TAMAYA

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Simple and Complete

DIGITAL

Astro-Navigation
Piloting
and
Dead Reckoning

BY TAMAYA NC-2 ASTRO-NAVIGATION CALCULATOR

Contents

Introduction

NOW ANYBODY CAN LEARN NAVIGATION.
With TAMAYA NC-2 ASTRO-NAVIGATION CALCULATOR we can digitally solve most navigational problems with scientific accuracy and incredible speed in a very easy way. In the beginning, however, it is essential to learn a little bit about the sources of input data, auxiliary tools and some principles of navigation to use NC-2 Calculator effectively.

In PART ONE, determining position by Astro-Navigation illustrated in Fig. 1 is explained, step by step, in Chapters I through IV. Chapter V is especially added for the identification of unknown star.

In Chapter 1, PART TWO, Dead Reckoning, Course and Distance, and Great Circle Sailing computations are explained with examples. Problems in navigating through current and wind are solved in Chapter II. The glossary of useful mathematical formulas for navigational problems other than those programmed in NC-2 is given in Chapter III. They are very simple and can be applied practically as a matter of course without the internal programming.

In the course of learning in this texbook, if any question arises about the meaning of keys and dialogue symbols of NC-2 we can refer to the Appendix where the full explanation is given with illustrations.

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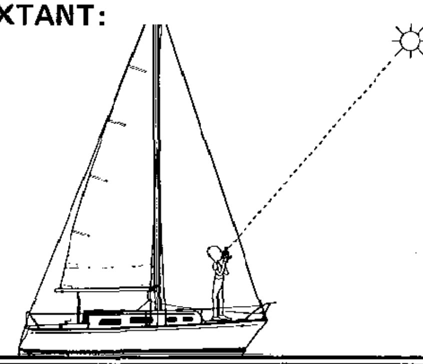
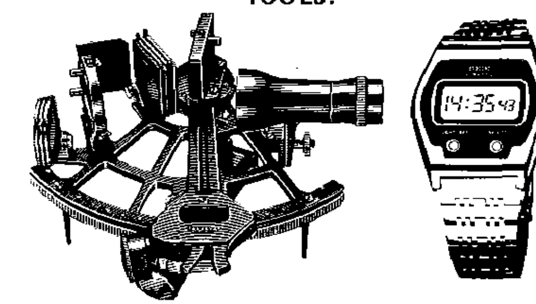
Finding Your Position by Astro-Navigation — WITH THE AID OF TAMAYA NC-2 ASTRO-NAVIGATION CALCULATOR —

(I) TAKING SIGHTS WITH A SEXTANT:

Measure the altitude of the heavenly body (Sun, Moon, planet or star) above the horizon at your DR Position. (A ship's position determined by applying the course and distance travelled from some known position, e.g., the departing port, is called Dead Reckoning Position.)
Record the exact Greenwich Mean Time (GMT) of the sight.



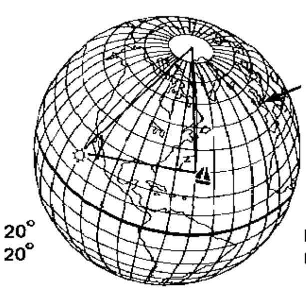
TOOLS:



• Sextant • Watch

(II) FINDING GREENWICH HOUR ANGLE AND DECLINATION IN THE NAUTICAL ALMANAC

Find the Geographical Position (GP) of the same body sighted in Step (I). The GP is the point on the earth directly beneath the heavenly body, and it is expressed by Greenwich Hour Angle (GHA) and Declination (DEC).



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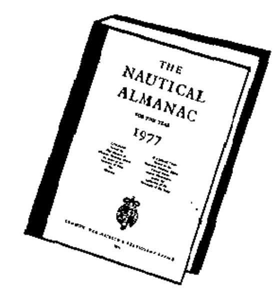
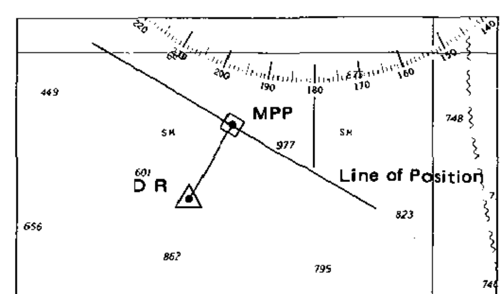


• Nautical Almanac

(III) COMPUTATION BY NC-2 AND PLOTTING:

Compute the Azimuth (Z) and Altitude (Hc) of the same body by NC-2 using the factors found in Step (I) and (II) and the DR position. Compare the computed Altitude (Hc) with the actually observed Altitude (Ho).
From the above factors we can (a) digitally compute the Most Probable Position (MPP) by NC-2, or (b) determine our position by plotting the line of position (LOP) on the chart or plotting sheet.



