In memory (3) store the day of the month (naturally, it is positive).

So that is exactly what the first column of the card tells you to do: (1), (2), (3) are latitude, longitude, day; south and west are minus.

Providing memories (6) to (9) are right the calculator is now set up for a sun sight. So, continuing to follow the card:

Enter the GMT of the sight as hours, decimal point, minutes, seconds.

Key [1:] The button in the top row. This is an Aries ephemeris but you need it when doing the sun too. It takes less than two seconds to run.

Key [2:] This is the sun ephemeris. It takes about 8 seconds. The calculator now knows the position of the sun. (You can have a look and compare it with the Nautical Almanac if you want but more on that later.) Now for the actual sight reduction:

Key 2nd Make sure 2ndF shows in the display, then

Key [3:] Which is really the [1:] button. In about 6 seconds the azimuth to the sun shows. It is in degrees and decimals (this is for plotting convenience). Copy it down.

Enter the corrected altitude in degrees, decimal point, minutes, seconds. Key 2nd [4:] and after 3 seconds the intercept shows in nautical miles.

If it is negative that means it is "away". You copy this down too.

That's it - just as the reference card shows.

As can be seen from the card, a star sight is much the same as the sun except that you store the star's declination and sidereal hour angle in memories (4) and (5) and then leave out program [2:]. The dec and SHA of the star are to be found in Annex B. Look after Annex B for these lists are not widely available.

For a moon or planet sight you need the current almanac - and then, of course, you do not run the star or sun ephemeris programs. More on this later.

EXAMPLE 1, SUN

Let us suppose it is March 1984. Let us set up the memories (6) to (9) as they should be. The values for (6) and (7) are on the reference card. The number for (8) for 1984 is 102.637 and, from the table, we see that the YM number for March 1984 is 160.296. (In the real situation you would have stored the YM into (9) on the first of the month and it would still be there.)

So these memories should now hold:	(6)	0.91747
	(7)	0.985647
	(8)	102.637
	(9)	160.296

Make sure they do have these values. Set 2nd TAB • so that the display will show all figures and inspect each in turn using C.CE Kn....

On the Greenwich date of 5. March 84 you take one sun sight. The GMT was $0^h\ 42^m\ 57^s$; the corrected altitude works out to $54^\circ\ 49'$; your DR position was $11^\circ\ 05'$ S, $152^\circ\ 33'$ W (in the Society Islands in Polynesia).

Follow the reference card and store:	(1)	-11.05
	(2)	-152.33
	(3)	5

Now just check them and make sure they are exactly right, minus signs and all.

For convenience Key 2nd TAB 1 to set the display to show one decimal place. Watch the reference card as you perform the following.

Enter 0.4257 thus putting the GMT into the display.

Key [1:] A number will show. It doesn't matter what: it is actually whatever happens to be in memory (5).

Key [2:] Wait till it finishes. -6.1 will show. If you want to know, it is the sun's declination.

Key 2nd [3:] 275.2 shows. This is the azimuth to the sun from your estimated position at the time of observation. Note it down.

Enter 54.49 putting the corrected altitude into the display.

Key 2nd [4:] 3.1 shows. This is the intercept. Since it is positive it means 3.1 nautical miles "towards". (As an aid to memory: "+" resembles "t".) As the card indicates, if the intercept shows negative then it is "away".

The sight reduction is complete and may be plotted.

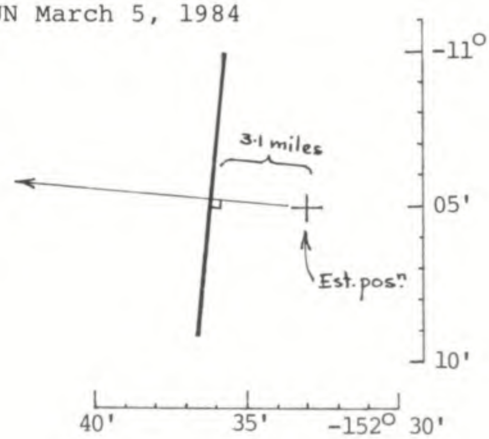
If you had taken a second sight to the sun you would now enter its GMT, run programs [1:][2:][3:], note the azimuth, enter the corresponding corrected altitude and run [4:] for the intercept. And so on for as many sights as you took. You'd then plot the average value.

There is something else: after the computation of a sight, Merlin leaves the <u>computed</u> altitude in memory (M) in degrees, minutes and seconds. To have a look:

Key RM , 54.5 shows. We would need 4 figures so Key 2nd TAB 4 and 54° 45' 54" shows as the computed altitude. This is 54° 45'.9. The difference between this and the observed altitude is 3'.1, ie. the intercept, and since the observed altitude was the greater it is "towards".

This should give you some insight into the workings of the machine. The actual purpose of holding onto the computed altitude is for star predictions - of which more later.

SUN March 5, 1984



To plot the above, mark the estimated position on your chart. Place a protractor on the point and mark the azimuth. From the estimated position measure off 3.1 miles towards the sun and draw the position line at right angles to the azimuth. You are somewhere on this line.

EXAMPLE 2, SUN

Calculate the four sights set out below. The working-out has been entered in a different hand from the bookings to make things clearer. The clock was two seconds slow on GMT so the GMT's are slightly modified. The numbers in the "alt corr." column are index, dip, and main corrections. The sum of them is +13'.7 but 13'.5 is quite good enough. This value, ie. 13' 30", has been added to the sextant readings to give the corrected altitudes.

When you are running the sights through the machine you can always tell where you are up to in the [1:][2:][3:][4:] sequence by looking to the top of the display where a little dot will be under one of the numbers printed above the display. This dot indicates which program you last ran. If you make a mistake re-enter the GMT and run the sight again from the beginning.

EXAMPLE 2. NORTH PACIFIC. MERLIN

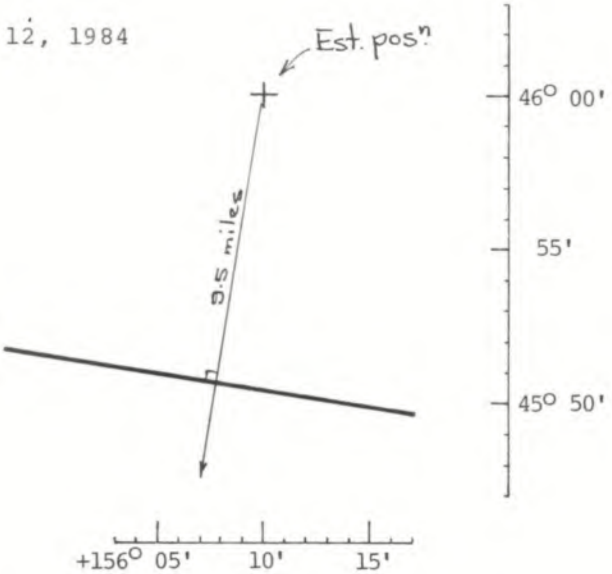
Log: ______ (1)Est.lat: +/- + 46° 00' (2)Est.long: +/- + 156° 10' (3)Gr.date: 12 Mar. 84

Course: ______ Index corr: +1 Ht. of eye: 1·8 m, dip corr: − 2'3 (9)YM: 160·296

Clock corr: + 2 s	GMT [1:] h m s	Sext.alt ° '	alt corr (index, dip, main)	corr.alt [4:] ° ' "	Az °	+/- Int. n.m.
Body: SUN L.L.	2 09 34^{6}	40 21	+1	40 34 30	188·0	+10·1
(4)dec: +/-	2 10 57^{9}	40 18	−2·3	40 31 30	188·5	+9·1
(5)SHA:	2 12 12^{4}	40 16	+15·0 / +13'·7	40 29 30	188·9	+9·0
Body:	2 13 50^{2}	40 15	= 13'30"	40 28 30	189·4	+10·7
(4)dec: +/-						
(5)SHA:					(189)	(+9·5)

The calculated intercepts range form 9.0 to 10.7 miles: a spread of 1.7 miles. This is satisfactory observing for a vessel in the ocean. When taking the average the nearest 0.5 mile is, once again, quite adequate. to go to any more trouble is to credit the observations with a precision that sextant sights generally do not have. The azimuth in this case varies quite a lot for the simple reason that it was shortly after local noon and the sun was moving rapidly across the sky. The movement will make no difference to the plot.

SUN March 12, 1984



Take note that this sun sight is a substitute for the sailor's classic "noon latitude". Merlin makes the reduction of any sight easier than even that simplest of all calculations, the noon fix. With Merlin there is no point in sitting around at lunch time with a sextant waiting for local noon to occur - just take an ordinary observation somewhere around the right time.

EXAMPLE 3 STARS

The reduction of star observations differs from the sun only in that memories (4) and (5) have to be filled with the dec and SHA, and that program [2:] is omitted. (Note: In navigation SHA is usual. If you want to use right ascension put a minus sign in front of it.)

The dec and SHA are best taken from Annex B where they are tabulated in degrees and decimals of a degree. That is how Merlin must have them. You can take them from a printed almanac but if you do you must convert the almanac values into degrees decimal (with the calculator's →DEG button, see page 21) before storing them in (4) and (5).

Annex B gives values for the 1st of January and 1st of July each year. For in-between months you interpolate. But don't break your head over it. A rough guess will be fine - in fact most of the time you could take the nearest tabulation and use it directly. The reason you can do this is because the stars shift only very gradually and the tabulated precision to three decimal places is extreme. ($0^{o}.001$ is 0'.06 or 3".6!) For practical navigation $0^{o}.01$, ie. 0'.6, would generally suffice. In Annex B the extra figure is given to be on the safe side but it doesn't mean you have to do extra work.

In this example the date is 11.11.84. That's about 2 months before the 1st January. You could use the January 1985 figures and incur negligible error. You could take halfway between the July 1984 and January 1985 values if you're fussy. And if you're an accuracy fanatic you can estimate what one third of the difference is and amend the January 1985 figure accordingly. If you do go to this trouble (such as it is) pencil the value in small figures into the table. Since one tends to use the same stars every day the value will do for the rest of the voyage.

Eg.: for Achernar we find the tabulated values of declination for July 1984 and January 1985 to be $-57^{o}.312$ and $-57^{o}.319$ so early November 1984 will be $-57^{o}.317$. For SHA we find tabulations of $335^{o}.719$ and $335^{o}.708$ so early November is $335^{o}.711$.

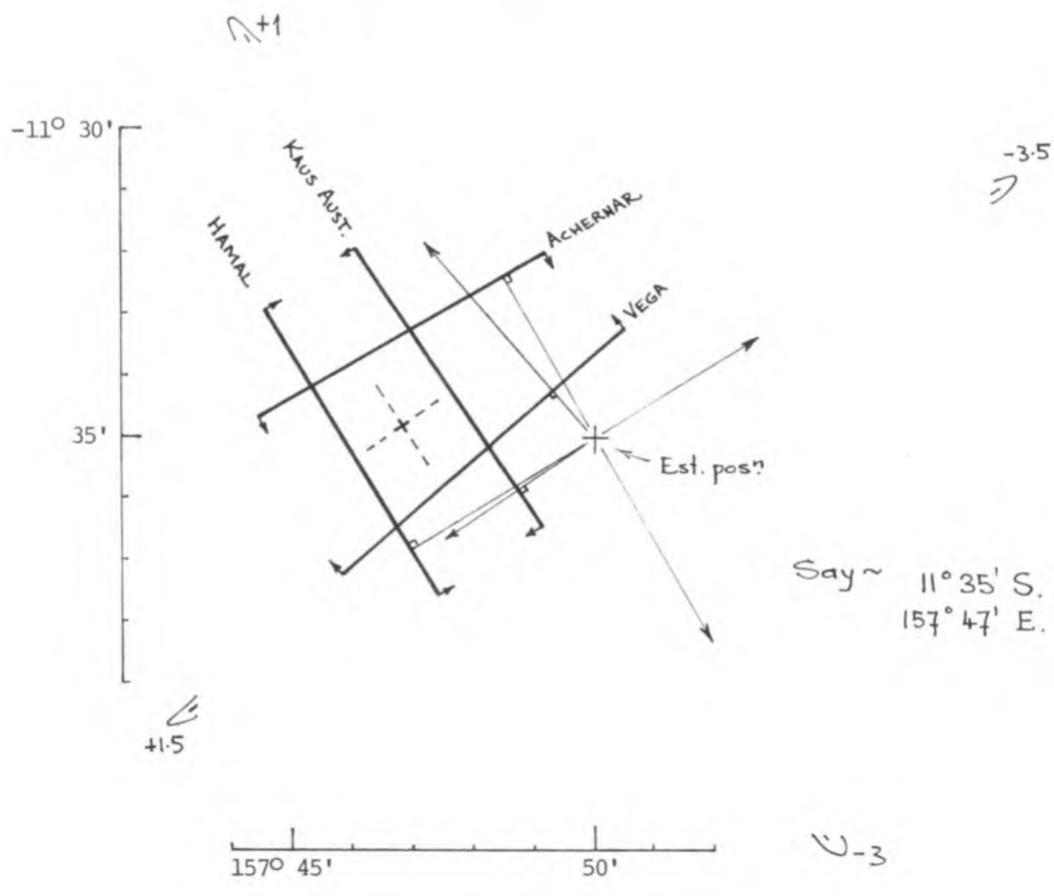
In the example below the interpolation has been fairly carefully done. (Check them yourself, run a sight with very slightly wrong values and see what difference it makes.) If you miss-key, re-enter the GMT and start again BUT if you accidentally run [2:] (either thoughtlessly or instead of [4:]) the star's dec in memory (4) will be destroyed and will have to be re-stored. You can always tell which program has just been run by looking at the little dot in the top of the display.

EXAMPLE 3. DUSK, CORAL SEA. MERLIN

Log: ________ (1)Est.lat: +/- − 11° 35' (2)Est.long: +/- + 157° 50' (3)Gr.date: 11 Nov. 84

Course: ________ Index corr: + 2'.5 Ht. of eye: 2.0 m, dip corr: − 2'.5 (9)YM: 405 · 296

Clock corr: nil	GMT [1:] h m s	Sext.alt ° '	alt corr (index, dip, main) '	corr.alt [4:] ° ' "	Az °	+/- Int. n.m.
Body: ACHERNAR 150°T	8 04 38	28 21	−2.8	28 19	150.0	−3.0
(4)dec: +/- − 57.317	8 10 48	29 06	−2'	29 04	150.4	−3.2
(5)SHA: 335.711						(−3)
Body: VEGA 318°T	8 06 01	20 56	−2'.5	20 53 30	319.7	+1.9
(4)dec: +/- + 38.787	8 09 45	20 18		20 15 30	319.2	−0.4
(5)SHA: 80.899						(+1)
Body: KAUS AUST. 237°T	8 07 55	35 33	−1.3	35 31 30	235.8	+1.4
(4)dec: +/- − 34.395	8 08 45	35 23.5	−1'.5	35 22	235.8	+2.0
(5)SHA: 84.216						(+1.5)
Body: HAMAL 59°T	8 13 40	21 59	−2'.3	21 56 30	58.7	−2.7
(4)dec: +/- + 23.391	8 14 32	22 08	−2'.5	22 05 30	58.6	−4.6
(5)SHA: 328.426						(−3.5)



This example illustrates other useful practices:

1. The clock used was spot on. There is no correction to apply. This is easy to achieve with modern quartz watches which will stay accurate to the second for a week or more.

2. The normal height of eye for this observer is 2.0 m which gives a dip correction of -2'.5. So the observer has adjusted the sextant's index error such that the index correction exactly compensates. Thus the only altitude correction is the main correction.

3. Corrected compass bearings were noted to each body. This checks the identification, checks the compass, and is a gross check on the calculation.

4. It is good practice to write a "+" in front of numbers which are positive but which are sometimes negative. The machine's display does not show the + and you don't actually do any entering of it, of course. But if you write the + then you always write something, ie, you perform the same actions for both positive and negative numbers and it forces you to take careful note every time.

STOP PRESS

It has been suggested that where multiple sights are taken (and they generally should be) the altitude correction ought to be applied not to the altitude but to the intercept. That is, raw sextant readings should be entered directly into the calculator. The resulting raw intercepts are then inspected, averaged, and the altitude correction applied to give the actual intercept.

The advantages are that the observer gets quicker feedback on the quality of the sights, there is no need to apply the correction to each reading, and the matter of converting tenths of a minute to seconds pretty much falls away.

The example below is from page 16. The form has been modified.

EXAMPLE 2 NORTH PACIFIC. MERLIN

Log: ______ (1)Est.lat: +/- + 46° 00' (2)Est.long: +/- + 156° 10' (3)Gr.date: 12 Mar. 84

Course: ______ Index corr: +1 Ht. of eye: 1·8 m, dip corr: - 2'3 (9)YM: 160 · 296

Clock corr: + 2 s	GMT [1:] h m s	Az °	Sext.alt ° '	+/- RAW Int.	Av. Int.	alt corr ' (index, dip, main)	+/- Int. n.m.
Body: SUN L.L.	2 09 34 (6)	188·0	40 21	-3·4		+1	
(4)dec: +/-	2 10 57 (9)	188·5	40 18	-4·4	-4	-2·3 +15·0	(+9·5)
(5)SHA:	2 12 12 (4)	188·9	40 16	-4·5		+13'·7	
Body:	2 13 56 (2)	189·4	40 15	-2·8			
(4)dec: +/-							
(5)SHA:		(189)					

UNLISTED STARS

In the unlikely event that you take a sight to a star not included in the Annex B list you can reduce it by taking its dec and SHA from a printed almanac. You must convert both values to degrees decimal before storing them in (4) and (5).

eg. You have taken sights to a star not in Annex B. Your almanac gives its dec as 23^{o} 15'.7 South, and its SHA as 196^{o} 47'.3.
Enter 23.1542 (ie. 23^{o} 15' 42" where 42 = 7 x 6)
Key +/- -23.1542 shows
" →DEG -23.2617 shows
" 2nd STO 4 and dec is safely stored.

Enter 196.4718 (ie. 196^{o} 47' 18")
Key →DEG 196.7883 shows
" 2nd STO 5 and SHA is in (5)
Now proceed as usual for a star sight reduction.

This is what you must do if you want to practice on old sights. The YM numbers back to 1976 are given to enable this.

MOON & PLANET SIGHTS

Programs [3:] and [4:] do the sight reduction after the position of the body has been found.

So you can reduce a moon or planet sight using [3:] and [4:]. You must take the dec and GHA from a current almanac, convert them to decimal degrees using the →DEG button, and store them in (4) and (M).

As the reference card indicates you run [3:] , note the azimuth, put in the observed altitude, run [4:] and note the intercept.

The GHA has been destroyed.

If you took multiple sights you can either use the average time and average observed altitude or you can take out the dec and GHA for each observation and run them individually. For a planet, reducing each individual sight goes quite well as GHA's are fairly easy to take out of the almanac (for a short cut see page 30) and the dec will not vary during the observing period, so it conveniently stays in memory (4) undisturbed. For the moon the dec can change noticeably in a few minutes. Because of that and the general tedium of taking moon values from the almanac, it is easier to use averages and just make one reduction.

Note: The mathematically inclined will recognize the value of the EL-512's linear regression facility for this averaging. If you use it, you must fix up memories (8) and (9) afterward.

HOW MERLIN WORKS

Summary of the Programs

[1:] is an Aries almanac which calculates GHA Aries and adds it to SHA to give GHA star which it stores in (M). It leaves some vital numbers in the display for the benefit of ...

[2:] which, when run immediately after [1:], computes the sun's dec which it stores in (4), and the sun's GHA which it stores in (M).

So at this stage, whether you are reducing a star or a sun sight, the result will be that the GHA of the body is in (M). It is in degrees decimal.

2nd [3:] uses spherical trigonometry to compute the azimuth from the earthly position given by memories (1) and (2) to the celestial position given by memories (4) and (M). It stores a needed intermediate value in (M) - thus destroying the GHA - and stops to display the azimuth.

2nd [4:] calculates the computed altitude and stores it (in the ° ' " form) in (M). It subtracts the computed altitude from the observed altitude - which you put into the display before running [4:] - and multiplies the result by 60 to display the intercept in nautical miles.

Notes

1. DEG must always be showing in the bottom of the display.

2. Don't forget the minus sign for south and west.

3. Don't forget to use the →DEG key to convert almanac values to decimal degrees. As a rule:

   Heavenly values are in degrees decimal.

   Earthly values are in ^{o}.' " (except Az).

   Putting this another way:

   (4), (5) are decimal degrees.

   (1), (2) are in ^{o}.' "

4. The altitude computed by Merlin is always between 0^{o} and 90^{o}. That is to say it is not signed and any negative altitude will be stored in (M) as a positive number. Therefore:

   a) if your altitude exceeds 90°, correct for index and dip, subtract from 180°, apply the main correction for the opposite apparent limb, then reduce as usual.

   b) if your altitude is less than zero you must omit the minus sign when you enter it and apply the opposite convention to the intercept, ie. the intercept becomes negative "towards".

   c) a predicted altitude shows always positive so if you chose a star that was not visible (because it is below the horizon) Merlin will not tell you.

   Of course, (a) is a rare circumstance, (b) will only occur for horizon sights and (c) only if you make a faulty choice.

EXERCISE: SUN, STARS, PLANET

Fill in the blanks on the form on the next page. For plotting practice make your own chart by tracing the values of latitude and longitude onto a blank piece of paper.

EXERCISE. ARAFURA SEA. MERLIN

Log: ________ (1)Est.lat: +/- − 11° 30′ (2)Est.long: +/- + 130° 00′ (3)Gr.date: 2. Oct. 84

Course: ________ Index corr: +1 Ht. of eye: 1.8 m, dip corr: − 2′.4 (9)YM: 374.296

Clock corr: nil

	GMT [1:] h m s	Sext.alt ° ′	alt corr (index, dip, main)	corr.alt [4:] ° ′ ″	Az °	+/- Int. n.m.
Body: SUN L.L.	8 19 02	12 51	+ 1	13 01 30	268.8	− 1.1
(4)dec: +/-	8 19 40	12 41	− 2.4			
(5)SHA:	8 20 16	12 32	+ 11.8			
Body:	8 20 50	12 24	+ 10.5			
(4)dec: +/-	8 21 18	12 18				
(5)SHA:	8 21 54	12 08.5				
Body:						
(4)dec: +/-						− 1.5
(5)SHA:		long = 130° 01′.5				
Body:						
(4)dec: +/-						
(5)SHA:						

EXERCISE. ARAFURA SEA. MERLIN

Log: ________ (1)Est.lat: +/- − 10° 45′ (2)Est.long: +/- + 130° 05′ (3)Gr.date: 3. Oct. 84

Course: ________ Index corr: +1 Ht. of eye: 2 m, dip corr: − 2′.5 (9)YM: 374.296

Clock corr: nil

	GMT [1:] h m s	Sext.alt ° ′	alt corr (index, dip, main)	corr.alt [4:] ° ′ ″	Az °	+/- Int. n.m.	
Body: VEGA 350°T	9 38 25	39 59	+ 1	39 56	352.0	− 0.6	
(4)dec: +/- + 38.767	9 39 45	39 57	− 2.5				0
(5)SHA: 80.897	9 40 35	39 55	− 1.6				
			− 3				
Body: RIGIL KENT. 210°T	9 44 56	19 44		19 40	208.9	+ 5.8	
(4)dec: +/-	9 45 33	19 39					+5.5
(5)SHA:	9 46 35	19 32					
Body: FORMALHAUT 120°T	9 49 35	35 56		35 53	119.1	− 11.1	
(4)dec: +/-	9 51 09	36 17					−10
(5)SHA:	9 51 56	36 28					
Body: VENUS 258°T	9 58 08	17 19				+ 3.5	
(4)dec: +/- − 14° 47′ 42″	9 59 12	17 06				+ 5.9	+5
~~(5)SHA:~~ = − 14.795	10 00 14	16 49				+ 3.7	
	10 01 01	16 41		16 36 30	257.6	+ 7.1	

Stars (′)	App alt	L.L. (′)	U.L. (′)
-5.7	9° 20′	+10.5	-21.5
-5.2	10° 20′	+11	-21
-4.6	11° 30′	+11.5	-20.5
-4.1	13°	+12	-20
-3.6	15°	+12.5	-19.5
-3.1	17°	+13	-19
-2.6	20°	+13.5	-18.5
-2.1	24°	+14	-18
-1.6	31°	+14.5	-17.5
-1.1	41°	+15	-17
-0.6	59°	+15.5	-16.5
-0.1	85°	+16	-16

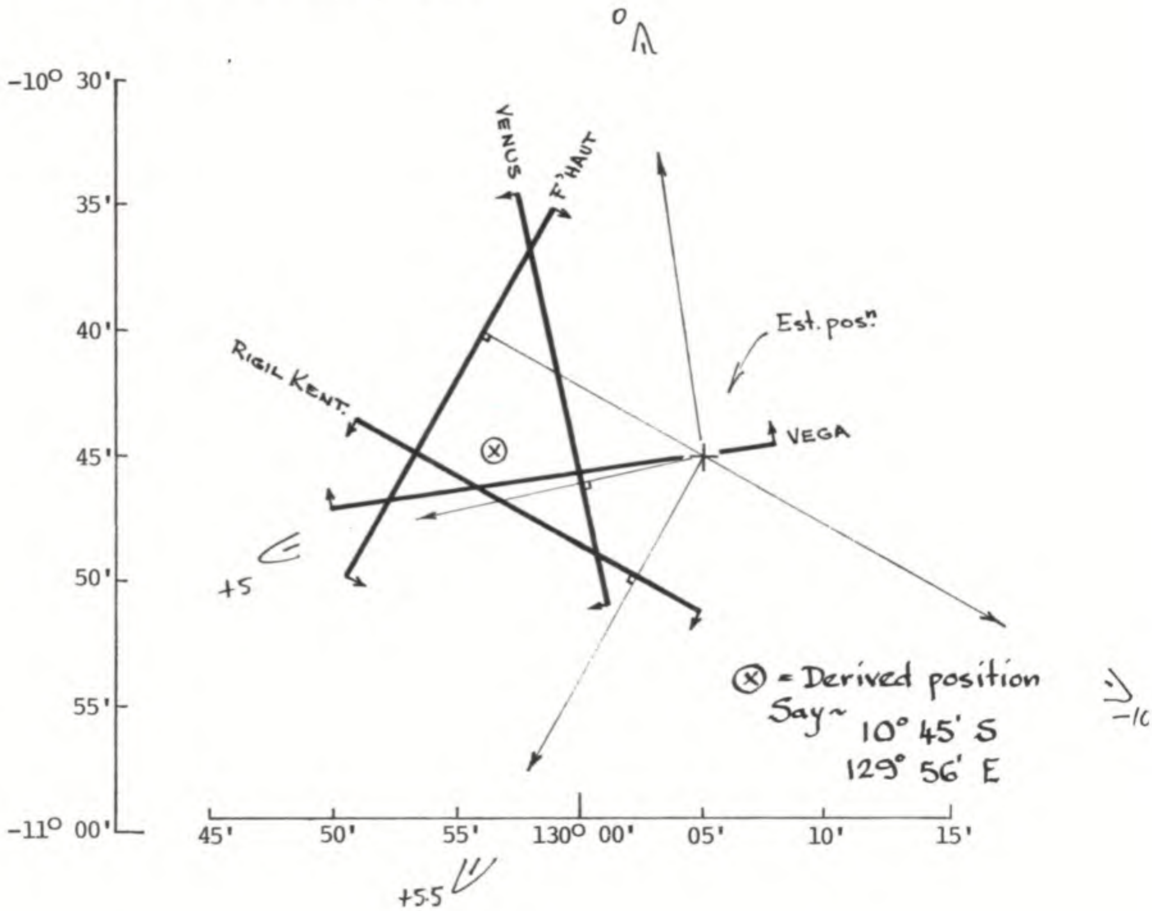
for GHA Venus. v = − .5

9^h:	290° 16.2	290° 16.2	10^h:	305° 15.7	305° 15.7
incr:	14 32.0				15.3
V corr:	− .5	− .5		0	0
GHA =	304° 47′.7				305° 31′.0
=	304.7950				305.5167

Ht. (m)	Dip (′)
0.7	-1.5
1.3	-2
2.0	-2.5
2.9	-3
3.9	-3.5
5.1	-4
6.4	-4.5
7.9	-5

(l) lat, (2) long, alt, in deg. min sec. (4) dec, (5)SHA, (M) GHA, in degrees.

ARAFURA SEA October 3, 1984



ERRATUM: The altitude correction for Vega ought to have been -2'.5 not -3'.

Notes

Earlier examples in this manual were specially structured or modified. The sights in this exercise, however, are as read on the dates shown.

Conditions for the sun sight were evidently excellent: 6 observations inside 3 minutes with the intercepts varying only from -0.8 to -2.0 miles. There is no need to plot this sun line: it must run practically north-south since the azimuth of the sun was nearly due west. The average intercept is about -1.5 miles so the observer's longitude was 1'.5 further east (ie. away from the sun) than the estimated position. Being so near the equator 1 mile may be taken as 1' of longitude.

Conditions for the star sights the following evening must have been fair: the first two stars show good consistency; the third, Formalhaut, has a spread of nearly 2 miles while Venus has a spread of 3½ miles. The plot shows that the bodies were in a less than optimal configuration (example 3 was optimal) but in these latitudes twilight is brief, the horizon is murky, and the brightest stars have to be taken. The position marked on the plot is one which gives most weight to the two good sights. Putting it there amounts to saying that the Vega and Rigil Kent. lines are in error by one mile and the other two are in error by about 3 miles.

The cause of these errors is a matter for speculation. The lesson from them is that even consistent intercepts don't guarantee a precise position. Moreover, even these visible errors are not the whole story; if, for instance, the clock was wrong by one minute, the longitude will be wrong by 15' but the plot will look the same. To determine absolute error the celestial fix must be compared with a value known from other means.

If any of these sights had been omitted the result would have been a classic "cocked hat". Depending which observation is left out there are four possible 3-line patterns. You might care to see if you agree that:

if Rigil Kent.	is omitted the position is	10^{o} 43' S	129^{o} 57' E
" Formalhaut	" " " " "	10^{o} 47' S	130^{o} 02' E
" Vega	" " " " "	10^{o} 52' S	129^{o} 56' E
" Venus	" " " " "	10^{o} 46' S	129^{o} 53' E

Quite a variation isn't there? Draw these inferences:

- a position line might be <u>relied</u> on to no better than about 5 miles.
- there's no point in precisions finer than half a mile or half a minute.
- four lines are better than three lines.

FINDING MISTAKES

If DEG was showing in the display and you followed the instructions of the quick reference card and your answer is clearly not correct then you have a data error.

It might be in the original readings of time and altitude (so never read anything only once). If you used the Almanac check the values, in particular that you looked up the correct day. Check the altitude corrections.

Otherwise you've either entered the wrong time and altitude or the memories are wrong. Far the most common mistake is leaving off a minus sign on latitude, longitude or declination.

Memories (6) to (9) don't play a role if you consulted a printed Almanac. Don't forget to change (9) on the first of the month. If you accidentally ran [2:] when you are doing a star you have to fix up memory (4).

Wrong answers will occur but the reasons will always turn out to be foolishly simple.

COMPARING MERLIN VALUES WITH THE NAUTICAL ALMANAC

Program [1:] gives the GHA of a star. Since

GHA star = GHA Aries + SHA

if you store zero in (5) and run [1:] , the GHA of Aries for whatever time and date you entered will be in (M). Keying RM 2nd →DMS will show it in ° . ' " and you can compare it with the almanac listing. The difference will be negligible. (You may have to subtract 360° or 720°.)

Programs [1:] then [2:] give the sun's dec and GHA in memories (4) and (M). Recall them, convert them to ° . ' " with 2nd →DMS, and compare them with the almanac. They should be within 0'.5 of the almanac's values. The Nautical Almanac can be in error by up to 0'.25 in GHA sun, incidentally. Do not touch the calculator between [1:] and [2:] (read p. 22).

Similarly you can compare the Annex B values - first convert to °. ' " then compare with the lists for 1st Jan or 1st July. They will be very close: perhaps 0'.1.

OTHER USES FOR MERLIN

STAR PREDICTION

To compute the direction and sextant setting for a particular star is practically identical with normal sight reduction.

(1) lat S-
(2) long W-
(3) day
(4) dec S-
(5) SHA
GMT [1:]
  2nd [3:] →Az
  2nd [4:] ignore this
    RM →computed alt °.' "

The computed altitude will show positive no matter what star you choose. Use commonsense and only run predictions for stars you know will be above the horizon. You can use the standard worksheet, crossing out "intercept" and putting in "predicted altitude".

Such predicting may be done at the moment it is required. It is very easy - but the small boat sailor will find it even easier to look at the previous day's settings. The same goes for predicting twilight.

The lazy way of star navigation is to shoot first and ask questions afterward: ie. pick suitable stars from those on display and use a systematic procedure to identify them later on. Even that is only necessary on the first day or two of the voyage if you go on using the same stars.

LHA ARIES FOR STAR FINDER

(3) day
(5) long in ° W-
GMT [1:]
  RM → LHA Aries (in °)

The identification will not be affected if you do not bother to convert the longitude into degrees decimal. GMT to the nearest quarter of an hour will be fine.

You may have to subtract 360 (key - 360 =) and sometimes a second 360.

Use the LHA Aries and your latitude to set the finder. The observed altitude and the corrected compass bearing will yield the star's name. The same value of LHA Aries will suffice for other stars that were observed at the same time.

If you do not have a finder Merlin will do the identification.

STAR IDENTIFICATION (WITHOUT STAR FINDER)

Example: At 11° 35' S, 157° 50' E on the 11th of November 1984 a star bearing 150° true was observed. GMT about 8^h; alt about 28°.

Instruction	Example
(3) day	(3) 11
(5) long W-	(5) 158
GMT [1:] ignore result	8
RM → LHA Aries. Note it.	688.6
(1) lat S-	(1) -11.35
(2) zero	(2) 0
(4) alt	(4) 28
(M) Az	(M) 150
2nd [3:] → LHA star	304.8
key - (the subtract key)	
enter LHA Aries	688.6
key = → SHA. If negative key + 360 = and if still negative key = again. Note SHA.	-383.8 -23.8 336.2
2nd [4:] ignore result	
RM → dec. Note it and sign it.	57.3 -57.3 (must be negative in this case)

You must sign the dec North or South. Usually you can do this using commonsense. These SHA and dec are approximate values to enter the table on the first page of Annex B. This table will identify the star and you can then take its real dec and SHA from Annex B in the usual manner.

If further unknown stars were observed at the same time the LHA Aries will stay valid. So just store the next star's alt and Az in (4) and (M) and carry on from there. For practice pretend all the stars on page 19 are unknown. Identify them.

This star bears 150° from an observer in the southern hemisphere so the star is also a southerly one. From the first page of Annex B we see that the only star that fits is Achernar with 335°.7 and -57°.3. As a confirmation note that Achernar is very bright. If you had trouble with this example check your YM in memory (9).

If the body was bright but no star corresponds to the computed values, it must be a planet. Planets are very bright and the dec is within 26° N or S.

SHORT CUT FOR PLANET SIGHTS

When you are familiar with Merlin you might like to try a short cut when you take a series of sights to a planet.

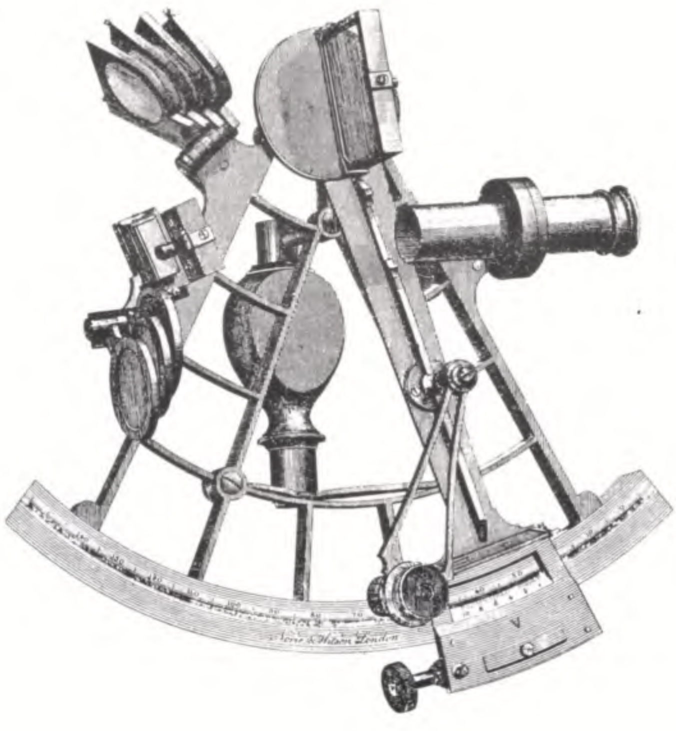
If the SHA of a planet were found and stored in (5) then the sights might be reduced just like star sights and it would save looking up the GHA for each GMT.

The SHA's of planets vary rather faster than SHA's of stars so you have to find the SHA around the time of the observations: within 5 minutes for Venus, 10 minutes for Mars and half an hour for Jupiter and Saturn.

To find SHA subtract the GHA Aries from the GHA planet - then store it in (5) in decimal degrees.

It is convenient for Jupiter and Saturn as the GHA value for the nearest whole hour can be taken out without interpolation. You can use Merlin or the printed almanac for GHA Aries.

It does not work for the moon.



GREAT CIRCLE COURSE

The shortest route between two points is a great circle, not a rhumb line drawn on a Mercator chart. In fact there is no significant difference except on transoceanic routes in high latitudes. Even then wind, current and the wish to visit places en route will be overriding considerations.

However Merlin will do it so here it is:

Instructions	Example
from: lat_1 $long_1$	Cape Town: 34^o S 18^o E
to: lat_2 $long_2$	to Rio : 23^o S 43^o W
(1) lat_1 ^{o}.' " S-	(1) -34
(2) $long_1$ ^{o}.' " W-	(2) 18
(4) lat_2 in ^{o} S-	(4) -23
(M) $-long_2$ in ^{o} E-, W+!	(M) +43 note sign!
2nd [3:] → Course ^{o}	$264^o.7$
enter 90	
2nd [4:] → distance, miles	3237 n. miles

Note that the values in (1) and (2) must be in degrees minutes seconds and those in (4) and (M) must be degrees decimal. The longitude in (M) must have its sign reversed.

One thing: if the distance will be greater than 5400 miles (ie. greater than 90^o of the Earth's surface) you put in -90 instead of 90. The distance will then show with a minus sign which doesn't mean anything.

In the example above the course to start is $264^o.7$. After steering on this for a couple of hundred miles use your position as a new lat_1 $long_1$ to compute a new heading. If you would like a further example compute the Rio to Cape Town course. The answer is $116^o.3$ and the distance is, naturally, the same 3237 miles.

The illustration opposite is from the frontispiece of the 1900 edition of Norie's "Complete Epitome of Practical Navigation and Nautical Astronomy". Sextants have changed only in detail since then.

(5)SHA:						

MERLIN

Log: ______ (1)Est.lat: +/- ______ (2)Est.long: +/- ______ (3)Gr.date: ______

Course: ______ Index corr: ______ Ht. of eye: ______, dip corr: − ______ (9)YM: ______

Clock corr:	*GMT [1:]* h m s	*Sext.alt* ° '	*alt corr* ' (index, dip, main)	*corr.alt [4:]* ° ' ''	*Az* °	+/- *Int.* *n.m.*
Body:						
(4)dec: +/-						
(5)SHA:						
Body:						
(4)dec: +/-						
(5)SHA:						
Body:						
(4)dec: +/-						
(5)SHA:						
Body:						
(4)dec: +/-						
(5)SHA:						

Stars (')	App alt	L.L. (')	U.L. (')
-5.7	9° 20'	+10.5	-21.5
-5.2	10° 20'	+11	-21
-4.6	11° 30'	+11.5	-20.5
-4.1	13°	+12	-20
-3.6	15°	+12.5	-19.5
-3.1	17°	+13	-19
-2.6	20°	+13.5	-18.5
-2.1	24°	+14	-18
-1.6	31°	+14.5	-17.5
-1.1	41°	+15	-17
-0.6	59°	+15.5	-16.5
-0.1	85°	+16	-16

Ht. (m)	Dip (')
0.7	-1.5
1.3	-2
2.0	-2.5
2.9	-3
3.9	-3.5
5.1	-4
6.4	-4.5
7.9	-5

(l) lat, (2) long, alt, in deg. min sec. (4) dec, (5)SHA, (M) GHA, in degrees.

This form is standard A4 size.
Make photocopies as required.

MERLIN

Log: ______ (1)Est.lat: +/- ______ (2)Est.long: +/- ______ (3)Gr.date: ______

Course: ______ Index corr: ______ Ht. of eye: ______, dip corr: – ______ (9)YM: ______

Clock corr:	*GMT [1:]* *h m s*	*Sext.alt* ° '	*alt corr* ' *index dip main*	*corr.alt [4:]* ° ' ''	*Az* °	+/- *Int.* *n.m.*
Body: ______ *(4)dec:* +/- ______ *(5)SHA:*						
Body: ______ *(4)dec:* +/- ______ *(5)SHA:*						
Body: ______ *(4)dec:* +/- ______ *(5)SHA:*						
Body: ______ *(4)dec:* +/- ______ *(5)SHA:*						

MERLIN

Log: ______ (1)Est.lat: +/- ______ (2)Est.long: +/- ______ (3)Gr.date: ______

CELESTIAL NAVIGATION TIPS

The foolproof method of getting a chosen star in the field of view of a sextant is to hold the instrument upside down in the left hand, sight up to the star, move the index arm with the right hand until the horizon appears, clamp, turn right way up and take the sights.

Observations from a small boat must be taken from the top of the wave with a clear view to a distant horizon - which consists of similar wave tops.

For optimal accuracy do not observe three stars as is conventional but four in four directions as per Example 3. Their altitudes should be greater than 15^o if possible. Using four stars in four directions will do much to eliminate systematic errors in the sextant and in the altitude corrections. Position is given by drawing an average line for each parallel pair. It is likely to be much more reliable than position from three bodies and you do not have to try to interpret a "cocked hat". If four well distributed stars are available there is little point in observing any others. Take three or more sights to each and reduce them all. This will indicate your accuracy and expose any blunder.

On moonlit nights the horizon is often sufficiently defined for star sights. But the horizon glass and the lenses, particularly the eye lens, must be spotlessly clean.

Keep your sextant in adjustment. The adjustments are, in order:

1. index mirror: check perpendicularity to the arc by reflection test on the arc.
2. horizon mirror perpendicularity: the direct and reflected images of a star must pass through each other.
3. horizon mirror index: when direct and reflected images of a star are superimposed the reading should be zero or else set to read <u>below</u> zero by the amount of your usual dip correction. Check the index error often. Always record both dip and index.