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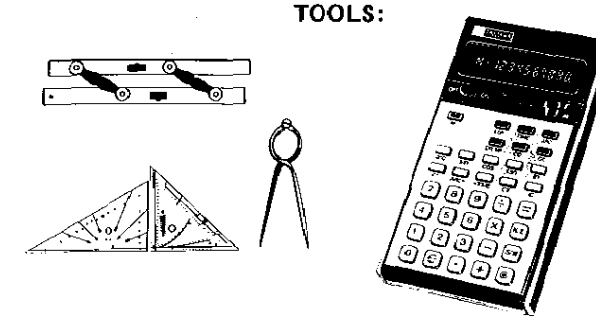


• Plotting Instruments • NC-2 Astro-Navigation Calculator

Fig. 1

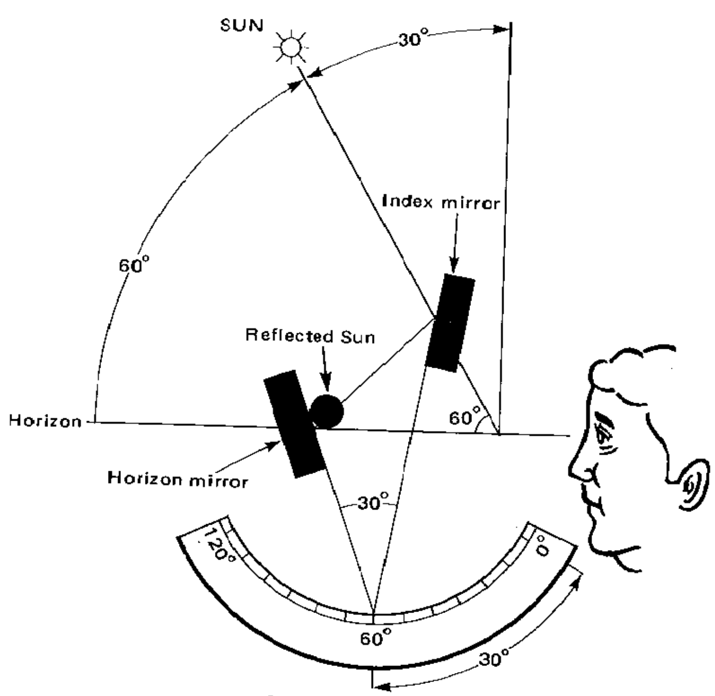
PART ONE : ASTRO-NAVIGATION BY NC-2
CHAPTER I

Taking Sight with a Sextant

1. SEXTANT

Taking a sight means to measure the vertical angle or altitude between a heavenly body and the horizon in order to ascertain the ship's position at sea. The sextant is used as a tool to accomplish this aim.

All marine sextants have two mirros arranged as shown in Fig. 2 and work on the same principle. The index miror reflects the image of the body to the horizon mirror. The horizon mirror is so constracted that one can see the horizon at the same time he sees the reflected image of the whole body. Thus, the altitude of the body is measured by adjusting the angle of the index mirror until the reflected image contacts the horizon (Fig. 3).



Sextant arc and reading
Fig. 2

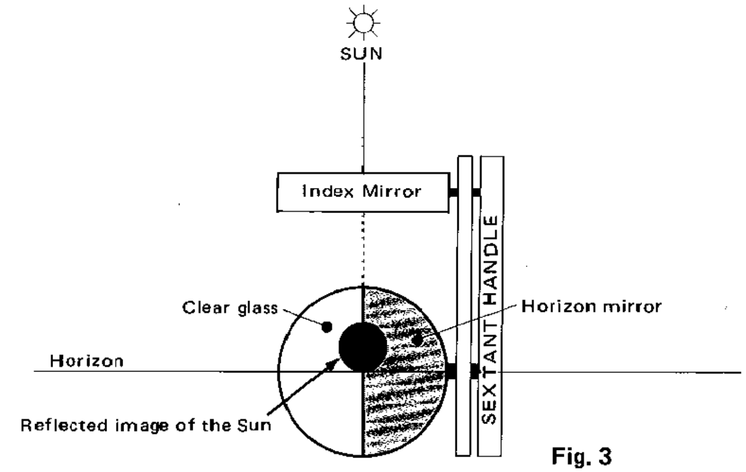


Fig. 3

In a high quality sextant the altitude can be read by degrees, minutes and 1/10 minutes. One minute of the sextant reading is equivalent to one nautical mile.