On a cheap plastic sextant sun filters can cause large index errors - of the order of 5'. If they can be determined and allowed for, the sextant should yield satisfactory results.

Take compass bearings to stars as a check on identification, a check on the compass, and a rough check on the calculation.

Make a practice of noting the times of sunset ("sextantless sunshots") - both L.L. and U.L. Then if the weather prevents star sights at least you will have something. Annex D gives corrected altitude directly. Any body may be observed in this way if the horizon is clear enough. For stars, use binoculars. The corrected altitude is negative, but when entering it into Merlin ignore the sign - and then call a negative intercept "towards", positive "away".

A five inch square protractor ("combined protractor and parallel rule") quite outclasses the common circular type, because it can be oriented anywhere. If it is marked with extra angular values (eg. counterclockwise, etc.) obliterate them as a precaution against blunders. The expensive parallelogram type parallel rule is less useful than the cheap square protractor.

Plot on the chart and not on plotting sheets. When a fix was calculated by traditional methods, it required the plotting of several assumed positions and, because intercepts could be very long, considerable care with the azimuths was needed. So, although many sailors never used them, plotting sheets had some justification. None of this applies to a computerized reduction. Apart from the saving of effort and expense, plotting directly on the chart obviates the chance of a transfer mistake and often, on ocean crossings, the scale is so small that the intercepts are almost invisible. In those cases plotting is simply eliminated or restricted to a couple of rough pencil strokes.

Preserve all observations and computations until you are safely at your destination: don't work on loose scraps of paper. Record the position derived from the fix in your log along with a remark on how it compares with your dead reckoning.

For observing practice in the backyard use an artificial horizon. See Appendix 4 for details.

Special Note on Time

Even if you are comfortable with the notions of zone time, summer time, local time, the standard meridian and the international date line, do not apply your knowledge. Apply some wisdom instead: use Zulu time.

The aviation industry woke up to this long ago but there are still some sailors who haven't. Although mariners speak of Greenwich or Zulu time the correct term is Universal Time. The name is apt. You need not concern yourself with any other sort and in the interests of safety you should not. Adjust your clocks directly to the date and time given by the short wave signals. If you set them in 24 hour mode accurate to the second you have no corrections or conversions to make. None. GMT is what Merlin wants, it's what the almanac wants, it's the time used on radio skeds, it's universal. Use no other.

If, for some reason, you do need to have a clock marking time according to someone's parochial measure, label the instrument clearly and keep it in a place where it cannot pollute the atmosphere of the navigation table.

The day of the "ship's chronometer" is gone. Quartz watches, almost a giveaway item, are superior to the expensive chronometers of a few years ago. Keep several. Your main watch should show the seconds without having to press any buttons. Check your clocks often against the time signal. Avoid using the built-in light for it will flatten the battery.

Do not use a stopwatch for it is a nuisance. It would be pointless anyway unless you correct the time signals which can be in error by up to $0^s.9$. The procedure for determining this correction is set out in Appendix 3. For navigation it may be neglected. A systematic error of 1^s in time causes a longitude error of 0'.25 which is a maximum of a quarter of a mile. A systematic time error causes no error in latitude determined by position lines.

When observing alone wear your watch on the right wrist so that the left hand can shine a light on it. Count (aloud) the seconds between the moment of the sight and the viewing of the watch. Mentally subtract the count from the time showing and book the resulting GMT.

CARE OF THE CALCULATOR, CONTINGENCY PLANS

Safety considerations require that breakdown, however unlikely, be anticipated.

Keep the calculator in a place where it has no chance of falling, being leant on, or sat upon or of getting wet. Operate it with dry hands.

As with other electronic equipment you might save it if it gets wet by wiping or rinsing or even soaking it with fresh water. There must be no possibility of salt remaining in it and it must be dry before it is used.

Do not leave the machine in direct sunshine.

It is probably well to store it clear of radio transmitters and large magnets such as are in loudspeakers and generators.

Masters of small vessels might consider the following options:
- Carry on with a spare Merlin or substitute[1].
- Navigate with noon shots[2].
- Use a traditional tabular method of sight reduction.
- Ask a friend (via ham radio) to reduce your sights.
- Ask a passing ship on VHF channel 16 for a fix.

Before starting an ocean passage you might consider using Merlin to write your own almanac. Make a list of dec and GHA of the sun for 0^h GMT for every day of the proposed voyage. It would be advisable to convert the values to degrees, minutes, seconds - and perhaps record the decimal value as well. You use such an almanac according to the instructions in Appendix 2, the time adjustment being nil.

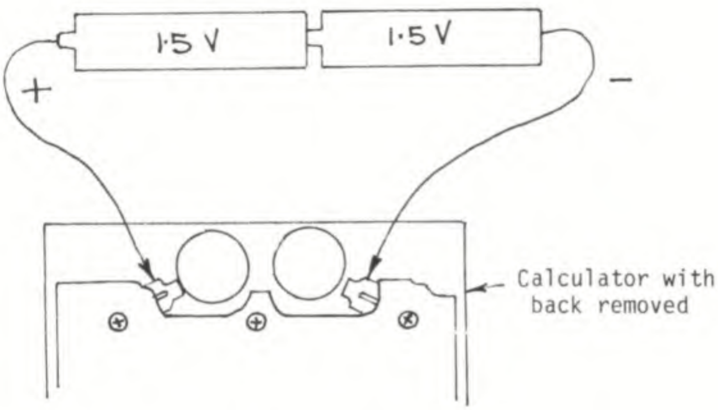
---

1) Keep it, along with instructions and star list, in a waterproof container. Do the same with a spare watch and radio.
2) See Appendix 2.

BATTERY REPLACEMENT WITHOUT POWER LOSS

When the grey dot on the left side of the display fades it means the pair of batteries needs replacing. As the batteries weaken the dot becomes fainter and the display becomes sluggish. (The computation time is not affected.) With further decline there will be insufficient power to drive the display at all and the machine will be apparently dead. At this point, though it is not usable, its programs will still be in place and can be completely resuscitated if you follow the instructions below. Even when it is switched off the calculator uses some current so eventually if the batteries are not replaced they will go quite flat and you will be left with an ordinary EL-512. The battery type is the LR44 or equivalent or the longer lasting G13 or equivalent.

If power is interrupted even for an instant the programs will be lost. To avoid this supply three volts to the machine while making the exchange. Make sure the contacts are firm. Do not get the polarity wrong. Connect at the points shown on the sketch (the screw heads are not live). Before removing the old batteries clean the new ones carefully and have them ready to hand. If you use a knife blade for prising out the old batteries make sure you do not short any of the contacts.



Some multitesters supply three volts to the probes for resistance measurement. Such an instrument is a convenient temporary power supply. Ensure that its batteries are in order. You can make certain of the polarity by touch-testing the resistance of a small battery in both directions.

The above procedure will preserve your Merlin. There is no reason to slip up but if you do you will lose all the programs entirely and E for error will appear when you try to run them. Should this happen air mail it in its box without any manuals direct to Meridian Survey Services, Box 1264 Booragoon, WA 6154, Australia with an explanatory note. Please send the equivalent of $US 10 to cover costs. It will be fixed and returned. Alternatively or as an interim measure prise off the cap from the COMP/LRN key and load the substitute programs.

The illustration opposite is from the 1934 edition of Bowditch: "American Practical Navigator". On modern theodolites the graduated horizontal and vertical circles are made of glass and are fully enclosed. This and other changes make later instruments rather different in appearance.

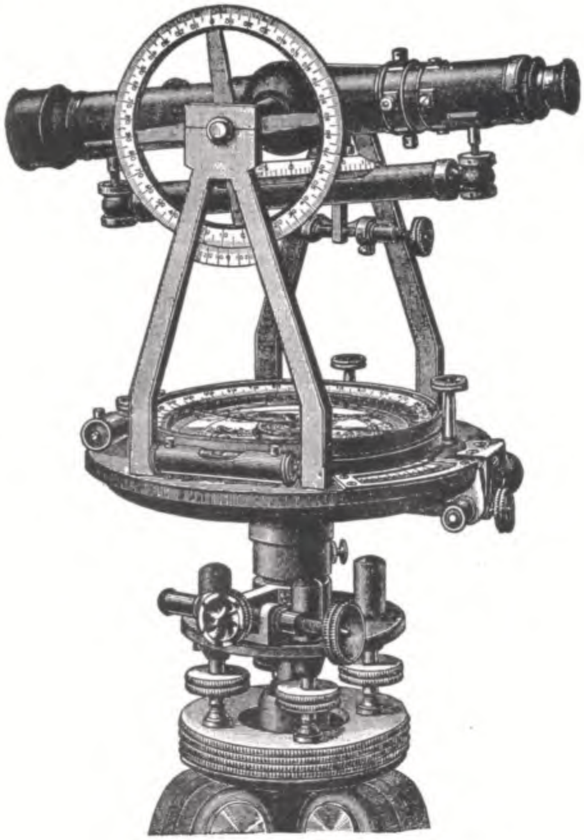
SUBSTITUTE PROGRAMS

Programs for Aries and sight reduction are given overleaf. There is a substitute for [2:] on page 40. The purpose of revealing them is to enable you to make backups to Merlin. The programs can be loaded into any Sharp model EL-512 or EL-522 calculator.

To enter the programs ensure that the memories are as listed then press the buttons exactly as indicated. Check the display all the time. If it differs from that shown you have made a mistake. Switch off the calculator and begin again with that program. When each program is in, test it as shown. If it doesn't check out, something is wrong: either data or program.

These programs do everything Merlin does. For stars, operating the calculator is the same though you will find that when computing LHA Aries or GHA Aries there is no need to press the RM key as the answer is already showing. You don't need Merlin's values in (6) and (8).

The operating procedure for sunsights is different from Merlin. You must take values out of the perpetual Almanac printed in Appendix 2 (page 45). (8) must hold a special "Year adjustment".



[1:] ARIES EPHEMERIS

Store in memories:

(3) 5
(5) 1.5
(7) 0.985647
(9) 160.294

DEG in display

Key:	Display
2nd TAB 4	
2nd LRN	0.0000 (dots flash)
[1:]	"
→DEG	"
X	"
15.04107	15.04107
+	0.0000
Kn 5	1.5000
+	"
Kn 7	0.9856
(	0.0000
Kn 3	5.0000
+	"
Kn 9	160.2940
=	164.4215
x→M	"
2nd LRN	0.0000

TEST OF PROGRAM [1:]

With memories (3) (5) (7) (9) as above:

enter 2.1		
key[1:]	197.0105	shows
C.CE	0.0000	shows
RM	197.0105	shows

[3:] AZIMUTH COMPUTATION

Store in memories:

(1) -11.05
(2) 152.5
(4) -6.03
(M) 209.6

DEG in display

Key:	Display
2nd TAB 4	
2nd LRN	0.0000 (dots flash)
2nd [3:]	"
RM	209.6000
+	"
Kn 2	152.5000
→DEG	152.8333
=	362.4333
x→M	"
cos	0.9991
X	"
Kn 1	-11.0500
→DEG	-11.0833
sin	-0.1922
-	-0.1921
Kn 1	-11.0500
→DEG	-11.0833
cos	0.9813
X	"
Kn 4	-6.0300
tan	-0.1056
+	-0.0884
RM	362.4333
sin	0.0425
2nd →rθ	0.0981
x→M	"
180	180
=	334.3458
2nd LRN	0.0000

TEST OF PROGRAM [3:]

With (1) (2) (4) (M) as above (check (M)!)

key 2nd [3:]	334.3458	shows
" RM	0.0981	shows

[4:] INTERCEPT COMPUTATION

Store in memories:

(4) -6.03
(M) 0.1

DEG in display

Key:	Display
2nd TAB 4	
2nd LRN	0.0000 (dots flash)
2nd [4:]	"
→DEG	"
-	"
(	"
RM	0.1000
X	"
Kn 4	-6.0300
cos	0.9945
)	0.0994
2nd $\cos^{-1}$	84.2927
2nd →DMS	84.1733
x→M	"
→DEG	84.2927
=	-84.2927
X	"
60	60
=	-5057.5614
2nd LRN	0.0000

TEST OF PROGRAM [4:]

With (4) and (M) as above (check (M)!)

enter 84.1
key 2nd [4:] -7.5614 shows
" RM 84.1734 shows

OVERALL TEST OF SUBSTITUTE PROGRAMS [1:], [3:] and [4:]

Set memories:

(1) 1.1
(2) 2.2
(3) 3.3
(4) 4.4
(5) 5.5
(7) 0.985647
(9) 9.9

DEG in display

enter 2.1
key [1:] 51.0995 shows
key 2nd [3:] 274.6127 shows
enter 36.3
key 2nd [4:] -2.6721 shows
key RM 36.3240 shows

After programming a substitute EL-512 make sure that it passes this overall test.

For a substitute [2:] see overleaf

Programs [3:] and [4:] are the actual Merlin programs ([1:] is not) and represent:

[3:]

LHA = GHA + long

tan (Az - 180) = sin LHA/(cos LHA sin lat - tan dec cos lat)

[4:]

cos comp. alt = |sin LHA/sin Az| . cos dec

Intercept = 60 (obs. alt - comp. alt)

[2:] SUBSTITUTE - INTERPOLATOR FOR THE SUN ALMANAC LISTED IN APPENDIX 2

Store in memories:

(5) 182.12
(6) 182.17
(8) 12

Key:		Display
2nd	TAB 4	
2nd	LRN	0.0000
	[2:]	
	→DEG	
	X	
	15	15
	=	0.0000
	x→M	
2nd	↕	
	+	
Kn	8	12.0000
	=	
	X	
	(	0.0000
Kn	6	182.1700
	→DEG	182.2833
	—	
Kn	5	182.1200
	→DEG	182.2000
	)	0.0833
	÷	1.0000
	24	24
	+	0.0417
Kn	5	182.1200
	→DEG	182.2000
	M+	182.2417
2nd	LRN	0.0000

TEST OF [2:] SUBSTITUTE

With memories (5), (6) and (8) as above:

enter 19.5517
key [2:] 182.3108 shows
key RM 481.1317 shows

An EL-512 loaded with these programs becomes a powerful celestial navigation computer. It is slightly less elegant than the real Merlin for sunsights but since you don't need [1:] and this [2:] runs in 3 seconds it's faster for multiple sights. The usual numbers that go into (6) and (8) on Merlin are not wanted on the substitute machine. Instead the "Year adjustment" tabled below may stay in (8). This table is a more exact form of the rules given in Appendix 2 for adjusting the time 6 or 12 hours earlier or later. This program [2:] does the interpolating shown in Appendix 2. You put the dec into (4) then every time it is run it puts the GHA into (M) ready for [3:] and [4:].

The error is very unlikely to exceed one minute - mostly much better.

SUBSTITUTE QUICK REFERENCE SUN	EXAMPLE 2 of page 16. Set (8) with 10.8 for 1984.
(5) dec at 0^h	(5) -3.30
(6) dec at 24^h	(6) -3.07
Approx GMT	2.1
[2:] → dec	-3.2929
2nd STO 4	Put into (4)
(This dec will do for 20 minutes.)	
(1) lat S —	(1) 46
(2) long W —	(2) 156.1
(5) GHA at 0^h	(5) 177.3
(6) GHA at 24^h	(6) 177.35
GMT [2:]	2.0936
2nd [3:] → Az	188.0
corr. alt	40.343
2nd [4:] → Int a-	+9.9
(8)Year adjustment	The other intercepts are 9.0, 8.9 and 10.7

YEAR ADJUSTMENT

In leap years use the first number during January and February.

JF80	-14.0	JF84	-13.2	JF88	-12.4	JF92	-11.6	JF96	-10.8
1980	+10.0	1984	+10.8	1988	+11.6	1992	+12.4	1996	+13.2
81	+4.2	85	+5.0	89	+5.8	93	+6.6	97	+7.4
82	-1.6	86	-0.8	90	0	94	+0.8	98	+1.6
83	-7.4	87	-6.6	91	-5.8	95	-5.0	99	-4.2

YM NUMBERS

Month	No.
Jan	100
(Jan leap 99)	
Feb	131
(Feb leap 130)	
March	159
April	190
May	220
June	251
July	281
Aug.	312
Sept.	343
Oct.	373
Nov.	404
Dec.	434

YM = Month No + Year No

eg: Jan 1988: YM = 100.330

Jan 1989: YM = 101.088

Jan 1990: YM = 100.847

(1988 is a leap year)

Year	Year No.	(8) No.
1976	1.237	102.500
77	.994	102.517
78	.751	102.534
79	.508	102.552
1980	1.265	102.569
81	1.022	102.586
82	.780	102.603
83	.538	102.620
1984	1.296	102.637
85	1.054	102.655
86	.812	102.672
87	.571	102.689
1988	1.330	102.706
89	1.088	102.723
90	.847	102.741
91	.605	102.758
1992	1.363	102.775
93	1.120	102.792
94	.878	102.809
95	.635	102.827
1996	1.392	102.844
97	1.149	102.861
98	.906	102.878
99	.663	102.895
2000	1.420	102.912
01	1.178	102.930
02	.936	102.947
03	.694	102.964
2004	1.452	102.981

MAIN CORRECTION

Star	alt	L.L.	U.L.
−8′.2	6°15′	+ 8′	−24′
−7′.7	6°40′	+ 8′.5	−23′.5
−7′.2	7°20′	+ 9′	−23′
−6′.7	7°50′	+ 9′.5	−22′.5
−6′.2	8°30′	+10′	−22′
−5′.7	9°20′	+10′.5	−21′.5
−5′.2	10°20′	+11′	−21′
−4′.6	11°30′	+11′.5	−20′.5
−4′.1	13°	+12′	−20′
−3′.6	15°	+12′.5	−19′.5
−3′.1	17°	+13′	−19′
−2′.6	20°	+13′.5	−18′.5
−2′.1	24°	+14′	−18′
−1′.6	31°	+14′.5	−17′.5
−1′.1	41°	+15′	−17′
−0′.6	59°	+15′.5	−16′.5
−0′.1	85°	+16′	−16′
0	90°	+16′	−16′

Month No.	
Jan.	100
(Jan. leap 99)	
Feb.	131
(Feb. leap 130)	
March	159
April	190
May	220
June	251
July	281
Aug.	312
Sept.	343
Oct.	373
Nov.	404
Dec.	434

Year	Year No.	(8) No.
1984	1.296	102.637
85	1.054	102.655
86	.812	102.672
87	.571	102.689
1988	1.330	102.706
89	1.088	102.723
90	.847	102.741
91	.605	102.758
1992	1.363	102.775
93	1.120	102.792
94	.878	102.809
95	.635	102.827

YM = Month No. + Year No.

MERLIN QUICK REFERENCE

SUN	STAR	MOON/PL.
(1) lat S−	(1) lat S−	(1) lat S−
(2) long W−	(2) long W−	(2) long W−
(3) day	(3) day	
	(4) dec° S−	(4) dec° S−
	(5) SHA°	
		(M) GHA°
GMT [1:] [2:]	GMT [1:]	

2nd [3:] → Az°

alt 2nd [4:] → Int a−

(RM → computed alt° ′ ″)

(6) 0.91747
(7) 0.985647
(8) 102 . . . .
(9) YM

dec, SHA, GHA in degrees decimal

others in °. ′ ″

Ht.	Dip
0.7m	− 1′.5
1.3m	− 2′
2.0m	− 2′.5
2.9m	− 3′
3.9m	− 3′.5
5.1m	− 4′
6.4m	− 4′.5
7.9m	− 5′

IDENTIFICATION

(3) day
(5) long W−

GMT [1:]
RM → LHA Aries

(1) lat S−
(2) zero
(4) alt
(M) Az

2nd [3:] → LHA star

enter LHA Aries

= → SHA
(+ 360 =)

2nd [4:]

RM → dec
(put sign)

APPENDIX 1

PRINCIPLES OF NAVIGATIONAL ASTRONOMY

Celestial movement and position

The heavenly bodies rise in the east and set in the west. All of them do this every day. The cause is the Earth spinning but for our purposes we may consider the Earth to be stationary and the heavens in motion.

If a line be imagined from a body to the centre of the Earth, there will be a point where the line pierces the Earth's surface. This point is known as the body's ground position. An observer at the GP would find the body to be exactly overhead, though only for an instant because, of course, the GP is constantly moving. It moves westward, once around the planet every 24 hours, more or less.

It is the function of an almanac to give the location of the GP for a nominated body at a nominated moment of time. The almanac gives declination and Greenwich hour angle. Declination is the latitude of the GP; GHA is the longitude of the GP except that GHA is measured positive west from Greenwich. Longitude, at least in this volume, is considered positive east of Greenwich. Since the GP moves westward its latitude (the declination) will not change much. The GHA, on the other hand, is constantly increasing going from 0° to 360° every day.

When you take an observation you note the time carefully. Providing you know which body it was and you are equipped with an almanac for that body, then you can find its dec and GHA for that instant of time.