2. WATCH

In Astro-Navigation it is necessary to read hours, minutes, and seconds of time, so the digital watch having the seconds display is very convenient for such reading of accurate time. Four seconds of time is equivalent to one minute of longitude (one nautical mile at latitude 0°).
When a sight is taken, record the altitude of the body measured by the sextant and the exact Greenwich Mean Time (GMT) of the sight. Greenwich Mean Time is the time at longitude 0°. Local Mean Time (LMT) will depart 1 hour from GMT for every 15° of longitude. Therefore, Zone Time in New York, based on LMT at 75°W long., is 5 hours before GMT, and Zone Time in San Francisco based on LMT at 120°W Long. is 8 hours before GMT. If we go eastward, Tokyo based on LMT at 135°E long. is 9 hours after GMT. With this principle in mind, LMT can be easily converted to GMT.

CHAPTER II

Finding Greenwich Hour Angle and Declination in the Nautical Almanac

The Nautical Almanac tells the geographical position at any time of the year, of the Sun, Moon, Venus Mars, Jupiter, Saturn and fifty-seven selected navigational stars. It is published every year like a calendar. The geographical position is the point on the earth directly beneath the heavenly body, and it is expressed in terms of Greenwich Hour Angle (GHA) and Declination (DEC).

For instance, on pages 10 and 11 of the 1977 Nautical Almanac we will find the following information for Saturday January 1 (See Table 1 —Excerpt from Nautical Almanac).

1977 JANUARY 1: SAT

G.M.T.	SUN		MOON			VENUS	
d h	G.H.A. ° ′	Dec. ° ′	G.H.A. ° ′	Dec. ° ′	H.P. ′	G.H.A. ° ′	Dec. ° ′
1 00	179 08.9	S23 01.7	52 14.7	N16 12.6	54.2	131 42.2	S14 21.4
01	194 08.6	01.5	66 46.8	16 18.0	54.2	146 42.0	20.3
02	209 08.3	01.3	81 18.9	16 23.3	54.2	161 41.8	19.2
03	224 08.0	·· 01.1	95 50.9	16 28.6	54.2	176 41.5	·· 18.1
04	239 07.7	00.9	110 23.0	16 33.7	54.2	191 41.3	17.0
05	254 07.5	00.6	124 54.9	16 38.8	54.2	206 41.1	15.9
06	269 07.2	S23 00.4	139 26.9	N16 43.9	54.2	221 40.9	S14 14.8
07	284 06.9	00.2	153 58.8	16 48.8	54.2	236 40.6	13.8
S 08	299 06.6	23 00.0	168 30.7	16 53.7	54.2	251 40.4	12.7
A 09	314 06.3	22 59.8	183 02.5	16 58.6	54.2	266 40.2	·· 11.6
T 10	329 06.0	59.6	197 34.3	17 03.3	54.2	281 40.0	10.5
U 11	344 05.7	59.4	212 06.1	17 08.0	54.2	296 39.7	09.4
R 12	359 05.4	S22 59.2	226 37.8	N17 12.6	54.2	311 39.5	S14 08.3
D 13	14 05.1	59.0	241 09.5	17 17.1	54.2	326 39.3	07.2
A 14	29 04.8	58.8	255 41.2	17 21.5	54.2	341 39.1	06.1
Y 15	44 04.5	·· 58.6	270 12.8	17 25.9	54.2	356 38.9	·· 05.0
16	59 04.2	58.4	284 44.4	17 30.2	54.2	11 38.7	03.9
17	74 03.9	58.1	299 16.0	17 34.4	54.3	26 38.4	02.8
18	89 03.6	S22 57.9	313 47.5	N17 38.5	54.3	41 38.2	S14 01.7
19	104 03.3	57.7	328 19.0	17 42.5	54.3	56 38.0	14 00.6
20	119 03.1	57.5	342 50.4	17 46.5	54.3	71 37.8	13 59.6
21	134 02.8	·· 57.3	357 21.9	17 50.4	54.3	86 37.6	·· 58.5
22	149 02.5	57.1	11 53.2	17 54.2	54.3	101 37.4	57.4
23	164 02.2	56.9	26 24.6	17 58.0	54.3	116 37.2	56.3

Table 1.