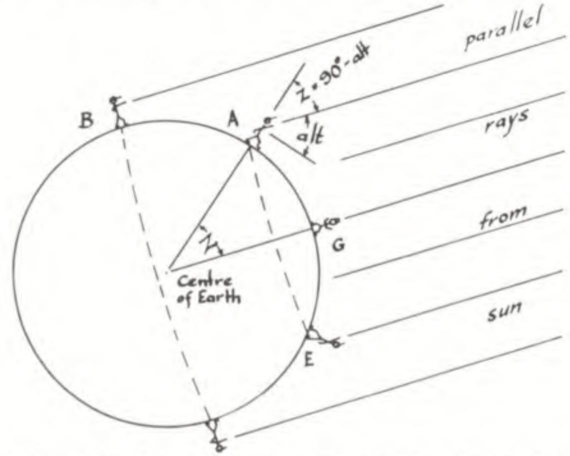
The sun, moon, Venus, Mars, Jupiter and Saturn follow the general course described above but each has its own peculiar movements as well. Thus each requires its own almanac. The stars, however, all move together. Because of this an almanac for each of them is not necessary. An almanac giving the GHA of one point suffices as long as it is accompanied by a table giving the difference between it and each of the stars. The point computed is the first point of Aries ("Aries" or ♈ for short). Its GHA is found with an Aries almanac and the difference, called the sidereal hour angle, is then added to the GHA♈ to give the GHA of the star. Annex B gives a list of the SHA's for 59 stars. As you can see they are not quite constant so they are given for every 6 months.

Relationship of observer to heavenly body

The figure below represents the Earth illuminated by the sun. The sun is so far away that rays from it may be considered parallel. One observer, G, is at the ground position, ie. on the line from the Earth's centre to the sun. For him the sun is exactly overhead. For observer B, however, the sun is on the horizon.

In terms of altitude, G would find the sun to be 90^{0} up from the horizontal, whereas for B the altitude is 0^{0}. For an observer, A, the sun's altitude is, perhaps, 50^{0} and we can see that A's altitude is the measure of his distance from the GP. The higher the altitude the less the distance.

The reason for this effect is the elementary fact that the Earth is round and, naturally, it holds for any heavenly body, not just the sun. This fact, that altitude indicates distance from the GP, is the central concept of navigational astronomy. If you grasp it clearly, the rest will follow.



Now the distance from A to G (and indeed any great circle distance) may be reckoned in terms of the angle it makes at the centre of the Earth. This angle is marked Z on the sketch and, from fundamental properties of parallel lines, it is equal to the angle between observer A's zenith and the sun. This angle is known as the zenith distance and is the difference between the altitude and 90^{0}.

All this means that when a navigator, using a sextant, determines an altitude, he has only to subtract this altitude from 90^{0} to find how far he is from the body's GP. In the sketch, if A found an altitude of 50^{0} then his distance from G was 40^{0}.

Providing A noted the time of his altitude observation he could find the location of the GP from an almanac. But, though he knows how far from the GP he is he cannot actually find his position. As the sketch shows, an observer, E, would have the same altitude, and anyone situated on the circle centred on G and passing through A and E would observe that same altitude at that particular moment of time.

So, without further information all A could say after taking an observation would be that he is somewhere on a circle. It is a fact that an observation of altitude and time to a single body does not yield position. All it yields is a position circle.

Since the navigator always has some idea of his location, only a small segment of the circle would be of interest. However even that cannot be drawn by plotting the GP and using a pair of compasses for the circle is too big. In the present example Z is 40^{0}. Each degree represents 60 nautical miles so that A's position circle is 2400 miles in radius.

Marcq St. Hilaire sight reduction

The need is to plot the short section of the circle that is of interest. There are a number of approaches but the procedure which is practically universal nowadays is the Marcq St. Hilaire or altitude intercept method.

The navigator knows (via time and almanac) the position of the GP and he makes an estimate, in latitude and longitude, of his own position. If you took a global model of the Earth you could mark these two points on it. If you stretched a string or tape between the points you would be able to measure the distance between them and, with the aid of a protractor, you could read off the bearing of this line at the observer's end. This bearing is known as the azimuth of the body. "Azimuth" is another word for "true bearing".

Navigators do not use globes. They are too inaccurate. Instead they use a portable computer or book of tables to compute, using appropriate mathematical formulae, the azimuth and distance from the observer to the GP. This distance is not reckoned in miles but in degrees and, in fact, it is not the zenith distance but the zenith distance subtracted from 90^{o}. This makes it the computed altitude. That is to say, it is the altitude the observer would have observed if he had been at his estimated position.

Of course a real altitude was observed. Chances are it will not be the same as the computed altitude - which means that the observer was not where he thought. The difference is known as the intercept. For example if the computed altitude was 28^{o} 34' and the observed (corrected) altitude was 28^{o} 37' then the observer was 3' - ie. 3 miles - nearer the GP than his estimated position. That is 3 miles in the direction of the azimuth. The actual location must be nearer to the GP because the actual observed altitude was greater.

To draw the small piece of position circle, the estimated position is plotted and a line drawn through it in the direction (azimuth) of the body. The intercept is measured off from the estimated position towards or away from the body as appropriate, and the point marked. A line drawn through this point at right angles to the azimuth is the position line. It is the required segment of the position circle and may be drawn as a straight line because the circle is so large.

A position line is a line somewhere upon which the observer must be (or have been at the time of sight). A second sight may be taken to another body and the position line corresponding to it also plotted. The observer lies somewhere on this line too. The only way he can be on both lines is to be where they intersect. Thus, with two lines from different directions a fix is obtained.

If more than two lines are plotted, it will doubtless occur that they do not all pass through the same point. Providing there have been no blunders the cause is small errors in reading the sextant and the clock and in the precision of the manufacture of these instruments. Examples showing and discussing such errors are to be found in this manual.

Other computational methods

The above is a minimal description of how the St.Hilaire approach is realized on a computer. Celestial computations are currently at a stage of transition with many, perhaps most, sailors still using tables.

Accurate navigation was made possible by the invention of accurate time-keepers two centuries ago (accurate almanacs had long been available) but the calculations, which were well understood by astronomers, proved to be something of a burden to seamen. The concept of celestial position line was explained by Thomas Sumner in 1837. St. Hilaire explained the altitude intercept in 1875 and with the development of inspection tables this became almost the only method.

Modern inspection tables consist of lists of pre-computed answers (ie azimuth and computed altitude) to possible situations. The number of possible combinations of observer's position and heavenly position is infinite, so the tables give solutions for combinations involving whole degrees. This would mean a lot of painful interpolating were it not that instead of using estimated position the navigator assumes a position which may be written with whole numbers. The assumed position consists of the nearest whole degree of latitude and such a longitude that the difference between longitude and GHA is a whole number. This difference is called the local hour angle (LHA).

By this trick with whole numbers, by making the one table serve all quadrants and hemispheres, by limiting the accuracy to that needed for navigation, and by restricting the latitudes covered to those where the navigator intends to go, the bulkiness of the tables is held to a minimum.

It is an effective system and has been the dominant one for the last generation or so. In the next few years, however, we may expect to see sight reduction tables go the way of the cross-staff and the mechanical clock - to the museum. The computation of position given time, altitude, and almanac data has been a unique mathematical and practical problem. For two centuries some of the best minds have wrestled with it. Hundreds of ingenious solutions have been invented. This problem, which has played a central role in the history of modern times, now appears to have been finally solved - with a programmed computer.

It is an irony that with a computer it matters little which formula is used - indeed the oldest and most fundamental forms are invariably employed. It is possible that we may see a decline in the use of the altitude intercept and a reversion to the Sumner method. When the azimuth is very close to 0° or 180° a Sumner reduction may fail and must be recomputed. Traditionally a considerable nuisance, this is of no consequence with a computer - and plotting the position line after Sumner is tidier, quicker and surer than after St. Hilaire.

Obviously, computers can do rather more than just the sight reduction. On machines substantially larger than Merlin moon and planet data can be generated. It is possible to write programs to compute sights to bodies that are not identified at all. Where more than one body is observed a computer can work out the final position, obviating the plotting of position lines. This is a fine convenience as long as the procedures for detecting and rejecting faulty observations and for assessing the consistency of the sights are straightforward. Where sights are taken to more than one body there is, in principle, no need for an estimated position.

In recent years an entirely new method of celestial navigation has become widespread. Computerised on-board equipment is used to interrogate special artificial satellites by radio. It is very accurate, it requires no training to operate and it is becoming normal on ocean vessels. It is also complex and power dependent so presumably the natural objects will remain in use, at the very least as a back-up.

APPENDIX 2

NOON SIGHTS FOR LATITUDE AND LONGITUDE

Latitude and longitude can be found at noon with almost no calculation.

Local noon is the instant when the sun stops rising and starts setting. It is exactly due north or due south of the observer at this moment. In principle any body may be used to take such sights except that the moon should not be used for longitude as its declination changes too rapidly. In practice, of course, sights are limited to times when the horizon is visible.

LATITUDE

As noon approaches keep reading the sun's altitude, watching it slowly increase. When noon (more generally known as "meridian passage") occurs the altitude appears to stay the same for a while before beginning to decrease. Note the sextant reading at noon and the approximate GMT. Apply the usual altitude corrections. Subtract the altitude from 90° to give the zenith distance, Z. This Z is the angle from your zenith to the sun and it indicates how far you are north of, or south of, the sun. Z may be regarded as a sort of latitude with respect to the sun instead of the equator. Since the sun's declination is actually <u>its</u> latitude, if you add Z to it you will get <u>your</u> latitude.

<u>Example</u>: In the northern hemisphere you observe the sun to the south of you at noon. The corrected alt is 70°. From an almanac the sun's dec at that time was 10° N. So Z is (90 - 70) = 20° and your latitude is 30° N.

In strictly algebraic terms: latitude = Z + sun's dec

<u>where</u> lat is negative if south
dec is negative if south
Z is negative if you were south of the sun (ie looking north).

<u>Example</u>: Sun to the north, alt = 85° 32' thus Z = -4° 28'
The almanac gives dec as 15° 45' S.

lat = -4° 28' -15° 45' = -20° 13' , ie 20° 13' S.

<u>Example</u>: Sun to the south, alt = 78° 04' thus Z = 11° 56'
The sun's dec is 21° 27' S

lat = 11° 56' -21° 27' = -9° 31' , ie 9° 31' S.

LONGITUDE

At the instant of local noon you and the sun have the same longitude. Since the sun's longitude is its GHA, if you can find the GMT of local noon it is only necessary to look up the GHA to find your longitude. However the GMT of noon can't be read directly because with a sextant you can't pick the exact moment.

The procedure, in principle, is to measure the altitude 20 minutes to an hour (or more) before the time you expect noon to occur, noting the GMT. After noon is past set the sextant to the same altitude and keep watching the sun until it descends to that altitude. Note the GMT of that moment. The average of the two GMT's is the GMT of local noon. An almanac will yield the sun's GHA for that instant. This is your longitude <u>west</u>.

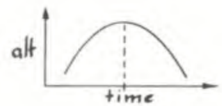
<u>Example</u>: Sun's GHA at GMT of local noon = 47° 38'
Therefore longitude = 47° 38' W.

<u>Example</u>: Sun's GHA at GMT of local noon = 256° 31'.5
Longitude is thus 256° 31'.5 west but longitude is only measured to 180°, so subtract the value from 360° and call it east:

360° - 256° 31'.5 = 103° 28'.5 E.

In practice one sight before and after meridian passage is not satisfactory. Instead take half a dozen before noon, spread over a quarter of an hour or so. After noon has occurred set the sextant to the highest of the forenoon readings and note the time when the sun descends to this altitude. Do the same for the rest of the observations. You then have half a dozen pairs you can average. Of course they should all give the same answer for GMT noon but they won't so take a new average of them and look up your longitude. The reasons for this procedure are (a) this equal altitudes method of finding longitude does not, in general, give really good results and it is improved by taking multiple sights; (b) if you only took one sight cloud might obscure the sun at the critical moment when you want the second one. The more you take the better.

You don't necessarily have to take the <u>same</u> altitudes before and after noon. You can just take random altitudes and graph them, time against altitude, and put a smooth curve through the values. The GMT of noon is at the centre of the curve. It is handy to have some squared paper and for accuracy you should draw it so that it takes up nearly a whole page.



Latitude at noon is as accurate as any other sextant position line - right up to altitudes near 90° too. But longitude may be good or it might not. There is an important reservation with longitude as well: your vessel must not be moving north-south during the period between the forenoon and afternoon sights. If you move east-west (parallel with the movement of the sun) there is no error but be sure to take log readings so the noon log reading can be figured out.

EMERGENCY ALMANAC

Presumably the only reason you will take noon sights is if your electronic navigation equipment has failed. You will need an almanac. The one here lists the declination and GHA of the sun for 0^h GMT for each day of the year. The maximum error in it for the rest of this century is 2'. To use it first roughly adjust the GMT of the observation according to the kind of year, viz:

In a year preceding a leap year make the adjusted time 6 hours earlier
In a leap year in Jan and Feb " " " " 12 " "
" " " " " March to Dec " " " " 12 " later
In a year after a leap year " " " " 6 " "
In even numbered non-leap years the adjusted time is the same as the GMT.

<u>For dec</u>: Interpolate the value for the adjusted time from the table.

<u>For GHA</u>: Interpolate a "datum GHA" from the table using the adjusted time. Convert the actual GMT to arc by multiplying by 15. Add this arc to the datum GHA.

<u>Example</u>: Find the sun's dec and GHA at GMT $19^h\ 55^m\ 17^s$ on September 27, 1992. It's a leap year; here add 12^h so adjusted time becomes 8^h on September 28.

<u>For dec</u>:
dec at 0^h Sept 28 = -1° 50'
dec at 0^h Sept 29 = -2° 13'
difference = 23'

$23 \times \frac{8}{24} = 8'$

so dec = -1° 50' - 8' = <u>-1° 58'</u>.

<u>For GHA</u>: The interpolation can be done by eye. At 0^h on the 28th the GHA is 182° 17'. On the 29th it is 182° 22' so at 8^h it would be 182° 19'. Converting $19^h\ 55^m\ 17^s$ to arc gives 298° 49' 15". If you have a calculator use the →DEG button to express the time in decimal hours, multiply by 15 then change back with →DMS. Otherwise do it manually as below or use an arc-to-time conversion table such as found on the first yellow page of the Nautical Almanac.

19^h	55^m	4) 17^s	datum GHA = 182° 19'
x 15	x 15	4'.25	arc = 298° 49'
95	275		481° 08'
19	55	(arc = 298° 49'.25)	
285°	825' = 13° 45'		so GHA = <u>121° 08'</u>.

SUN'S DECLINATION AT 0^h GMT IN DEGREES AND MINUTES

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	
1	-23 2	-17 14	-7 46	4 21	14 56	21 59	23 8	18 8	8 27	-2 60	-14 16	-21 44	1
2	-22 57	-16 57	-7 23	4 44	15 14	22 7	23 4	17 53	8 6	-3 23	-14 36	-21 53	2
3	-22 52	-16 40	-7 0	5 8	15 32	22 15	22 60	17 38	7 44	-3 46	-14 55	-22 2	3
4	-22 46	-16 22	-6 37	5 31	15 50	22 23	22 55	17 22	7 22	-4 10	-15 13	-22 10	4
5	-22 40	-16 4	-6 14	5 53	16 7	22 30	22 50	17 6	6 60	-4 33	-15 32	-22 18	5
6	-22 33	-15 46	-5 51	6 16	16 24	22 36	22 44	16 50	6 37	-4 56	-15 50	-22 26	6
7	-22 26	-15 27	-5 28	6 39	16 41	22 42	22 38	16 33	6 15	-5 19	-16 8	-22 33	7
8	-22 18	-15 8	-5 4	7 1	16 57	22 48	22 32	16 17	5 52	-5 42	-16 26	-22 40	8
9	-22 10	-14 49	-4 41	7 24	17 14	22 53	22 25	15 60	5 30	-6 5	-16 43	-22 46	9
10	-22 2	-14 30	-4 18	7 46	17 30	22 58	22 18	15 42	5 7	-6 28	-17 0	-22 52	10
11	-21 53	-14 11	-3 54	8 8	17 45	23 3	22 10	15 25	4 45	-6 50	-17 17	-22 57	11
12	-21 43	-13 51	-3 30	8 30	18 1	23 7	22 2	15 7	4 22	-7 13	-17 34	-23 2	12
13	-21 33	-13 31	-3 7	8 52	18 16	23 11	21 54	14 49	3 59	-7 35	-17 50	-23 7	13
14	-21 23	-13 11	-2 43	9 14	18 31	23 14	21 45	14 31	3 36	-7 58	-18 6	-23 11	14
15	-21 13	-12 50	-2 20	9 36	18 45	23 17	21 36	14 12	3 13	-8 20	-18 22	-23 15	15
16	-21 2	-12 30	-1 56	9 57	18 59	23 20	21 27	13 53	2 50	-8 42	-18 37	-23 18	16
17	-20 50	-12 9	-1 32	10 18	19 13	23 22	21 17	13 34	2 27	-9 5	-18 52	-23 20	17
18	-20 38	-11 48	-1 8	10 39	19 27	23 24	21 7	13 15	2 3	-9 26	-19 7	-23 22	18
19	-20 26	-11 27	-0 45	11 0	19 40	23 25	20 56	12 56	1 40	-9 48	-19 21	-23 24	19
20	-20 13	-11 5	-0 21	11 21	19 53	23 26	20 45	12 36	1 17	-10 10	-19 35	-23 25	20
21	-20 0	-10 44	0 3	11 42	20 5	23 26	20 34	12 17	0 54	-10 31	-19 48	-23 26	21
22	-19 47	-10 22	0 26	12 2	20 17	23 26	20 22	11 57	0 30	-10 53	-20 2	-23 26	22
23	-19 33	-10 0	0 50	12 22	20 29	23 26	20 10	11 36	0 7	-11 14	-20 15	-23 26	23
24	-19 19	-9 38	1 14	12 42	20 41	23 25	19 58	11 16	-0 16	-11 35	-20 27	-23 26	24
25	-19 5	-9 16	1 37	13 2	20 52	23 24	19 45	10 56	-0 40	-11 56	-20 39	-23 25	25
26	-18 50	-8 54	2 1	13 22	21 3	23 23	19 33	10 35	-1 3	-12 17	-20 51	-23 23	26
27	-18 35	-8 31	2 25	13 41	21 13	23 21	19 19	10 14	-1 27	-12 37	-21 2	-23 21	27
28	-18 19	-8 9	2 48	13 60	21 23	23 18	19 6	9 53	-1 50	-12 57	-21 13	-23 18	28
29	-18 3	-7 46	3 11	14 19	21 33	23 15	18 52	9 32	-2 13	-13 17	-21 24	-23 15	29
30	-17 47	-7 23	3 35	14 37	21 42	23 12	18 38	9 10	-2 37	-13 37	-21 34	-23 12	30
31	-17 31		3 58	14 56	21 51	23 8	18 23	8 49	-2 60	-13 57	-21 44	-23 8	31
32	-17 14		4 21		21 59		18 8	8 27		-14 16		-23 4	32

SUN'S GHA AT 0^h GMT IN DEGREES AND MINUTES

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	
1	179 11	176 37	176 52	178 59	180 43	180 35	179 5	178 25	179 57	182 32	184 5	182 48	1
2	179 3	176 35	176 55	179 3	180 44	180 33	179 2	178 26	180 2	182 36	184 6	182 42	2
3	178 56	176 33	176 58	179 7	180 46	180 30	178 59	178 27	180 6	182 41	184 6	182 37	3
4	178 50	176 32	177 2	179 12	180 48	180 28	178 56	178 28	180 11	182 46	184 6	182 31	4
5	178 43	176 30	177 5	179 16	180 49	180 25	178 54	178 29	180 16	182 50	184 6	182 25	5
6	178 36	176 29	177 8	179 21	180 50	180 23	178 51	178 31	180 21	182 55	184 5	182 18	6
7	178 29	176 28	177 12	179 25	180 52	180 20	178 49	178 33	180 26	182 59	184 5	182 12	7
8	178 23	176 27	177 15	179 29	180 53	180 17	178 46	178 34	180 31	183 4	184 4	182 6	8
9	178 17	176 27	177 19	179 33	180 53	180 14	178 44	178 36	180 37	183 8	184 3	181 59	9
10	178 10	176 26	177 23	179 37	180 54	180 11	178 42	178 39	180 42	183 12	184 2	181 52	10
11	178 4	176 26	177 27	179 41	180 55	180 8	178 40	178 41	180 47	183 16	184 0	181 46	11
12	177 58	176 26	177 30	179 45	180 55	180 5	178 38	178 43	180 52	183 20	183 59	181 39	12
13	177 53	176 26	177 35	179 49	180 55	180 2	178 36	178 46	180 58	183 24	183 57	181 32	13
14	177 47	176 27	177 39	179 53	180 56	179 59	178 34	178 48	181 3	183 27	183 55	181 25	14
15	177 42	176 27	177 43	179 57	180 56	179 56	178 32	178 51	181 8	183 31	183 52	181 17	15
16	177 36	176 28	177 47	180 1	180 55	179 53	178 31	178 54	181 14	183 34	183 50	181 10	16
17	177 31	176 29	177 51	180 4	180 55	179 50	178 29	178 57	181 19	183 37	183 47	181 3	17
18	177 26	176 30	177 56	180 8	180 55	179 46	178 28	179 0	181 24	183 40	183 44	180 56	18
19	177 22	176 31	177 60	180 11	180 54	179 43	178 27	179 4	181 30	183 43	183 41	180 48	19
20	177 17	176 33	178 4	180 14	180 53	179 40	178 26	179 7	181 35	183 46	183 38	180 41	20
21	177 13	176 34	178 9	180 17	180 53	179 36	178 25	179 11	181 40	183 49	183 34	180 33	21
22	177 8	176 36	178 13	180 20	180 52	179 33	178 24	179 14	181 46	183 51	183 30	180 26	22
23	177 4	176 38	178 18	180 23	180 50	179 30	178 24	179 18	181 51	183 53	183 26	180 19	23
24	177 0	176 40	178 22	180 26	180 49	179 27	178 23	179 22	181 56	183 55	183 22	180 11	24
25	176 57	176 42	178 27	180 29	180 48	179 24	178 23	179 26	182 1	183 57	183 18	180 4	25
26	176 53	176 44	178 31	180 31	180 46	179 20	178 23	179 30	182 6	183 59	183 13	179 56	26
27	176 50	176 47	178 36	180 34	180 45	179 17	178 23	179 34	182 12	184 1	183 9	179 49	27
28	176 47	176 50	178 40	180 36	180 43	179 14	178 23	179 39	182 17	184 2	183 4	179 41	28
29	176 44	176 52	178 45	180 39	180 41	179 11	178 23	179 43	182 22	184 3	182 59	179 34	29
30	176 42	176 55	178 50	180 41	180 39	179 8	178 24	179 48	182 27	184 4	182 53	179 27	30
31	176 39		178 54	180 43	180 37	179 5	178 24	179 52	182 32	184 5	182 48	179 19	31
32	176 37		178 59		180 35		178 25	179 57		184 5		179 12	32

APPENDIX 3

ASTRONOMICAL AZIMUTH WITH A THEODOLITE

Merlin provides the solution generally known as "azimuth by hour angle". The advice in this appendix should enable an observer with "ordinary" equipment to obtain a good azimuth in tropical and temperate latitudes.