1977 JANUARY 1: SAT

G.M.T.	ARIES	STARS		
d h	G.H.A. ° ′	Name	S.H.A. ° ′	Dec. ° ′
1 00	100 31.9	Acamar	315 38.9	S40 24.0
01	115 34.4	Achernar	335 47.1	S57 21.5
02	130 36.8	Acrux	173 39.8	S62 58.1
03	145 39.3	Adhara	255 33.7	S28 56.6
04	160 41.8	Aldebaran	291 20.5	N16 27.8
05	175 44.2			
06	190 46.7	Alioth	166 44.8	N56 04.7
07	205 49.2	Alkaid	153 20.7	N49 25.4
S 08	220 51.6	Al Na'ir	28 18.4	S47 04.5
A 09	235 54.1	Alnilam	276 13.9	S 1 13.1
T 10	250 56.6	Alphard	218 22.7	S 8 33.6
U 11	265 59.0			
R 12	281 01.5	Alphecca	126 34.5	N26 47.4
D 13	296 04.0	Alpheratz	358 11.9	N28 58.0
A 14	311 06.4	Altair	62 35.3	N 8 48.5
Y 15	326 08.9	Ankaa	353 42.8	S42 26.1
16	341 11.3	Antares	113 00.2	S26 22.8
17	356 13.8			
18	11 16.3	Arcturus	146 20.9	N19 18.0
19	26 18.7	Atria	108 27.2	S68 59.0
20	41 21.2	Avior	234 28.5	S59 26.2
21	56 23.7	Bellatrix	279 01.1	N 6 19.7
22	71 26.1	Betelgeuse	271 30.6	N 7 24.1
23	86 28.6			

1977 JANUARY 1: SAT

G.M.T.	MARS		JUPITER		SATURN	
d h	G.H.A. ° ′	Dec. ° ′	G.H.A. ° ′	Dec. ° ′	G.H.A. ° ′	Dec. ° ′
1 00	190 33.4	S24 03.6	51 09.4	N17 12.1	321 58.2	N16 55.9
01	205 33.8	03.6	66 12.0	12.0	337 00.8	55.9
02	220 34.2	03.7	81 14.6	12.0	352 03.4	56.0
03	235 34.6	·· 03.7	96 17.2	·· 12.0	7 06.0	·· 56.0
04	250 35.0	03.7	111 19.8	12.0	22 08.6	56.1
05	265 35.5	03.7	126 22.4	12.0	37 11.2	56.1
06	280 35.9	S24 03.8	141 25.0	N17 11.9	52 13.8	N16 56.2
07	295 36.3	03.8	156 27.5	11.9	67 16.4	56.2
S 08	310 36.7	03.8	171 30.1	11.9	82 19.0	56.3
A 09	325 37.1	·· 03.8	186 32.7	·· 11.9	97 21.6	·· 56.3
T 10	340 37.5	03.8	201 35.3	11.9	112 24.2	56.4
U 11	355 38.0	03.9	216 37.9	11.8	127 26.9	56.4
R 12	10 38.4	S24 03.9	231 40.5	N17 11.8	142 29.5	N16 56.5
D 13	25 38.8	03.9	246 43.1	11.8	157 32.1	56.5
A 14	40 39.2	03.9	261 45.7	11.8	172 34.7	56.6
Y 15	55 39.6	·· 03.9	276 48.2	·· 11.8	187 37.3	·· 56.6
16	70 40.0	03.9	291 50.8	11.7	202 39.9	56.7
17	85 40.5	04.0	306 53.4	11.7	217 42.5	56.7
18	100 40.9	S24 04.0	321 56.0	N17 11.7	232 45.1	N16 56.8
19	115 41.3	04.0	336 58.6	11.7	247 47.7	56.8
20	130 41.7	04.0	352 01.2	11.7	262 50.3	56.9
21	145 42.1	·· 04.0	7 03.8	·· 11.6	277 53.0	·· 56.9
22	160 42.5	04.0	22 06.3	11.6	292 55.6	57.0
23	175 43.0	04.0	37 08.9	11.6	307 58.2	57.0

Table 1.

HOW TO FIND GHA AND DEC

Problem (1): Find the GHA and DEC of the Sun at GMT 14 35m43s on Jan. 1, 1977.

From Table 1:	GHA	DEC
For 14h	29°04'.8	S22°58'.8
15h	44°04'.5	S22°58'.6
	14°59'.7. increase	0'.2 decrease
For 35m43s	$14°59'.7 \times \frac{35.72}{60}$ *1	$0'.2 \times \frac{35.72}{60}$ *1 = 0'.1
	= 8°55'.6 (Key sequence on NC-2 is ARC 14.597 × 35.72 ÷ 60 = 8.556)	

Total GHA for 14h35m43s	Total DEC
= 29°04'8 + 8°55'.6	= S22° 58'.8 − 0'.1
= 38°00'.4	= S22° 58'.7

*1. 43 seconds is 0.72 minutes. This can be obtained by (43÷60) in N mode. Use ARC mode in NC-2 for the rest of the calculations. Do not fail to make the decimal point properly when entering the figures in ARC mode in NC-2. For instance, 14°59.7' is keyed in as 14.597, and 0'.2 as 0.002.

Problem (2): Find the GHA and DEC of the Moon at GMT 05h25m 18s on Jan. 1, 1977.

From Table 1 :	GHA	DEC
for 05h	124°54'.9	N16°38'.8
06h	139°26'.9	N16°43'.9
	14°32'.0 increase	5'.1 increase
For 25m 18s	$14°32'.0 \times \frac{25.3}{60}$	$5'.1 \times \frac{25.3}{60}$ = 2'.2
	= 6°07'.7	
Total GHA	124°54'.9 + 6°07'.7	N16°38'.8 + 2'.2
	=131°02'.6	= N16°41'.0

Problem (3): Find the GHA and DEC of Venus at GMT 14h45m52s on Jan. 1, 1977.

From Table 1:	GHA	DEC
For 14h	341°39'.1	S14°06'.1
15h	356°38'.9	S14°05'.0
	14°59'.8 increase	1'.1 decrease
For 45m52s	$14°59'.8 \times \frac{45.87}{60}$	$1'.1 \times \frac{45.87}{60}$ = 0'.8
	= 11°27'.9	
Total GHA	341°39'.1 + 11°27'.9	S14°06'.1 − 0'.8
	= 353°07'.0	= S14°05'.3

Problem (4): Find the GHA and DEC of Arcturus at 16h16m39s on Jan. 1, 1977.

From Table 1:	**GHA**		**DEC Arcturus**
for 16h	GHA Aries 341°11'.3		for Jan. 1 N19°18'.0
17h	GHA Aries 356°13'.8		
	15°02'.5 increas		
for 16m39s	$15°02'.5 \times \frac{16.65}{60} = 4°10'.4$		
Total GHA Aries 341°11'.3 + 4°10'.4 =	345°21'.7		
SHA Arcturus for Jan. 1 (From Table 1)	146°20'.9		
	491°42'.6	*1	
	−360°00'.0		
GHA Arcturus:	131°42'.6		

*1. GHA star = GHA Aries + SHA of the star. If GHA star exceeds 360°, subtract 360°.

Note: GHA and DEC may also be determined by means of the INCREMENTS AND CORRECTIONS tables on pages ii through xxxi in the Nautical Almanac, as explained on pages 255 and 256 of the Almanac.

GHA/DEC vs. Longitude/Latitude

Both GHA/DEC and Long./Lat. are used to designate position on the earth. For instance, we say Tokyo, Japan is situated at Lat. 35°40'N Long. 139°45'E, and Honolulu, Hawaii is Lat. 21°20'N Long. 157°50' W. In designating the geographical position of a heavenly body, we say instead, the Sun's GP is GHA 353° DEC S14°, and so forth. Note that Latitude and Declination are similarly measured from the equator to 90° north and 90° south, whereas, Longitude and GHA are not expressed exactly the same. Longitude is measured from the Greenwich meridian (longitude line) to 180° east and to 180° west, but GHA is measured from the Greenwich meridian 360° westward only. That is why we sometimes have GHA greater than 180° (See the globe in Fig. 1).

CHAPTER III

Computation and Plotting

Now we are ready to compute and plot our position.

Problem (1): The DR position of a vessel is 30°22'.8N 69°35'.5W at GMT 14h35m43s on Jan. 1, 1977. The sextant reading of the lower limb of the Sun at this moment is 28°20'.5.