Procedure The method requires pointing to the body with the vertical wire, noting time and horizontal circle reading. A horizontal reading to the reference object (RO) yields the horizontal angle from the body. This angle is added to the azimuth computed by Merlin to give the azimuth of the RO.

Merlin is operated as per the reference card. Azimuth of the body shows in decimal degrees. Altitude is not observed but if [4:] is run then the computed altitude will be left in (M) in ^{o}.' "

The error in azimuth originated by the Merlin almanacs depends on the observer's latitude and the position of the body observed. It should always be less than 30" and will normally be quite a lot less.

Apart from any value it may have for determining position, program [4:] is useful for finding the semi-diameter correction to azimuth, viz:

SD corr. = SD/cosalt

The semi-diameter may be taken from the graph.

Do not follow the common practice of averaging left and right limb observations. It is preferable to compute out each sight and apply its SD correction. With Merlin it is also the easy way. Moreover it allows observations to the trailing limb only. (Pointing accuracy is likely to be lower to the leading limb.)

Though the theodolite be in good adjustment, it is important, because of the likely steepness of the sights, that an equal number of right and left face readings be taken to balance residual collimation error. Again: do not average readings but compute out each sight.

An adequate programme of horizontal circle readings for a sunsight might be:

Left face : RO, swing left, four sights to trailing edge, close RO.

Right face : " " right " " " " " " "

Compass bearing to RO to catch gross error.

For each face average the opening and closing RO readings before taking the differences with the sun readings to give the horizontal angles. Compute the azimuths and semi-diameter corrections. The end result will be four left face and four right face azimuths to the RO.

For a star it is the same except that there is no semi-diameter.

The theodolite must be levelled with extreme care. Make sure that the sun does not strike the bubble during levelling. For star sights where high accuracy is sought observe many rounds, disturbing the footscrews and re-levelling between rounds. The steeper the sight, the more important the levelling.

If you are new to astronomy you should carry out some sun observations (which are easy) before taking on the stars with their complications of prediction, identification and administration.

Timing Take note of the remarks on time on page 34. If you do not want to reset your watch then compare it with the UT signal and record the difference: one single figure that represents your watch correction to UT. Zone time, standard meridian, sidereal time and so forth play no role.

In high latitudes you may feel it is worthwhile to obtain time to better than a second. Use the lap timing function in stopwatch mode for both the time signal comparisons and the observations. Correction to the broadcast U.T. is made by noting emphasized second markers ("pips") during the first 16 seconds after the minute marker. If, say, the 1st and 2nd pips are emphasized the correction is $+0^s.2$. If the first eight markers were emphasized the correction would be $+0^s.8$. If the ninth marker is emphasized the correction is $-0^s.1$. If the 9th, 10th, 11th were emphasized the correction would be $-0^s.3$ And so on.

Equipment A glimpse of the sun through an unfiltered telescope will cause serious eye injury. A dark glass is, however, not essential for observations. Set the telescope focus to infinity and direct it at the sun while holding a blank page several centimetres behind the telescope. By adjusting the eyepiece-ring a sharp image of the sun and the cross hairs will be cast upon the page and a normal observing programme may be carried out. If the reading microscope is alongside the telescope be careful to shade the instrument before looking into it.

For night observations a lighting set, though convenient, is not essential. It is perfectly satisfactory to shine a light into the appropriate ports and across the objective lens. To minimize fatigue it is very desirable that the lamp be light in weight.

Night targets can be makeshift. For an RO at about 10 km use a cheap strobe. It should run all night without attention. At a couple of kilometres a car battery powering a 12V bulb (eg. interior vehicle light) will serve. The wires ought to be soldered to the bulb. At 100 m an illuminated plumb-bob string is satisfactory. In an emergency use the cross hairs of another telescope about 10 m away. The telescope and cross hairs must be focussed at infinity and illuminated from behind. Both instruments must remain in place till visibility permits transfer to a permanent RO.

Daylight stars A sun observation should give azimuth to perhaps 30" and if you want better you must use the stars. This is easiest to do at night when you can pick and choose but stars brighter than magnitude 1.5 or so can also be observed during daytime if the sky is clear. Since they are not visible to the naked eye they must be predicted for the intended time of observation.

Merlin does not sign computed altitude so you have to make sure that the predicted star is above, not below the horizon. Unlike the navigator you are probably not staring at them every night so you are unlikely to know which part of the sky is up. To settle this find LHA Aries for the proposed observation time. This value is also the right ascension which is on the meridian at that moment. Subtract it from 360° to get the SHA on the meridian and consult the list on the first page of Annex B for some bright stars to predict.

To find LHA Aries you can follow the reference card or, even easier:

(3) day
(5) zero
enter approx local time [1:]
RM → approx LHA Aries

If you intend to make a habit of daylight star observation you should buy a star finder from a ship chandler. This lets you see at a glance which bright stars are at what altitudes and directions. Moreover, if you transfer the elongation curve from the graph here onto the appropriate latitude template of the finder you can see precisely which stars to choose and when the optimal observing time will be.

Optimal conditions — The body observed should preferably be moving slowly in azimuth. Altitudes should be kept low. There is no particular minimum altitude but ground-skimming sights are likely to incur horizontal refraction error, particularly in warm weather with a breeze blowing. (This applies also to the sight to the RO.)

The best object, when it is visible, is the pole star (up to latitude 50° perhaps). Sights to it are least sensitive to errors in latitude, longitude and timing. Pole star co-ordinates linearly interpolated from Annex B may be improved by applying the corrections given by the graphs. Large though they are, these corrections will make only a modest difference to the computed azimuth. Applying them gives an accuracy almost certainly greater than warranted by your instrument or your knowledge of local deviation of the vertical.

The southern pole star, sigma Octantis, is quite faint. To find it direct the telescope to any convenient known star, noting the time. Merlin will yield this star's azimuth enabling the orientation of the theodolite circle to be deduced. Sigma Octantis can then be predicted and the telescope pointed at it.

If the pole star is not visible observations should be made to a star near elongation. This minimizes the effects of errors in longitude, GHA and time (they are much the same thing). The altitude and direction of elongation may be read off the nomogram.

If observations are made to two such stars such that their azimuths are symmetric to the meridian (ie. $Az_1 = 360° - Az_2$) then the influence of an error in latitude will be equal but opposite and taking the mean will result in its cancellation. Paired observations to the sun in the morning and afternoon are the rough equivalent of this.

If longitude is in doubt determine it by observing altitudes to a body to the east or west and plotting the position line. You may use the sun providing it is near east or west - which it will probably (though not necessarily) be for azimuth observations. In the past some surveyors (in suitable latitudes) have preferred the "azimuth by altitude" procedure to the hour angle method because it avoids the latter's requirement for time and longitude. Precise time has in recent years ceased to be a bother and with Merlin the determination of longitude is also fairly trivial. Even in the limited circumstances where the altitude method may be used, the hour angle method is more accurate.

High latitudes — In high latitudes pole star and elongation observations are not suitable owing to steepness of sight. In this case, for any given altitude, the slowest moving stars are underneath the pole, ie. at lower culmination. The higher the dec the slower the movement - but this makes the sight steeper. Use stars towards the elevated pole up to about 30° or 40° altitude being very particular with the levelling. Time (and longitude and GHA) must be accurate. If no stars present themselves at lower transit a balanced pair in directions 90° and 270° makes a good substitute.

The determination of azimuth in high latitudes needs special techniques. The Merlin almanacs are also not appropriate. However it is worth noting that the almanac error is smooth and over moderate time periods may be regarded as constant. If such a slightly wrong almanac is used to find longitude and that somewhat wrong longitude and the same wrong almanac used to compute azimuth then two wrongs will tend to make a right: the azimuth will be pretty much in order.

Astro-fix — Of course, Merlin can be used to determine position by the navigator's usual procedure. With careful observation to four well distributed stars you might look for an accuracy of half a minute - ie. half a mile. There will be an additional, probably unknown, error due to local deviation of the vertical. It is not unusual for this to amount to 15" and in rare cases it reaches 1'. Astronomically determined position would usually be quite good enough for use as input to determine azimuth.

For position keep altitudes above 15°. Determine vertical index correction and apply it to each reading. Observing both faces is unnecessary and inconvenient. If you do observe both do not mean any observed values. There is no dip correction. Use the altitude correction for stars, and for sunsights apply the semi-diameter from the graph as well.

If you want both azimuth and position line from the same body, take separate sights for horizontal and vertical readings. Accuracy will suffer if you try to do both simultaneously.

Judging accuracy — The above discussion suggests optimal procedures but the effects of errors must be assessed in every instance. It is one of the significant benefits of a programmed solution that error investigation is easy: merely introduce a small change and watch what happens. For example, if you think the maximum error in latitude might be 1' then change the value in the memory by this amount and recompute to see how much the azimuth is affected. In this manner check what 20" in dec and 30" in GHA (which is the same as 30" in long or 2 seconds of time) would do to the azimuth. 20" and 30" are extremes for the Merlin sun almanac - the stars should be better.

T.M. bearing — The astronomical ("true") azimuth may be converted to transverse mercator grid bearing by adding grid convergence where:

$$\tan(\text{gr. conv}) = \tan(\text{long CM} - \text{long}) \cdot \sin \text{lat}$$

in which long CM is the longitude of the central meridian of the zone. Sign conventions are to be observed. In the UTM and AMG systems the nearest CM can be deduced by knowing that the edges of the 6° zones are at longitudes evenly divisible by 6.

Example: Find the UTM grid convergence at 30° 14' 50" S, 149° 22' 10" W.

150 is divisible by 6 so the central meridian is 147°.

$$\tan \text{conv} = \tan(+2^\circ\, 22'\, 10'') \cdot \sin(-30^\circ\, 14'\, 50'')$$

$$\text{conv} = -1^\circ\, 11'\, 38''.7$$

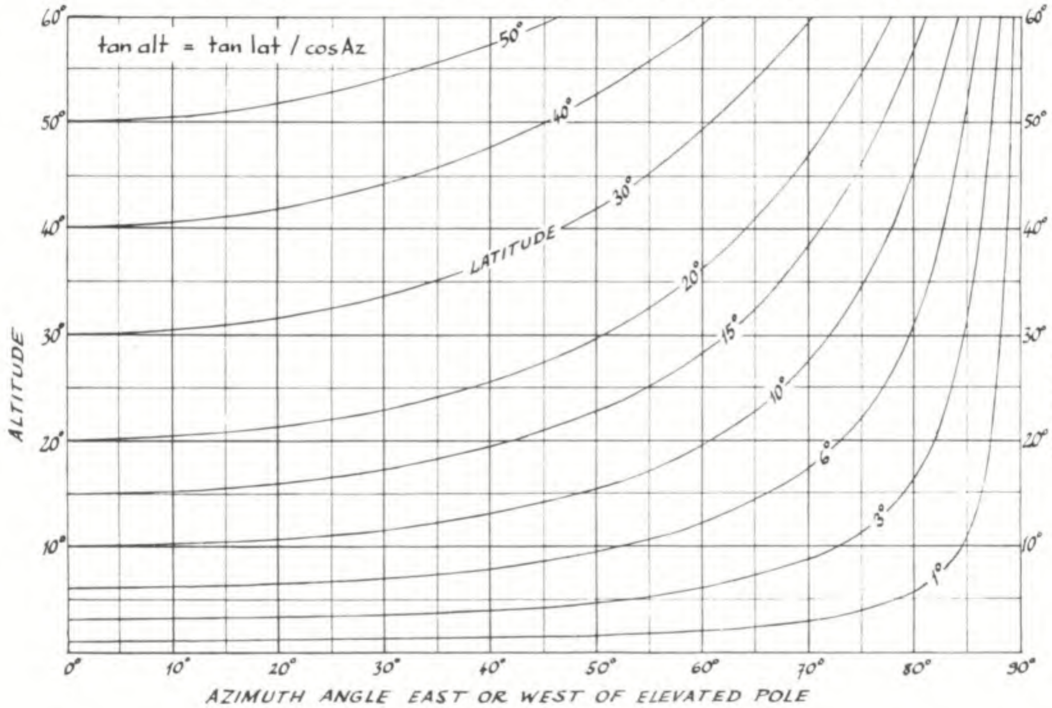
Thus UTM grid bearing is 1° 11' 38".7 less than astronomical at this place.

Bibliography

Bennett, G.G. and Freislich, J.G. Field astronomy for surveyors, New South Wales University, Sydney, 1980

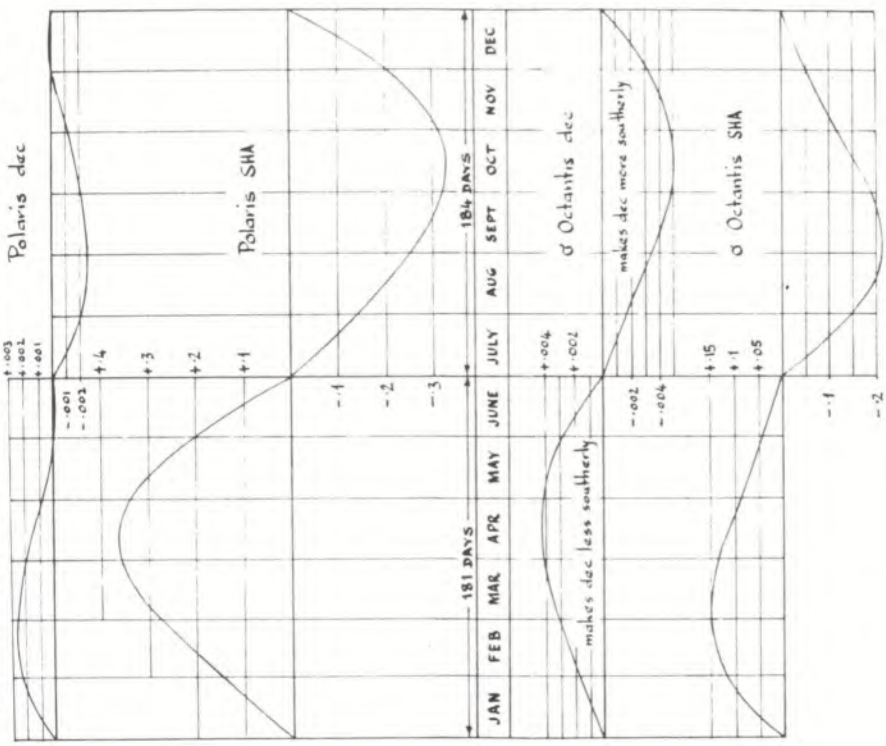
Robbins, A.R. Field and geodetic astronomy, Military Engineering Volume XIII - Part IX, Ministry of Defence, Great Britain, 1976.

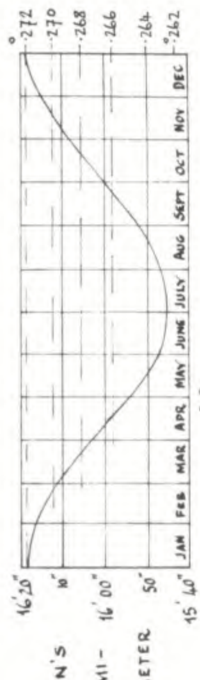
Sketch a line for your latitude. Read off combinations of altitude and azimuth angle where elongation occurs.



3-6

Corrections to pole star coordinates interpolated from Annex B, in DEGREES.





3-5

APPENDIX 4

CELESTIAL NAVIGATION ON LAND

Equipment

In general the appropriate instrument is a marine sextant with an artificial horizon. However there are some other possibilities.

In skilled hands a theodolite is convenient. A theodolite and a quality metal sextant are constructed to comparable precision but the theodolite telescope is of much higher magnification. This permits greater pointing accuracy and better determination of index error. The instrument is levelled on a tripod and the horizon is, in effect, built in. For altitudes greater than about 35 degrees special eyepiece fittings are needed.

A theodolite is around five times the cost, weight, and bulk of a sextant. Moreover in use there are traps for the inexperienced. If you have to carry a theodolite for other survey purposes then use it for position finding. Otherwise, even if you are competent, you would probably be better off with a marine sextant. By taking observations to opposed pairs of stars you will, in good conditions, obtain a fix to the same precision as with a theodolite.

A bubble (aircraft) sextant is less useful. These instruments have a circular bubble built into the optics. To take a reading the body is made to appear in the centre of the bubble. The trouble is that the bubble indicates not the true local horizontal but the resultant of the acceleration of gravity and accelerations from the observer's unsteady hand. The errors are unacceptable. They would be improved by setting the instrument on a camera tripod or perhaps an adjustable staff. The bubble sextant's advantage is independence of natural or artificial horizons and no limits to altitude.

Marine sextants are readily available at a range of prices and are quite portable. There is a pocket type (with lower accuracy) which might be appropriate if weight is critical. With a standard marine sextant and artificial horizon altitudes cannot be measured beyond 60 degrees. This is not serious: 87% of the visible sky is below 60 degrees.

Whichever instrument you choose you must be competent in its maintenance and adjustment. Any number of reference books are available.

An artificial horizon is a level reflecting surface. Traditionally and perhaps ideally this is a dish of mercury. For sunsights a pan of water succeeds if there is no breeze. Engine oil is steadier and the smaller the pan the quicker it will settle between puffs. Water and oil work for star sights but only the brightest stars are satisfactorily reflected. Use a pan with a blackened interior surface. To keep the wind from ruffling the surface a cover can be used but its glass must be optically flat. Stretching clear plastic food wrapper over the pan works with oil but fogs with water and at night the film gives a stronger reflection than the liquid causing error.

An alternative to liquid is a levelled mirror. It can be set horizontal using three wooden wedges and a spirit level. A carpenter's line level is just barely good enough. The mirror is the best system for backyard practice but any unflatness or mislevellment will cause a systematic error in position. It can be applied in earnest providing the glass is truly flat. Sometimes a piece of high quality looking glass is good enough. It may be tested by taking a large number of observations with several relevellings from a known position.

The celestial navigator needs maps that show latitude and longitude. Suitable topographic maps are published by governments to scales between 1 to 100 000 and 1 to 1 000 000. Air navigation charts may also be available. Topographic maps are usually covered with a reference grid of squares which is not useful. Latitude and longitude are indicated by edge ticks. You need a ruler to connect them. Like the ocean navigator you also need a square protractor - and a clock, a short wave radio, and a compass.

Observations

Learners will find it very much easier to start with the sun rather than stars.

Set the pan (artificial horizon) on the ground or on a box or a stump. Place yourself so you can see the sun's reflection in the liquid - dazzling you.

Select some suitable filters on the sextant and sight the image in the pan. Release the index arm and slide it forward until a second image of the sun appears in the telescope. If this does not happen - assuming the upper filter is not too dark - it will be because you are not holding the instrument vertical or you are pointing it too much to the right and thus looking too much past the horizon glass and not seeing the reflection in the silvered part.

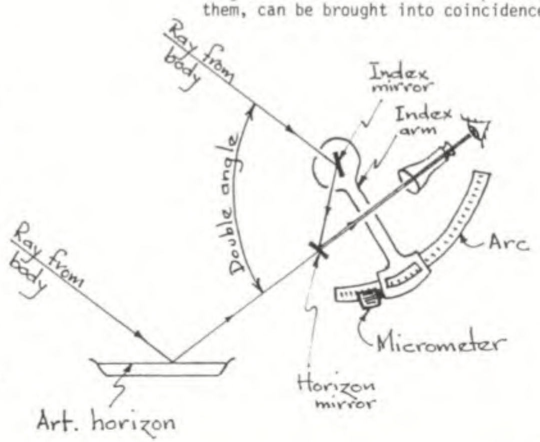
The remedy is to ROTATE the instrument about the telescope axis and WAVE it from right to left. At the same time you have to move the index arm back and forth and the whole time you have to keep the pan image in view. The sketch shows what you are aiming for.

Most people find it quite difficult at first. Read the last paragraph again. Persist. After a while you'll get the knack. When both images are in the field of view clamp the index arm. Experiment a little by ROTATING the sextant about the telescope axis and WAVING it left and right. Use the micrometer knob to superimpose the two images. Note the GMT of the moment of superimposition.

For star sights make sure the sextant optics are clean. Stand comfortably so that you can see the reflection in the pan (or mirror). Set the sextant arc near zero, look up and sight the star in the sky through the telescope. There will be two images close together.