Required:
(1) Compute the Altitude and Azimuth of the Sun.
(2) Compute Altitude Intercept.
(3) Compute the Most Probable Position.
(4) Plot the Line of Position.

(1) COMPUTATION OF ALTITUDE (Hc) AND AZIMUTH (Z) BY NC-2

A convenient NC-2 LOP COMPUTATION CARD has been prepared to assure the proper order of input data. See the enclosed card.

Enter the date, GMT, name of body, DR Lat. and DR Long. in the blanks so designated. The GHA and DEC at GMT 14h35m43s on Jan. 1, 1977 have been obtained in Problem (1) CHAPTER (II), as 38°00'.4 and S22°58'.7. Fill in the appropriate blanks with these data. Then, follow the steps shown below.

Key	Display	Answer
[LOP]	H 0.	computed Altitude is 28°37'.8
38.004	H 38.004	Azimuth is 146°40'.6
[+] 69.355 [S/W]	H −69.355	(measured clockwise from north)
[=]	H −31.351	
[⊙]	d 0.	
22.587 [S/W]	d − 22.587	
[⊙]	L 0.	
30.228 [N/E]	L 30.228	
[⊙]	A 28.378	
[⊙]	Z 146.406 (A and Z can be repeated by [⊙] key)	

(2) COMPUTATION OF ALTITUDE INTERCEPT

The Intercept is simply the difference between the observed altitude (Ho) and the computed altitude (Hc). The observed altitude is the true altitude obtained by adding corrections to the direct sextant reading. These altitude corrections, consisting of multiple factors, are easily found in the Nautical Almanac, and are explained separately in CHAPTER (IV) Sextant Altitude Corrections(See problem1 on page 21).

For purposes of this problem, just take 12'.0 as the altitude correction and add it to the sextant altitude reading. Now we have the observed altitude (28°20'.5 + 12'.0) = 28°32'.5 and the Intercept (Ho − Hc) = (28°32'.5 − 28°37'.8) = −5'.3 (5.3 miles).

(3) COMPUTATION OF MOST PROBABLE POSITION (MPP) BY NC-2

From the known factors: DR position, Azimuth and Intercept, we can compute the Most Probable Position as follows.

Input	NC-2 Key	Display	Answer
D R Lat	[DR-MP]	L 0.	MPP Latitude
30°22'.8N	30.228 [N/E]	L 30.228	30°27'.2N
D R Long	[⊙]	II 0.	Longitude
69°35'.5W	69.355 [S/W]	II −69.355	69°38'.9W
Azimuth	[⊙]	c 0.	
146°40'.6	146.406	c 146.406	
Intercept	[⊙]	d 0.	
−5'.3	5.3 [±]	d − 5.3	
	[⊙]	L 30.272	
	[⊙]	II −69.389	

(4) PLOTTING A LINE OF POSITION

Looking at the illustration in Fig. 4, we can figure out that when Ho (the actual altitude) is bigger than Hc (the computed altitude with the assumption that our DR position is correct), we should shift our position from the DR position towards the Sun along the Azimuth line. The opposite should be done if Ho is smaller than Hc.

In the computation of the MPP, we have done this automatically with NC-2. With the same principle, the MPP can be plotted on the chart or plotting sheet. We take the intercept 5′.3 from the latitude scale of the chart by marine dividers and transfer it onto the azimuth line. 5′.3 of latitude is 5.3 nautical miles on the earth. The line crossing the azimuth line at right angles at MPP is called Line of Position (LOP) (Fig. 5).