Unclamp the arm and slide it forward while simultaneously lowering the sextant. You have to keep one image in view all the time. Continue lowering the sextant till you see the image in the pan as well. This procedure is known as "bringing down" the star. It is often recommended for sailors but it only works in calm conditions. On land you have to use it in order to make sure the star you see via the index mirror is the same one you are viewing in the pan. You can't afford to lose sight of it on the way down. 49

Superimpose the two images and note the time. For repeat sights leave the sextant set and look into the pan: the two images will still be there, as long as not too much time has passed, and after rotating and waving to find them, can be brought into coincidence again.



With practice observing with an artificial horizon is no problem. It is easier than on a small boat and more accurate too. Remember heat waves bend light so don't look over a car body or a campfire.

Reduction

To the sextant reading apply the index correction, then halve the angle, then apply the main correction for stars. The star correction is for the sun as well if you superimposed the two images.

There is no dip correction.

Compute and plot as usual.

In good conditions with good gear you should be able to achieve a consistency around half a mile in the intercepts of multiple sights.

ANNEX A

SELECTED SHORT WAVE RADIO TIME SIGNALS

Call sign	Frequency MHz	Power kW	Second Pulse (ms)	Minute Pulse (ms)	Transmission Time and Remarks (All times GMT)
JJY Sanwa Japan	2.5, 5,8 10, 15	2	8	8	24 hours with silence 35^m to 39^m past each hour. Minute warning beep of 655ms during last second of each minute.
LOL B.Aires Argentina	5 10 15	2	5	5	11^h-12^h, 14^h-15^h, 17^h-18^h, 20^h-21^h, 23^h-24^h Pulse for 59^s omitted every minute.
MSF Rugby England	2.5 5 10	5	5	100	24 hours: 5 minutes on/5 minutes silence alternating from 00^h 00^m.
RWM Moscow USSR	4.996 9.996 14.996	5 5 8	100	500	24 hours, each hour from 10^m-20^m and 40^m-50^m.
VNG Lyndhurst Australia	4.5 7.5 12	10	50	500	← 09^h 45^m to 21^h 30^m ← 24 hours except 22^h 30^m - 22^h 45^m ← 21^h 45^m to 09^h 30^m Pulses are 5 ms for 55^s to 58^s and 50^s to 58^s every fifth minute. 59^s marker omitted.
WWV Fort Collins USA	2.5 5, 10, 15 20	2.5 10 2.5	5	800	24 hours 29^s and 59^s pulses omitted. Male voice every minute. Atlantic storm info 8^m to 8^m 45^s Pacific storm info 10^m to 10^m 45^s
WWVH Hawaii USA	2.5 5, 10, 15	5 10	5	800	24 hours 29^s and 59^s pulses omitted. Female voice every minute. Pacific storm info 48^m to 48^m 45^s
Y3S Nauen Germany	4.525	5	100	500	24 hours except 08^h 15^m to 09^h 45^m.
ZUO Olifantsfontein S.Africa	2.5, 5	4	5	500	2.5 MHz is from 18^h to 04^h. 5 MHz is 24 hours.

For full list see Admiralty List of Radio Signals, Volume 5. Optimal long distance reception is most likely in 7 to 15 MHz range. Station power is of secondary importance.

ANNEX B

STARS IN ORDER OF SHA (JAN 1990)

MAG	STAR	DEC	SHA
2.2	Alpheratz	29.0	358.0
2.4	Ankaa	-42.4	353.5
2.5	Schedar	56.5	350.0
2.2	Diphda	-18.0	349.2
0.6	Achernar	-57.3	335.7
2.2	Hamal	23.4	328.3
2.1	Polaris	89.2	324.6
3.1	Acamar	-40.3	315.5
2.8	Menkar	4.1	314.6
1.9	Mirfak	49.8	309.1
1.1	Aldebaran	16.5	291.2
0.3	Rigel	-8.2	281.5
0.2	Capella	46.0	281.0
1.7	Bellatrix	6.3	278.8
1.8	Elnath	28.6	278.6
1.8	Alnilam	-1.2	276.1
1.0	Betelgeuse	7.4	271.3
-0.9	Canopus	-52.7	264.1
-1.6	Sirius	-16.7	258.8
1.6	Adhara	-29.0	255.4
0.5	Procyon	5.3	245.3
1.2	Pollux	28.1	243.8
1.7	Avior	-59.5	234.4
2.2	Suhail	-43.4	223.1
1.8	Miaplacidus	-69.7	221.7
2.2	Alphard	-8.6	218.2
1.3	Regulus	12.0	208.0
2.0	Dubhe	61.8	194.2
2.2	Denebola	14.6	182.9
2.8	Gienah	-17.5	176.2
1.1	Acrux	-63.0	173.5
1.6	Gacrux	-57.1	172.3
1.7	Alioth	56.0	166.6
1.2	Spica	-11.1	158.8
1.9	Alkaid	49.4	153.2
0.9	Hadar	-60.3	149.2
2.3	Menkent	-36.3	148.5
0.2	Arcturus	19.2	146.2
0.1	Rigil Kent.	-60.8	140.3
2.9	Zuben'ubi	-16.0	137.4
2.2	Kochab	74.2	137.3
2.3	Alphecca	26.7	126.4
1.2	Antares	-26.4	112.8
1.9	Atria	-69.0	108.1
2.6	Sabik	-15.7	102.6
1.7	Shaula	-37.1	96.8
2.1	Raselhague	12.6	96.4
2.4	Eltanin	51.5	90.9
2.0	Kaus Aust.	-34.4	84.1
0.1	Vega	38.8	80.9
2.1	Nunki	-26.3	76.3
0.9	Altair	8.8	62.4
2.1	Peacock	-56.8	53.8
1.3	Deneb	45.2	49.7
2.5	Enif	9.8	34.1
2.2	Al Na'ir	-47.0	28.1
1.3	Formalhaut	-29.7	15.7
2.6	Markab	15.2	13.9

This list is for star identification purposes.

DECLINATION IN DEGREES + = NORTH - = SOUTH

MAG	STAR		1984	1985		1986		1987		1988	
			JUL	JAN	JUL	JAN	JUL	JAN	JUL	JAN	JUL
3.1	Acamar	-40	.363	.367	.359	.363	.354	.358	.349	.354	.345
0.6	Achernar	-57	.312	.319	.306	.313	.300	.307	.295	.301	.289
1.1	Acrux	-63	.017	.010	.023	.016	.029	.022	.035	.028	.041
1.6	Adhara	-28	.949	.949	.950	.950	.951	.951	.952	.953	.953
1.1	Aldebaran	+16	.479	.481	.481	.484	.484	.486	.487	.489	.489
1.7	Alioth	+56	.050	.037	.044	.031	.038	.025	.032	.019	.026
1.9	Alkaid	+49	.395	.384	.390	.378	.384	.373	.378	.367	.373
2.2	Al Na'ir	-47	.035	.039	.030	.034	.025	.029	.019	.024	.014
1.8	Alnilam	-1	.210	.210	.208	.209	.207	.208	.206	.207	.206
2.2	Alphard	-8	.589	.591	.594	.595	.598	.600	.603	.605	.608
2.3	Alphecca	+26	.768	.762	.764	.758	.760	.754	.756	.750	.752
2.2	Alpheratz	+29	.001	.008	.007	.014	.013	.021	.019	.027	.025
0.9	Altair	+8	.825	.826	.827	.828	.830	.831	.832	.834	.835
2.4	Ankaa	-42	.388	.393	.382	.387	.376	.381	.369	.374	.363
1.2	Antares	-26	.400	.400	.403	.403	.406	.405	.409	.408	.411
0.2	Arcturus	+19	.265	.259	.260	.253	.255	.248	.249	.243	.244
1.9	Atria	-69	.004	.001	.006	.003	.009	.005	.011	.007	.013
1.7	Avior	-59	.459	.457	.462	.460	.465	.463	.469	.466	.472
1.7	Bellatrix	+6	.337	.337	.339	.339	.340	.340	.341	.341	.342
1.0	Betelgeuse	+7	.406	.406	.407	.407	.407	.407	.408	.407	.408
-0.9	Canopus	-52	.685	.686	.685	.686	.685	.686	.686	.687	.686
0.2	Capella	+45	.983	.987	.985	.988	.987	.990	.988	.991	.990
1.3	Deneb	+45	.221	.226	.224	.230	.228	.233	.232	.237	.236
2.2	Denebola	+14	.663	.656	.657	.650	.651	.644	.645	.638	.638
2.2	Diphda	-18	.071	.072	.065	.066	.059	.060	.053	.054	.047
2.0	Dubhe	+61	.841	.829	.836	.823	.830	.817	.824	.811	.818
1.8	Elnath	+28	.595	.597	.597	.599	.598	.600	.600	.601	.600
2.4	Eltanin	+51	.490	.488	.489	.487	.489	.487	.488	.487	.488
2.5	Enif	+9	.801	.804	.806	.809	.811	.814	.816	.819	.821
1.3	Formalhaut	-29	.704	.707	.698	.701	.693	.696	.687	.690	.681
1.6	Gacrux	-57	.029	.023	.035	.029	.041	.035	.048	.042	.054
2.8	Gienah	-17	.455	.456	.461	.462	.468	.468	.474	.474	.480
0.9	Hadar	-60	.302	.296	.308	.302	.313	.307	.319	.313	.324
2.2	Hamal	+23	.387	.393	.393	.399	.398	.404	.403	.410	.409
2.0	Kaus Aust.	-34	.394	.395	.394	.395	.394	.394	.394	.394	.393
2.2	Kochab	+74	.224	.212	.219	.207	.214	.203	.209	.198	.205
2.6	Markab	+15	.119	.124	.125	.129	.130	.135	.136	.141	.142
2.8	Menkar	+4	.029	.032	.034	.036	.039	.041	.043	.045	.047
2.3	Menkent	-36	.296	.293	.301	.298	.307	.304	.312	.309	.317
1.8	Miaplacidus	-69	.654	.650	.658	.654	.663	.658	.667	.663	.672
1.9	Mirfak	+49	.804	.812	.808	.817	.813	.821	.817	.825	.821
2.1	Nunki	-26	.318	.319	.317	.318	.316	.317	.315	.315	.313
2.1	Peacock	-56	.786	.789	.783	.786	.780	.783	.776	.779	.772
1.2	Pollux	+28	.067	.064	.065	.062	.063	.060	.061	.057	.058
0.5	Procyon	+5	.267	.265	.265	.263	.263	.261	.261	.259	.258
2.1	Raselhague	+12	.571	.569	.569	.567	.568	.566	.567	.565	.566
1.3	Regulus	+12	.046	.041	.041	.036	.036	.031	.031	.026	.025
0.3	Rigel	-8	.217	.218	.215	.216	.214	.214	.212	.213	.211
0.1	Rigil Kent.	-60	.775	.769	.780	.775	.785	.779	.790	.784	.795
2.6	Sabik	-15	.707	.708	.709	.710	.711	.712	.713	.713	.714
2.5	Schedar	+56	.446	.458	.452	.464	.458	.471	.464	.477	.471
1.7	Shaula	-37	.095	.095	.097	.096	.098	.097	.099	.098	.100
-1.6	Sirius	-16	.692	.693	.693	.694	.694	.695	.695	.696	.696
1.2	Spica	-11	.080	.081	.086	.087	.092	.093	.097	.099	.103
2.2	Suhail	-43	.369	.367	.373	.371	.377	.375	.382	.380	.386
0.1	Vega	+38	.768	.767	.768	.768	.768	.768	.769	.769	.770
2.9	Zuben'ubi	-15	.979	.979	.984	.984	.988	.989	.993	.993	.998
2.1	Polaris	+89	.188	.201	.194	.206	.199	.212	.204	.217	.209
5.5	Sigma Oct.	-89	.017	.022	.013	.018	.010	.014	.005	.010	.001

SIDEREAL HOUR ANGLE IN DEGREES

MAG	STAR		1984 JUL	1985 JAN	1985 JUL	1986 JAN	1986 JUL	1987 JAN	1987 JUL	1988 JAN	1988 JUL
3.1	Acamar	315	.589	.575	.579	.564	.568	.554	.557	.543	.547
0.6	Achernar	335	.719	.708	.708	.697	.698	.686	.687	.676	.677
1.1	Acrux	173	.575	.567	.561	.553	.547	.538	.532	.523	.516
1.6	Adhara	255	.506	.488	.495	.477	.485	.466	.474	.455	.463
1.1	Aldebaran	291	.253	.235	.238	.220	.222	.204	.206	.188	.190
1.7	Alioth	166	.663	.658	.650	.645	.637	.633	.625	.621	.613
1.9	Alkaid	153	.267	.267	.256	.256	.245	.244	.233	.233	.222
2.2	Al Na'ir	28	.184	.185	.167	.168	.149	.150	.132	.133	.114
1.8	Alnilam	276	.153	.135	.140	.122	.126	.108	.112	.094	.098
2.2	Alphard	218	.302	.287	.289	.274	.276	.261	.262	.247	.249
2.3	Alphecca	126	.491	.494	.480	.483	.468	.471	.456	.459	.444
2.2	Alpheratz	358	.108	.103	.095	.089	.081	.075	.067	.061	.052
0.9	Altair	62	.492	.497	.479	.484	.466	.470	.453	.457	.439
2.4	Ankaa	353	.623	.616	.609	.603	.595	.589	.582	.575	.568
1.2	Antares	112	.886	.889	.870	.872	.853	.855	.836	.838	.819
0.2	Arcturus	146	.262	.261	.250	.248	.237	.235	.224	.222	.211
1.9	Atria	108	.242	.256	.214	.228	.185	.199	.156	.169	.126
1.7	Avior	234	.463	.441	.459	.436	.454	.431	.448	.425	.442
1.7	Bellatrix	278	.935	.917	.921	.902	.906	.888	.891	.873	.876
1.0	Betelgeuse	271	.427	.409	.413	.394	.398	.379	.383	.364	.368
-0.9	Canopus	264	.109	.088	.104	.082	.098	.076	.091	.070	.085
0.2	Capella	281	.129	.104	.110	.084	.090	.064	.069	.043	.048
1.3	Deneb	49	.772	.781	.763	.772	.754	.763	.745	.754	.735
2.2	Denebola	182	.938	.929	.924	.915	.910	.900	.895	.886	.881
2.2	Diphda	349	.302	.294	.288	.281	.274	.267	.260	.253	.246
2.0	Dubhe	194	.313	.294	.295	.277	.277	.259	.260	.242	.243
1.8	Elnath	278	.684	.663	.668	.646	.650	.629	.633	.611	.615
2.4	Eltanin	90	.932	.947	.925	.940	.919	.934	.913	.927	.906
2.5	Enif	34	.144	.146	.131	.132	.118	.119	.104	.105	.091
1.3	Formalhaut	15	.802	.800	.788	.785	.772	.770	.757	.755	.742
1.6	Gacrux	172	.432	.425	.418	.411	.404	.396	.388	.380	.373
2.8	Gienah	176	.254	.246	.240	.232	.226	.218	.212	.204	.197
0.9	Hadar	149	.323	.323	.306	.305	.287	.286	.267	.266	.248
2.2	Hamal	328	.434	.422	.419	.407	.404	.391	.388	.376	.373
2.0	Kaus Aust.	84	.213	.218	.195	.200	.177	.181	.158	.163	.140
2.2	Kochab	137	.301	.324	.300	.323	.299	.323	.299	.323	.300
2.6	Markab	13	1.006	1.004	.993	.990	.979	.977	.966	.963	.952
2.8	Menkar	314	.641	.627	.627	.613	.613	.598	.598	.584	.584
2.3	Menkent	148	.561	.559	.546	.543	.530	.527	.513	.511	.497
1.8	Miaplacidus	221	.756	.730	.754	.728	.752	.726	.749	.723	.746
1.9	Mirfak	309	.210	.189	.192	.170	.173	.151	.153	.131	.133
2.1	Nunki	76	.422	.426	.406	.410	.389	.392	.371	.375	.354
2.1	Peacock	53	.889	.896	.867	.874	.845	.852	.823	.830	.801
1.2	Pollux	243	.919	.899	.903	.882	.886	.865	.868	.847	.851
0.5	Procyon	245	.387	.369	.373	.355	.359	.340	.344	.326	.329
2.1	Raselhague	96	.445	.450	.432	.437	.420	.424	.407	.412	.394
1.3	Regulus	208	.121	.106	.106	.092	.091	.077	.077	.062	.062
0.3	Rigel	281	.562	.545	.549	.532	.536	.518	.522	.505	.509
0.1	Rigil Kent.	140	.367	.369	.347	.349	.327	.329	.306	.307	.285
2.6	Sabik	102	.627	.630	.612	.615	.596	.599	.580	.583	.564
2.5	Schedar	350	.102	.094	.088	.080	.073	.065	.058	.049	.041
1.7	Shaula	96	.860	.865	.842	.847	.824	.828	.805	.809	.786
-1.6	Sirius	258	.894	.876	.882	.864	.869	.851	.857	.839	.845
1.2	Spica	158	.910	.905	.896	.891	.881	.877	.867	.862	.852
2.2	Suhail	223	.153	.136	.144	.127	.134	.117	.124	.107	.114
0.1	Vega	80	.892	.902	.883	.893	.874	.884	.865	.875	.856
2.9	Zuben'ubi	137	.497	.497	.483	.482	.468	.467	.452	.451	.437
2.1	Polaris	325	1.340	.893	1.137	.671	.912	.427	.665	.160	.390
5.5	Sigma Oct.	45	1.200	1.596	.910	1.302	.623	1.014	.346	.737	.077

DECLINATION IN DEGREES + = NORTH - = SOUTH

MAG	STAR		1988 JUL	1989 JAN	1989 JUL	1990 JAN	1990 JUL	1991 JAN	1991 JUL	1992 JAN	1992 JUL
3.1	Acamar	-40	.345	.349	.341	.345	.337	.341	.333	.338	.330
0.6	Achernar	-57	.289	.296	.283	.290	.278	.285	.273	.280	.268
1.1	Acrux	-63	.041	.034	.047	.040	.053	.046	.059	.052	.065
1.6	Adhara	-28	.953	.955	.955	.956	.957	.959	.960	.961	.962
1.1	Aldebaran	+16	.489	.491	.491	.493	.492	.494	.494	.495	.495
1.7	Alioth	+55	1.026	1.013	1.020	1.008	1.015	1.002	1.009	.996	1.004
1.9	Alkaid	+49	.373	.362	.368	.356	.362	.351	.358	.347	.353
2.2	Al Na'ir	-46	1.014	1.018	1.008	1.013	1.003	1.007	.997	1.002	.992
1.8	Alnilam	-1	.206	.206	.205	.206	.205	.206	.206	.206	.206
2.2	Alphard	-8	.608	.610	.613	.615	.618	.620	.623	.625	.628
2.3	Alphecca	+26	.752	.746	.749	.743	.746	.740	.743	.737	.740
2.2	Alpheratz	+29	.025	.033	.031	.039	.037	.045	.043	.051	.049
0.9	Altair	+8	.835	.837	.838	.840	.842	.843	.845	.847	.849
2.4	Ankaa	-42	.363	.368	.357	.362	.351	.356	.345	.351	.340
1.2	Antares	-26	.411	.410	.413	.412	.415	.414	.417	.415	.418
0.2	Arcturus	+19	.244	.238	.239	.233	.235	.228	.230	.224	.226
1.9	Atria	-69	.013	.009	.014	.011	.016	.012	.017	.013	.018
1.7	Avior	-59	.472	.470	.476	.474	.480	.478	.484	.482	.488
1.7	Bellatrix	+6	.342	.342	.343	.343	.343	.343	.343	.343	.343
1.0	Betelgeuse	+7	.408	.407	.408	.407	.407	.407	.407	.406	.406
-0.9	Canopus	-52	.686	.687	.687	.689	.688	.690	.690	.691	.691
0.2	Capella	+45	.990	.992	.990	.993	.991	.993	.991	.994	.992
1.3	Deneb	+45	.236	.242	.240	.246	.244	.250	.249	.255	.253
2.2	Denebola	+14	.638	.632	.632	.626	.626	.620	.620	.614	.615
2.2	Diphda	-18	.047	.048	.041	.042	.035	.036	.029	.031	.024
2.0	Dubhe	+61	.818	.805	.812	.799	.806	.793	.800	.787	.794
1.8	Elnath	+28	.600	.602	.601	.602	.601	.602	.602	.602	.602
2.4	Eltanin	+51	.488	.487	.489	.487	.489	.488	.490	.488	.491
2.5	Enif	+9	.821	.824	.826	.830	.831	.835	.837	.840	.842
1.3	Formalhaut	-29	.681	.684	.675	.678	.669	.672	.663	.666	.657
1.6	Gacrux	-57	.054	.048	.060	.054	.066	.059	.071	.065	.077
2.8	Gienah	-17	.480	.480	.486	.486	.492	.492	.498	.498	.503
0.9	Hadar	-60	.324	.318	.329	.323	.334	.328	.339	.332	.343
2.2	Hamal	+23	.409	.415	.414	.420	.419	.424	.423	.429	.428
2.0	Kaus Aust.	-34	.393	.393	.392	.392	.391	.391	.390	.389	.388
2.2	Kochab	+74	.205	.193	.201	.189	.197	.185	.193	.182	.189
2.6	Markab	+15	.142	.147	.148	.153	.154	.159	.160	.165	.166
2.8	Menkar	+4	.047	.049	.052	.053	.055	.057	.059	.061	.062
2.3	Menkent	-36	.317	.314	.322	.319	.327	.324	.332	.328	.336
1.8	Miaplacidus	-69	.672	.668	.677	.672	.681	.677	.686	.682	.691
1.9	Mirfak	+49	.821	.828	.824	.832	.828	.835	.831	.838	.834
2.1	Nunki	-26	.313	.314	.312	.312	.310	.310	.308	.308	.305
2.1	Peacock	-56	.772	.775	.769	.771	.764	.767	.760	.763	.756
1.2	Pollux	+28	.058	.054	.055	.051	.052	.048	.049	.045	.045
0.5	Procyon	+5	.258	.256	.255	.253	.252	.250	.249	.247	.246
2.1	Raselhague	+12	.566	.565	.566	.565	.566	.565	.566	.565	.566
1.3	Regulus	+12	.025	.020	.020	.014	.014	.009	.009	.003	.003
0.3	Rigel	-8	.211	.212	.210	.211	.209	.210	.209	.210	.209
0.1	Rigil Kent.	-60	.795	.789	.799	.793	.804	.798	.808	.801	.811
2.6	Sabik	-15	.714	.714	.715	.715	.716	.716	.716	.716	.717
2.5	Schedar	+56	.471	.483	.477	.489	.482	.494	.488	.500	.494
1.7	Shaula	-37	.100	.099	.100	.099	.100	.099	.100	.099	.100
-1.6	Sirius	-16	.696	.697	.697	.699	.699	.700	.701	.702	.703
1.2	Spica	-11	.103	.105	.109	.110	.114	.116	.120	.121	.124
2.2	Suhail	-43	.386	.384	.391	.389	.396	.394	.401	.399	.405
0.1	Vega	+38	.770	.770	.771	.772	.773	.773	.774	.775	.776
2.9	Zuben'ubi	-15	.998	.998	1.002	1.002	1.006	1.006	1.010	1.010	1.013
2.1	Polaris	+89	.209	.222	.214	.227	.219	.231	.223	.235	.227
5.5	Sigma Oct.	-88	1.001	1.005	.996	1.001	.992	.996	.987	.991	.982

SIDEREAL HOUR ANGLE IN DEGREES

MAG	STAR		1988 JUL	1989 JAN	1989 JUL	1990 JAN	1990 JUL	1991 JAN	1991 JUL	1992 JAN	1992 JUL
3.1	Acamar	315	.547	.533	.536	.522	.526	.513	.517	.503	.507
0.6	Achernar	335	.677	.666	.667	.656	.658	.647	.649	.639	.641
1.1	Acrux	173	.516	.507	.500	.491	.483	.474	.467	.458	.451
1.6	Adhara	255	.463	.444	.452	.434	.441	.423	.431	.413	.421
1.1	Aldebaran	291	.190	.172	.174	.156	.159	.141	.144	.126	.129
1.7	Alioth	166	.613	.609	.601	.597	.590	.587	.580	.577	.570
1.9	Alkaid	153	.222	.222	.212	.212	.202	.202	.192	.193	.183
2.2	Al Na'ir	28	.114	.115	.097	.099	.081	.083	.065	.067	.050
1.8	Alnilam	276	.098	.079	.084	.065	.070	.052	.056	.039	.043
2.2	Alphard	218	.249	.233	.235	.220	.221	.206	.208	.194	.196
2.3	Alphecca	126	.444	.447	.433	.436	.421	.425	.411	.414	.400
2.2	Alpheratz	357	1.052	1.046	1.038	1.032	1.023	1.018	1.009	1.004	.996
0.9	Altair	62	.439	.443	.426	.430	.413	.417	.400	.405	.388
2.4	Ankaa	353	.568	.562	.555	.549	.542	.536	.530	.524	.518
1.2	Antares	112	.819	.821	.802	.804	.785	.788	.769	.772	.753
0.2	Arcturus	146	.211	.209	.198	.196	.185	.184	.173	.172	.161
1.9	Atria	108	.126	.139	.096	.110	.067	.081	.038	.053	.010
1.7	Avior	234	.442	.419	.436	.413	.430	.407	.424	.401	.418
1.7	Bellatrix	278	.876	.858	.861	.843	.847	.829	.833	.815	.819
1.0	Betelgeuse	271	.368	.349	.353	.334	.338	.320	.324	.306	.310
-0.9	Canopus	264	.085	.063	.079	.057	.073	.051	.067	.045	.061
0.2	Capella	280	1.048	1.023	1.028	1.002	1.008	.982	.988	.963	.969
1.3	Deneb	49	.735	.744	.726	.734	.716	.725	.706	.715	.697
2.2	Denebola	182	.881	.872	.867	.858	.853	.844	.840	.831	.827
2.2	Diphda	349	.246	.239	.233	.226	.219	.212	.207	.200	.194
2.0	Dubhe	194	.243	.225	.226	.209	.211	.194	.196	.179	.182
1.8	Elnath	278	.615	.594	.598	.576	.580	.559	.564	.543	.547
2.4	Eltanin	90	.906	.921	.900	.915	.893	.908	.887	.902	.881
2.5	Enif	34	.091	.092	.077	.078	.064	.065	.051	.052	.038
1.3	Formalhaut	15	.742	.740	.727	.725	.712	.710	.698	.697	.685
1.6	Gacrux	172	.373	.364	.357	.349	.341	.333	.325	.317	.309
2.8	Gienah	176	.197	.189	.183	.175	.169	.161	.155	.147	.141
0.9	Hadar	149	.248	.246	.227	.226	.207	.206	.187	.186	.168
2.2	Hamal	328	.373	.360	.357	.344	.342	.329	.326	.314	.312
2.0	Kaus Aust.	84	.140	.144	.121	.126	.103	.108	.086	.091	.069
2.2	Kochab	137	.300	.324	.301	.326	.303	.328	.306	.331	.309
2.6	Markab	13	.952	.949	.938	.935	.924	.922	.911	.909	.898
2.8	Menkar	314	.584	.569	.569	.555	.555	.541	.541	.527	.528
2.3	Menkent	148	.497	.494	.480	.477	.463	.461	.447	.445	.431
1.8	Miaplacidus	221	.746	.719	.742	.715	.738	.711	.734	.706	.729
1.9	Mirfak	309	.133	.111	.113	.091	.093	.071	.073	.052	.054
2.1	Nunki	76	.354	.358	.337	.341	.320	.325	.304	.309	.288
2.1	Peacock	53	.801	.809	.780	.787	.759	.767	.739	.747	.720
1.2	Pollux	243	.851	.830	.834	.813	.817	.797	.801	.781	.786
0.5	Procyon	245	.329	.311	.315	.296	.300	.282	.286	.268	.273
2.1	Raselhague	96	.394	.399	.381	.386	.369	.374	.356	.362	.345
1.3	Regulus	208	.062	.047	.047	.033	.032	.018	.019	.005	.005
0.3	Rigel	281	.509	.491	.496	.478	.483	.465	.470	.453	.458
0.1	Rigil Kent.	140	.285	.286	.263	.264	.241	.243	.220	.222	.199
2.6	Sabik	102	.564	.567	.548	.551	.533	.536	.518	.521	.503
2.5	Schedar	349	1.041	1.033	1.025	1.016	1.009	1.000	.993	.984	.977
1.7	Shaula	96	.786	.790	.767	.771	.749	.753	.731	.736	.713
-1.6	Sirius	258	.845	.826	.832	.814	.820	.802	.808	.791	.797
1.2	Spica	158	.852	.847	.837	.833	.823	.818	.809	.804	.795
2.2	Suhail	223	.114	.096	.103	.086	.093	.075	.083	.065	.073
0.1	Vega	80	.856	.865	.846	.856	.837	.847	.828	.838	.819
2.9	Zuben'ubi	137	.437	.436	.421	.420	.406	.405	.391	.391	.377
2.1	Polaris	323	2.390	1.878	2.103	1.574	1.802	1.260	1.494	.942	1.180
5.5	Sigma Oct.	44	1.077	1.476	.828	1.230	.596	1.001	.381	.788	.176

DECLINATION IN DEGREES + = NORTH - = SOUTH

MAG	STAR		1992 JUL	1993 JAN	1993 JUL	1994 JAN	1994 JUL	1995 JAN	1995 JUL	1996 JAN	1996 JUL
3.1	Acamar	-40	.330	.335	.326	.331	.323	.328	.320	.325	.317
0.6	Achernar	-57	.268	.276	.264	.271	.259	.267	.255	.262	.250
1.1	Acrux	-63	.065	.057	.070	.063	.075	.068	.080	.073	.085
1.6	Adhara	-28	.962	.963	.964	.965	.966	.967	.968	.969	.970
1.1	Aldebaran	+16	.495	.497	.496	.498	.497	.499	.499	.500	.500
1.7	Alioth	+55	1.004	.991	.999	.986	.994	.981	.989	.977	.984
1.9	Alkaid	+49	.353	.342	.348	.338	.344	.333	.340	.329	.336
2.2	Al Na'ir	-46	.992	.996	.987	.991	.982	.986	.977	.982	.972
1.8	Alnilam	-1	.206	.207	.206	.207	.206	.207	.206	.207	.206
2.2	Alphard	-8	.628	.630	.633	.635	.637	.639	.642	.643	.646
2.3	Alphecca	+26	.740	.735	.738	.732	.735	.730	.733	.727	.730
2.2	Alpheratz	+29	.049	.056	.054	.062	.059	.067	.064	.072	.069
0.9	Altair	+8	.849	.850	.852	.853	.855	.856	.858	.859	.860
2.4	Ankaa	-42	.340	.345	.335	.340	.329	.335	.324	.330	.319
1.2	Antares	-26	.418	.417	.419	.418	.421	.419	.422	.421	.424
0.2	Arcturus	+19	.226	.220	.222	.216	.218	.212	.214	.208	.210
1.9	Atria	-69	.018	.014	.019	.015	.020	.016	.021	.017	.022
1.7	Avior	-59	.488	.486	.492	.490	.496	.494	.499	.497	.502
1.7	Bellatrix	+6	.343	.343	.343	.343	.343	.343	.344	.343	.344
1.0	Betelgeuse	+7	.406	.405	.405	.404	.405	.404	.404	.403	.404
-0.9	Canopus	-52	.691	.693	.693	.694	.694	.695	.695	.696	.696
0.2	Capella	+45	.992	.994	.992	.994	.992	.994	.992	.995	.993
1.3	Deneb	+45	.253	.259	.257	.263	.261	.267	.265	.270	.268
2.2	Denebola	+14	.615	.608	.609	.603	.604	.598	.599	.593	.594
2.2	Diphda	-18	.024	.026	.019	.020	.014	.016	.009	.011	.004
2.0	Dubhe	+61	.794	.782	.789	.776	.783	.771	.778	.766	.773
1.8	Elnath	+28	.602	.602	.601	.602	.601	.603	.602	.603	.602
2.4	Eltanin	+51	.491	.489	.491	.490	.492	.490	.493	.491	.493
2.5	Enif	+9	.842	.845	.847	.850	.852	.855	.856	.859	.861
1.3	Formalhaut	-29	.657	.660	.652	.655	.647	.650	.641	.645	.637
1.6	Gacrux	-57	.077	.070	.082	.076	.087	.081	.092	.086	.097
2.8	Gienah	-17	.503	.503	.509	.509	.514	.514	.519	.519	.524
0.9	Hadar	-60	.343	.336	.347	.341	.351	.345	.355	.349	.360
2.2	Hamal	+23	.428	.433	.432	.437	.436	.441	.440	.445	.444
2.0	Kaus Aust.	-34	.388	.388	.387	.386	.386	.385	.384	.384	.384
2.2	Kochab	+74	.189	.178	.186	.175	.182	.171	.179	.168	.176
2.6	Markab	+15	.166	.171	.171	.176	.177	.181	.182	.186	.187
2.8	Menkar	+4	.062	.064	.066	.067	.069	.070	.072	.073	.075
2.3	Menkent	-36	.336	.333	.340	.337	.345	.341	.349	.345	.353
1.8	Miaplacidus	-69	.691	.687	.696	.692	.700	.696	.704	.700	.708
1.9	Mirfak	+49	.834	.841	.836	.844	.839	.846	.842	.849	.845
2.1	Nunki	-26	.305	.305	.303	.303	.301	.301	.299	.300	.298
2.1	Peacock	-56	.756	.759	.752	.755	.749	.752	.745	.748	.742
1.2	Pollux	+28	.045	.041	.042	.038	.039	.035	.036	.033	.034
0.5	Procyon	+5	.246	.243	.243	.241	.240	.238	.237	.235	.235
2.1	Raselhague	+12	.566	.565	.567	.565	.567	.565	.567	.565	.567
1.3	Regulus	+11	1.003	.998	.998	.993	.993	.988	.988	.983	.984
0.3	Rigel	-8	.209	.210	.209	.210	.208	.209	.208	.209	.207
0.1	Rigil Kent.	-60	.811	.805	.815	.809	.819	.812	.822	.816	.826
2.6	Sabik	-15	.717	.717	.717	.717	.718	.717	.718	.718	.719
2.5	Schedar	+56	.494	.505	.499	.510	.504	.515	.509	.520	.514
1.7	Shaula	-37	.100	.099	.100	.098	.100	.098	.100	.098	.100
-1.6	Sirius	-16	.703	.704	.705	.706	.707	.708	.708	.709	.709
1.2	Spica	-11	.124	.126	.129	.130	.134	.135	.138	.139	.143
2.2	Suhail	-43	.405	.403	.410	.408	.414	.412	.418	.416	.422
0.1	Vega	+38	.776	.777	.778	.778	.780	.780	.781	.781	.782
2.9	Zuben'ubi	-16	.013	.013	.017	.017	.020	.020	.024	.023	.027
2.1	Polaris	+89	.227	.239	.231	.243	.235	.247	.239	.250	.242
5.5	Sigma Oct.	-88	.982	.987	.978	.982	.973	.978	.969	.974	.966

SIDEREAL HOUR ANGLE IN DEGREES

MAG	STAR		1992 JUL	1993 JAN	1993 JUL	1994 JAN	1994 JUL	1995 JAN	1995 JUL	1996 JAN	1996 JUL
3.1	Acamar	315	.507	.494	.499	.486	.490	.477	.482	.469	.474
0.6	Achernar	335	.641	.631	.633	.623	.625	.616	.618	.608	.610
1.1	Acrux	173	.451	.442	.435	.427	.421	.413	.407	.399	.393
1.6	Adhara	255	.421	.403	.411	.393	.401	.384	.392	.375	.383
1.1	Aldebaran	291	.129	.111	.115	.097	.101	.084	.088	.071	.075
1.7	Alioth	166	.570	.567	.561	.558	.551	.549	.542	.539	.533
1.9	Alkaid	153	.183	.184	.174	.175	.165	.167	.157	.158	.149
2.2	Al Na'ir	27	1.050	1.052	1.035	1.038	1.021	1.024	1.008	1.011	.994
1.8	Alnilam	275	1.043	1.026	1.031	1.014	1.019	1.002	1.007	.991	.996
2.2	Alphard	218	.196	.181	.184	.169	.172	.158	.161	.147	.150
2.3	Alphecca	126	.400	.404	.390	.394	.380	.384	.371	.375	.361
2.2	Alpheratz	357	.996	.990	.982	.977	.970	.965	.958	.953	.946
0.9	Altair	62	.388	.393	.376	.381	.365	.370	.353	.359	.343
2.4	Ankaa	353	.518	.513	.507	.502	.496	.491	.485	.480	.474
1.2	Antares	112	.753	.756	.738	.741	.723	.727	.709	.713	.695
0.2	Arcturus	146	.161	.161	.150	.150	.139	.139	.129	.129	.118
1.9	Atria	107	1.010	1.025	.984	.999	.958	.974	.933	.949	.909
1.7	Avior	234	.418	.395	.412	.389	.406	.384	.401	.379	.396
1.7	Bellatrix	278	.819	.801	.806	.788	.793	.776	.781	.764	.769
1.0	Betelgeuse	271	.310	.292	.297	.279	.284	.266	.272	.254	.260
-0.9	Canopus	264	.061	.040	.056	.034	.050	.029	.045	.024	.040
0.2	Capella	280	.969	.944	.951	.926	.933	.909	.916	.892	.900
1.3	Deneb	49	.697	.706	.688	.698	.680	.689	.672	.681	.664
2.2	Denebola	182	.827	.818	.814	.806	.802	.794	.791	.783	.779
2.2	Diphda	349	.194	.188	.182	.176	.171	.164	.159	.153	.148
2.0	Dubhe	194	.182	.165	.168	.152	.155	.139	.142	.126	.129
1.8	Elnath	278	.547	.527	.532	.512	.517	.497	.502	.483	.488
2.4	Eltanin	90	.881	.896	.876	.891	.870	.886	.865	.880	.860
2.5	Enif	33	1.038	1.039	1.026	1.028	1.014	1.016	1.003	1.005	.992
1.3	Formalhaut	15	.685	.684	.672	.671	.659	.659	.647	.646	.635
1.6	Gacrux	172	.309	.301	.294	.287	.280	.273	.266	.260	.253
2.8	Gienah	176	.141	.134	.128	.121	.116	.109	.104	.097	.092
0.9	Hadar	149	.168	.167	.149	.148	.131	.131	.114	.114	.097
2.2	Hamal	328	.312	.300	.298	.286	.284	.272	.271	.259	.258
2.0	Kaus Aust.	84	.069	.075	.053	.059	.037	.043	.022	.028	.007
2.2	Kochab	137	.309	.334	.312	.336	.314	.339	.316	.340	.317
2.6	Markab	13	.898	.896	.885	.884	.873	.872	.862	.861	.851
2.8	Menkar	314	.528	.514	.515	.501	.502	.489	.490	.477	.479
2.3	Menkent	148	.431	.429	.416	.414	.401	.400	.387	.386	.374
1.8	Miaplacidus	221	.729	.702	.725	.697	.720	.693	.717	.690	.714
1.9	Mirfak	308	1.054	1.033	1.036	1.015	1.019	.998	1.002	.982	.986
2.1	Nunki	76	.288	.293	.273	.278	.259	.264	.245	.250	.231
2.1	Peacock	53	.720	.728	.701	.710	.683	.693	.666	.675	.648
1.2	Pollux	243	.786	.766	.771	.751	.756	.737	.742	.723	.729
0.5	Procyon	245	.273	.255	.260	.242	.247	.230	.235	.218	.223
2.1	Raselhague	96	.345	.350	.333	.339	.322	.328	.312	.318	.301
1.3	Regulus	207	1.005	.991	.992	.979	.980	.967	.968	.955	.956
0.3	Rigel	281	.458	.441	.446	.429	.435	.418	.424	.407	.413
0.1	Rigil Kent.	140	.199	.201	.179	.182	.160	.163	.142	.145	.124
2.6	Sabik	102	.503	.507	.489	.493	.475	.480	.462	.467	.449
2.5	Schedar	349	.977	.968	.962	.953	.947	.939	.933	.926	.920
1.7	Shaula	96	.713	.718	.696	.702	.680	.686	.665	.671	.650
-1.6	Sirius	258	.797	.779	.786	.769	.775	.758	.765	.748	.755
1.2	Spica	158	.795	.791	.782	.778	.769	.766	.757	.754	.745
2.2	Suhail	223	.073	.055	.063	.046	.054	.037	.045	.028	.037
0.1	Vega	80	.819	.830	.811	.822	.803	.814	.795	.806	.788
2.9	Zuben'ubi	137	.377	.376	.363	.363	.350	.350	.337	.337	.325
2.1	Polaris	322	2.180	1.633	1.879	1.329	1.590	1.039	1.318	.767	1.056
5.5	Sigma Oct.	43	1.176	1.591	.986	1.399	.802	1.211	.619	1.022	.428

DECLINATION IN DEGREES + = NORTH - = SOUTH

MAG	STAR		1996 JUL	1997 JAN	1997 JUL	1998 JAN	1998 JUL	1999 JAN	1999 JUL	2000 JAN	2000 JUL
3.1	Acamar	-40	.317	.321	.313	.318	.310	.314	.306	.310	.301
0.6	Achernar	-57	.250	.258	.246	.253	.241	.249	.237	.244	.232
1.1	Acrux	-63	.085	.078	.090	.082	.095	.087	.100	.093	.105
1.6	Adhara	-28	.970	.970	.971	.972	.972	.972	.973	.973	.973
1.1	Aldebaran	+16	.500	.502	.502	.504	.504	.506	.506	.508	.509
1.7	Alioth	+55	.984	.972	.979	.967	.974	.962	.969	.957	.964
1.9	Alkaid	+49	.336	.325	.331	.320	.327	.316	.322	.311	.317
2.2	Al Na'ir	-46	.972	.977	.968	.973	.964	.969	.959	.964	.955
1.8	Alnilam	-1	.206	.207	.206	.206	.205	.205	.204	.204	.203
2.2	Alphard	-8	.646	.647	.650	.651	.653	.655	.657	.658	.661
2.3	Alphecca	+26	.730	.724	.727	.721	.724	.718	.721	.715	.717
2.2	Alpheratz	+29	.069	.077	.074	.082	.079	.087	.084	.092	.090
0.9	Altair	+8	.860	.861	.863	.864	.865	.866	.867	.867	.868
2.4	Ankaa	-42	.319	.325	.315	.320	.310	.315	.305	.310	.299
1.2	Antares	-26	.424	.423	.425	.425	.428	.427	.430	.429	.433
0.2	Arcturus	+19	.210	.204	.206	.200	.202	.196	.197	.191	.193
1.9	Atria	-69	.022	.018	.023	.020	.025	.022	.027	.024	.029
1.7	Avior	-59	.502	.500	.505	.503	.508	.505	.511	.508	.513
1.7	Bellatrix	+6	.344	.344	.345	.345	.346	.346	.347	.347	.348
1.0	Betelgeuse	+7	.404	.403	.404	.404	.404	.404	.405	.405	.406
-0.9	Canopus	-52	.696	.697	.696	.697	.697	.698	.697	.697	.696
0.2	Capella	+45	.993	.996	.994	.997	.995	.998	.997	1.000	.998
1.3	Deneb	+45	.268	.274	.272	.277	.275	.280	.277	.283	.280
2.2	Denebola	+14	.594	.588	.589	.583	.584	.578	.579	.573	.574
2.2	Diphda	-17	1.004	1.006	.999	1.001	.994	.996	.989	.991	.984
2.0	Dubhe	+61	.773	.761	.769	.757	.764	.752	.759	.747	.754
1.8	Elnath	+28	.602	.603	.603	.604	.604	.605	.605	.607	.606
2.4	Eltanin	+51	.493	.491	.493	.491	.492	.490	.492	.490	.491
2.5	Enif	+9	.861	.863	.865	.867	.869	.871	.873	.875	.877
1.3	Formalhaut	-29	.637	.640	.632	.635	.627	.631	.622	.626	.618
1.6	Gacrux	-57	.097	.090	.102	.095	.107	.100	.112	.105	.117
2.8	Gienah	-17	.524	.524	.529	.529	.534	.534	.539	.539	.544
0.9	Hadar	-60	.360	.353	.364	.357	.368	.362	.373	.366	.378
2.2	Hamal	+23	.444	.450	.448	.454	.452	.458	.457	.463	.462
2.0	Kaus Aust.	-34	.384	.384	.383	.383	.383	.383	.383	.383	.383
2.2	Kochab	+74	.176	.165	.172	.161	.168	.157	.164	.153	.160
2.6	Markab	+15	.187	.191	.192	.196	.196	.201	.201	.206	.206
2.8	Menkar	+4	.075	.077	.079	.080	.082	.084	.086	.088	.090
2.3	Menkent	-36	.353	.349	.357	.353	.361	.358	.366	.362	.370
1.8	Miaplacidus	-69	.708	.704	.712	.707	.716	.711	.719	.714	.722
1.9	Mirfak	+49	.845	.852	.848	.855	.851	.859	.855	.863	.858
2.1	Nunki	-26	.298	.298	.297	.297	.296	.297	.295	.296	.295
2.1	Peacock	-56	.742	.745	.739	.742	.736	.740	.734	.737	.731
1.2	Pollux	+28	.034	.030	.032	.028	.030	.026	.028	.025	.026
0.5	Procyon	+5	.235	.233	.233	.231	.231	.229	.229	.228	.228
2.1	Raselhague	+12	.567	.565	.566	.564	.565	.563	.564	.562	.563
1.3	Regulus	+11	.984	.979	.979	.975	.975	.970	.971	.966	.967
0.3	Rigel	-8	.207	.208	.206	.207	.205	.206	.204	.204	.202
0.1	Rigil Kent.	-60	.826	.819	.829	.823	.833	.827	.838	.832	.842
2.6	Sabik	-15	.719	.719	.720	.720	.721	.722	.723	.723	.725
2.5	Schedar	+56	.514	.525	.518	.530	.523	.535	.528	.540	.534
1.7	Shaula	-37	.100	.099	.100	.099	.101	.100	.102	.102	.103
-1.6	Sirius	-16	.709	.711	.710	.711	.711	.712	.712	.712	.712
1.2	Spica	-11	.143	.144	.148	.148	.152	.153	.157	.158	.162
2.2	Suhail	-43	.422	.420	.426	.423	.429	.427	.433	.430	.436
0.1	Vega	+38	.782	.782	.783	.783	.783	.783	.784	.783	.784
2.9	Zuben'ubi	-16	.027	.027	.031	.031	.034	.034	.038	.039	.043
2.1	Polaris	+89	.242	.254	.246	.258	.250	.262	.255	.267	.259
5.5	Sigma Oct.	-88	.966	.971	.962	.967	.958	.964	.955	.961	.952

SIDEREAL HOUR ANGLE IN DEGREES

MAG	STAR		1996 JUL	1997 JAN	1997 JUL	1998 JAN	1998 JUL	1999 JAN	1999 JUL	2000 JAN	2000 JUL
3.1	Acamar	315	.474	.461	.465	.452	.457	.443	.448	.434	.438
0.6	Achernar	335	.610	.600	.602	.592	.593	.583	.584	.574	.575
1.1	Acrux	173	.393	.386	.381	.374	.369	.362	.357	.350	.345
1.6	Adhara	255	.383	.366	.375	.357	.366	.349	.357	.340	.348
1.1	Aldebaran	291	.075	.058	.062	.045	.050	.033	.037	.020	.023
1.7	Alioth	166	.533	.530	.523	.520	.513	.510	.503	.499	.492
1.9	Alkaid	153	.149	.150	.140	.141	.131	.132	.121	.122	.111
2.2	Al Na'ir	27	.994	.997	.980	.983	.966	.969	.952	.954	.936
1.8	Alnilam	275	.996	.979	.985	.968	.974	.957	.962	.945	.950
2.2	Alphard	218	.150	.136	.139	.125	.128	.114	.117	.103	.105
2.3	Alphecca	126	.361	.366	.352	.356	.343	.347	.333	.337	.323
2.2	Alpheratz	357	.946	.942	.935	.930	.923	.919	.912	.907	.900
0.9	Altair	62	.343	.348	.332	.337	.321	.327	.310	.316	.299
2.4	Ankaa	353	.474	.470	.464	.459	.453	.447	.441	.436	.429
1.2	Antares	112	.695	.699	.682	.685	.668	.672	.654	.658	.640
0.2	Arcturus	146	.118	.118	.108	.108	.097	.097	.087	.086	.075
1.9	Atria	107	.909	.925	.885	.902	.862	.879	.838	.855	.814
1.7	Avior	234	.396	.374	.392	.370	.387	.365	.383	.361	.379
1.7	Bellatrix	278	.769	.752	.757	.740	.745	.728	.733	.716	.720
1.0	Betelgeuse	271	.260	.242	.248	.230	.236	.218	.223	.206	.211
-0.9	Canopus	264	.040	.019	.035	.014	.030	.009	.025	.004	.020
0.2	Capella	280	.900	.876	.883	.860	.867	.843	.850	.826	.833
1.3	Deneb	49	.664	.674	.656	.666	.649	.659	.641	.651	.634
2.2	Denebola	182	.779	.771	.768	.760	.756	.748	.745	.736	.732
2.2	Diphda	349	.148	.142	.137	.131	.126	.120	.115	.108	.103
2.0	Dubhe	194	.129	.113	.115	.099	.101	.085	.086	.070	.071
1.8	Elnath	278	.488	.469	.474	.455	.460	.441	.446	.426	.431
2.4	Eltanin	90	.860	.875	.855	.870	.849	.865	.844	.859	.839
2.5	Enif	33	.992	.994	.981	.983	.970	.972	.959	.961	.948
1.3	Formalhaut	15	.635	.635	.623	.622	.611	.610	.598	.597	.585
1.6	Gacrux	172	.253	.247	.241	.235	.229	.223	.217	.211	.205
2.8	Gienah	176	.092	.086	.081	.074	.069	.063	.058	.051	.046
0.9	Hadar	149	.097	.098	.081	.082	.066	.067	.051	.052	.035
2.2	Hamal	328	.258	.247	.246	.235	.233	.222	.221	.209	.208
2.0	Kaus Aust.	83	1.007	1.014	.993	.999	.978	.984	.963	.969	.947
2.2	Kochab	137	.317	.341	.318	.341	.318	.341	.317	.340	.316
2.6	Markab	13	.851	.850	.840	.839	.829	.827	.818	.816	.806
2.8	Menkar	314	.479	.466	.467	.454	.455	.443	.444	.431	.431
2.3	Menkent	148	.374	.373	.361	.359	.347	.346	.334	.333	.321
1.8	Miaplacidus	221	.714	.687	.711	.685	.709	.683	.707	.682	.706
1.9	Mirfak	308	.986	.966	.970	.950	.954	.934	.938	.918	.922
2.1	Nunki	76	.231	.236	.217	.223	.203	.209	.189	.195	.175
2.1	Peacock	53	.648	.658	.631	.641	.614	.623	.595	.604	.576
1.2	Pollux	243	.729	.709	.715	.696	.701	.682	.687	.667	.672
0.5	Procyon	245	.223	.206	.211	.195	.200	.183	.188	.170	.175
2.1	Raselhague	96	.301	.307	.291	.297	.281	.287	.270	.276	.260
1.3	Regulus	207	.956	.943	.944	.931	.932	.919	.920	.907	.907
0.3	Rigel	281	.413	.397	.402	.386	.392	.375	.381	.364	.370
0.1	Rigil Kent.	140	.124	.128	.107	.111	.090	.094	.074	.077	.057
2.6	Sabik	102	.449	.454	.437	.441	.424	.428	.411	.415	.398
2.5	Schedar	349	.920	.913	.907	.900	.895	.888	.883	.876	.870
1.7	Shaula	96	.650	.656	.635	.641	.619	.626	.604	.610	.588
-1.6	Sirius	258	.755	.738	.745	.728	.735	.718	.725	.708	.715
1.2	Spica	158	.745	.742	.734	.730	.722	.719	.710	.707	.698
2.2	Suhail	222	1.037	1.020	1.028	1.012	1.020	1.004	1.012	.996	1.004
0.1	Vega	80	.788	.799	.780	.791	.773	.784	.765	.776	.758
2.9	Zuben'ubi	137	.325	.325	.312	.313	.300	.300	.287	.288	.275
2.1	Polaris	321	2.056	1.519	1.819	1.280	1.595	1.054	1.381	.833	1.162
5.5	Sigma Oct.	42	1.428	1.829	1.233	1.624	1.026	1.406	0.806	1.176	.570

ANNEX C

MAIN CORRECTION

Stars Planets (')	App. alt	L.L. (')	U.L. (')
-34.5	0°00'	-18.3	-50.4
-33.2	0°06'	-17	-49
-32.2	0°11'	-16	-48
-31.2	0°16'	-15	-47
-30.2	0°22'	-14	-46
-29.2	0°27'	-13	-45
-28.2	0°33'	-12	-44
-27.2	0°39'	-11	-43
-26.2	0°46'	-10	-42
-25.2	0°53'	- 9	-41
-24.2	1°01'	- 8	-40
-23.2	1°09'	- 7	-39
-22.2	1°18'	- 6	-38
-21.2	1°28'	- 5	-37
-20.2	1°38'	- 4	-36
-19.2	1°49'	- 3	-35
-18.2	2°01'	- 2	-34
-17.2	2°15'	- 1	-33
-16.2	2°30'	0	-32
-15.2	2°46'	+ 1	-31
-14.2	3°02'	+ 2	-30
-13.2	3°26'	+ 3	-29
-12.2	3°50'	+ 4	-28
-11.2	4°17'	+ 5	-27
-10.2	4°50'	+ 6	-26
- 9.2	5°27'	+ 7	-25
- 8.7	5°50'	+ 7.5	-24.5
- 8.2	6°15'	+ 8	-24
- 7.7	6°40'	+ 8.5	-23.5
- 7.2	7°20'	+ 9	-23
- 6.7	7°50'	+ 9.5	-22.5
- 6.2	8°30'	+10	-22
- 5.7	9°20'	+10.5	-21.5
- 5.2	10°20'	+11	-21
- 4.6	11°30'	+11.5	-20.5
- 4.1	13°	+12	-20
- 3.6	15°	+12.5	-19.5
- 3.1	17°	+13	-19
- 2.6	20°	+13.5	-18.5
- 2.1	24°	+14	-18
- 1.6	31°	+14.5	-17.5
- 1.1	41°	+15	-17
- 0.6	59°	+15.5	-16.5
- 0.1	85°	+16	-16
0	90°	+16	-16

DIP

Height of eye (m)	Dip (')
0.7	-1.5
1.3	-2
2.0	-2.5
2.9	-3
3.9	-3.5
5.1	-4
6.4	-4.5
7.9	-5
9.6	-5.5
11.4	-6
13.4	-6.5
15.6	-7
18	-7.5
20	-8
23	-8.5
26	-9
29	-9.5
32	-10
35	-10.5
38	-11
42	-11.5
46	-12
50	-12.5

Dip may also be found using:

Dip in minutes equals square root of height of eye in feet.

This formula is appropriate for an aircraft using a marine sextant. There is no dip correction when using a bubble sextant or other kind of artificial horizon.

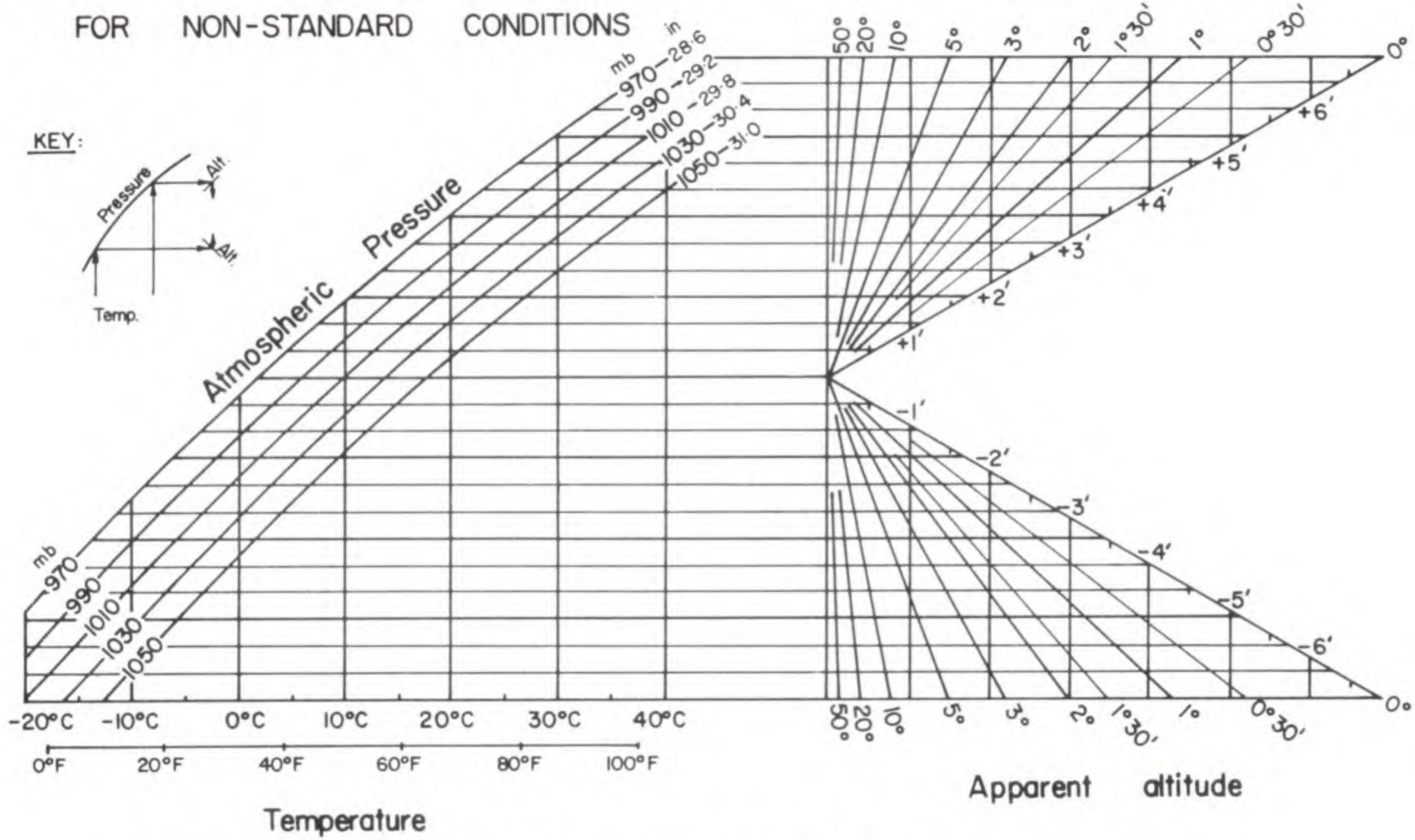
The feet to metres conversion factor is 0.3048 exactly.

The above dip table can be adapted to give visibility distance. To do this add 20% to the magnitude of the dip and call it miles.
Example: A lighthouse is 32 m high; an observer's eye is 2 m high. At what distance is the light visible?

For 32 m the distance is 12 miles
for 2 m the distance is 3 miles
So light is visible for 15 miles.

Note: For this observer if visible land is known to be more than 3 miles away then the sea horizon in front of the land may be used for normal celestial observations.

ADDITIONAL CORRECTION TO ALTITUDE FOR NON-STANDARD CONDITIONS



Enter the nomogram at bottom left with the temperature. Go up to the pressure, across to the altitude then down or up to the correction. This correction is additional to the standard one.

EXAMPLE: Observation to the sun's LL: Alt = 1° 15', Temp = 25° C, Pressure = 1020 mb.
Standard corr = -6'.3 additional corr = +1'.4 Therefore main correction is -4'.9

MERLIN CELESTIAL NAVIGATION COMPUTER

Sun almanac, star almanac and sight reduction at the touch of a button. The Merlin buttons stand directly in place of books of tables. Merlin works in a way that makes sense to the navigator. It does as you tell it-simply, instantly.

Merlin is a machine to "mass reduce" multiple sights. It gives immediate feedback on the quality of the sextant observations. You find out how good you are.

Merlin predicts the direction and sextant setting of a given star at will. If you don't know any stars shoot some anyway — Merlin will tell you which stars they were. Merlin computes great circles, too.

In the Merlin manual yachtsman/surveyor Mike Pepperday presents a lucid, detailed, graded course of examples and exercises which assumes no knowledge of electronic calculators and almost none of celestial navigation.

This third edition is an even more comprehensive source book. It contains practical tips, a list of time signals, altitude tables, a unique star catalogue and an emergency sun almanac. No other references are required. There are appendices on celestial principles, noon sights, land navigation, and theodolite observations. The manual even contains instructions to transform a standard calculator into a top rate back-up computer.

Here are some comments from Merlin owners:

"Merlin and its instruction manual are without doubt the best I have seen. Its compactness and simplicity are ideally suited to the cruising yachtsman."
—Brian Liddell, Member Royal Institute of Navigators, Morrinsville, NZ

"Merlin is indeed a wizard! It is now part of the navigation equipment aboard 'Ben Hall'. Sight reduction tables are going mouldy."
—David Marshall, Newport.

"I think it is an excellent calculator. The instruction manual, which has been compiled out of practical experience in ocean-going craft, is most impressive."
—Eddy Edwards, Member Australian Institute of Navigation, Perth.

"I am glad to inform you that the Merlin celestial navigation computer has been successfully used in several poorly mapped regions of the Brazilian Amazon Basin in a major tin exploration project."
—Camillo Premoli, International Mineral Research, Sydney.

"The Merlin sent for review won't be going back — I've bought it."
—Andrew Bray, Technical Editor, *Cruising Skipper*

"Merlin certainly passes my test and I have no hesitation in recommending its use to any navigator. I particularly like the manual, not only the technical parts but also the practical commonsense hints so carefully worded into layman's language."
—Captain Ian S. Pullar, RAN (ret.), National Coaching Director, Australian Yachting Federation.

Merlin, a converted general purpose calculator, is now sold all over the world. It is the most straightforward sight reduction ever developed.

MERLIN

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Log: ______ (1)Est.lat: +/- ______ (2)Est.long: +/- ______ (3)Gr.date: ______

Course: ______ Index corr: ______ Ht. of eye: ______, dip corr: – ______ (9)YM: ______

Clock corr:	*GMT [1:]* h m s	*Sext.alt* ° '	*alt corr* ' (index, dip, main)	*corr.alt [4:]* ° ' ''	*Az* °	+/- *Int.* *n.m.*
Body:						
(4)dec: +/-						
(5)SHA:						
Body:						
(4)dec: +/-						
(5)SHA:						
Body:						
(4)dec: +/-						
(5)SHA:						
Body:						
(4)dec: +/-						
(5)SHA:						

MERLIN

Log: ______ (1)Est.lat: +/- ______ (2)Est.long: +/- ______ (3)Gr.date: ______

Course: ______ Index corr: ______ Ht. of eye: ______, dip corr: – ______ (9)YM: ______

Clock corr:	*GMT [1:]* h m s	*Sext.alt* ° '	*alt corr* ' (index, dip, main)	*corr.alt [4:]* ° ' ''	*Az* °	+/- *Int.* *n.m.*
Body:						
(4)dec: +/-						
(5)SHA:						
Body:						
(4)dec: +/-						
(5)SHA:						
Body:						
(4)dec: +/-						
(5)SHA:						
Body:						
(4)dec: +/-						
(5)SHA:						

Stars (')	App alt	L.L. (')	U.L. (')
-5.7	9° 20'	+10.5	-21.5
-5.2	10° 20'	+11	-21
-4.6	11° 30'	+11.5	-20.5
-4.1	13°	+12	-20
-3.6	15°	+12.5	-19.5
-3.1	17°	+13	-19
-2.6	20°	+13.5	-18.5
-2.1	24°	+14	-18
-1.6	31°	+14.5	-17.5
-1.1	41°	+15	-17
-0.6	59°	+15.5	-16.5
-0.1	85°	+16	-16

(l) lat, (2) long, alt, in deg. min sec. (4) dec, (5)SHA, (M) GHA, in degrees.

Ht. (m)	Dip (')
0.7	-1.5
1.3	-2
2.0	-2.5
2.9	-3
3.9	-3.5
5.1	-4
6.4	-4.5
7.9	-5