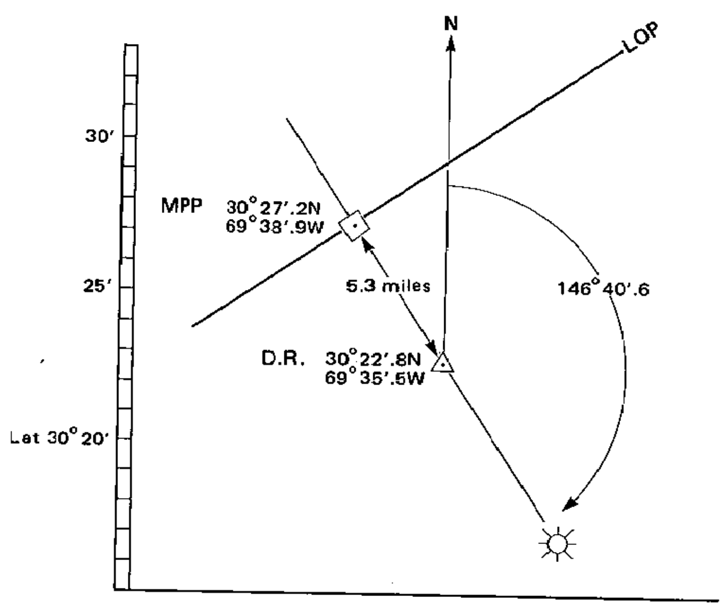
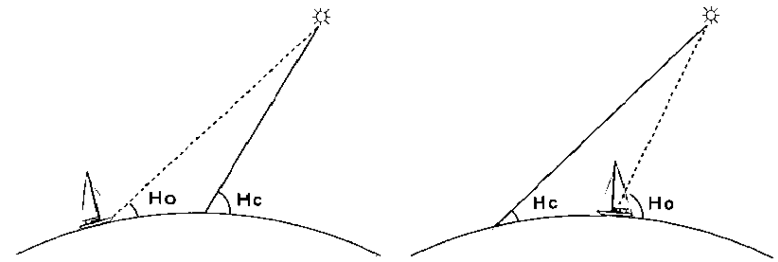


Fig. 5



Ho<Hc
Move from the D R away from the Sun

Ho>Hc
Move from the D R towards the Sun

Fig. 4

FIX BY TWO LOP's

In the theory of Astro-Navigation a ship's position can be determined only after at least two LOP's are obtained. The intersection of the two or more LOP's called "fix" is the ship's position (Fig. 6). If a triangle is formed by three LOP's the centroid of the triangle is the ship's position.

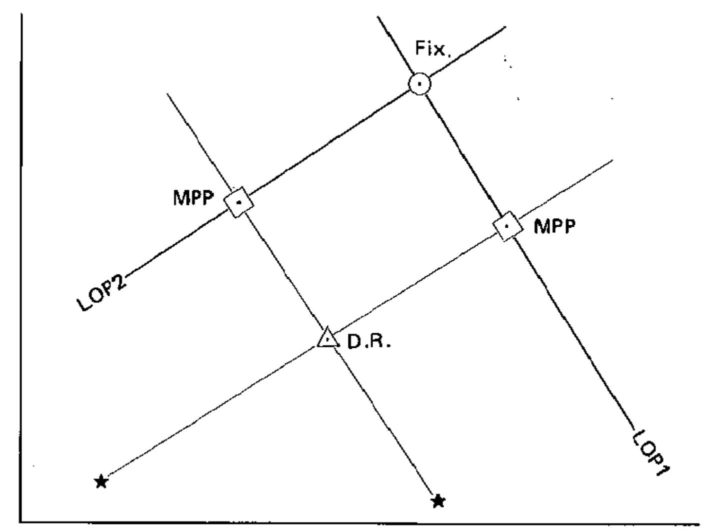


Fig. 6

WHY WE NEED TWO LOP's

Most probable position helps to improve the reliability of DR position but should be differenciated from the "fix" obtained by two or more LOP's.
The reason for plotting two LOP's can be explained by looking at the illustration (Fig. 7). Suppose we are at Waikiki Beach in Hawaii, position of which is 21°16'.8N and 157°50'.1W. We believe, however, that we are in the middle of the island at 21°30'.0N and 158°00'.0W (our DR position). On this assumption, if we take a Sun sight at 9 o'clock Hawaii time and compare the observed altitude (Ho) with the computed altitude (Hc) based on our DR position, we would obtain the MPP9h and LOP9h as plotted on (Fig. 7). In the same manner we would obtain another MPP and LOP, say at 13 o'clock and 15 o'clock. As we can see MPP9h, MPP13h and MPP15h are not in the same position, but any two of the three LOP's makes a "fix" at the same position, Waikiki.
We may take sights of two different bodies like the Sun and Moon, the Moon and a star, two different stars etc. The "fix" has the best reliability when the two LOP's are at right angles to each other. So the bodies to be observed should be selected taking this angle into consideration.

HOW TO FIND STARS

Suitable stars to make an ideal fix can be selected from the list of fifty-seven navigational stars, Polaris and four planets in the Nautical Almanac. Before taking a sight the azimuth and altitude of the desired star may be precomputed using the approximate time of the sight to be taken. In this way the star can be found very easily.

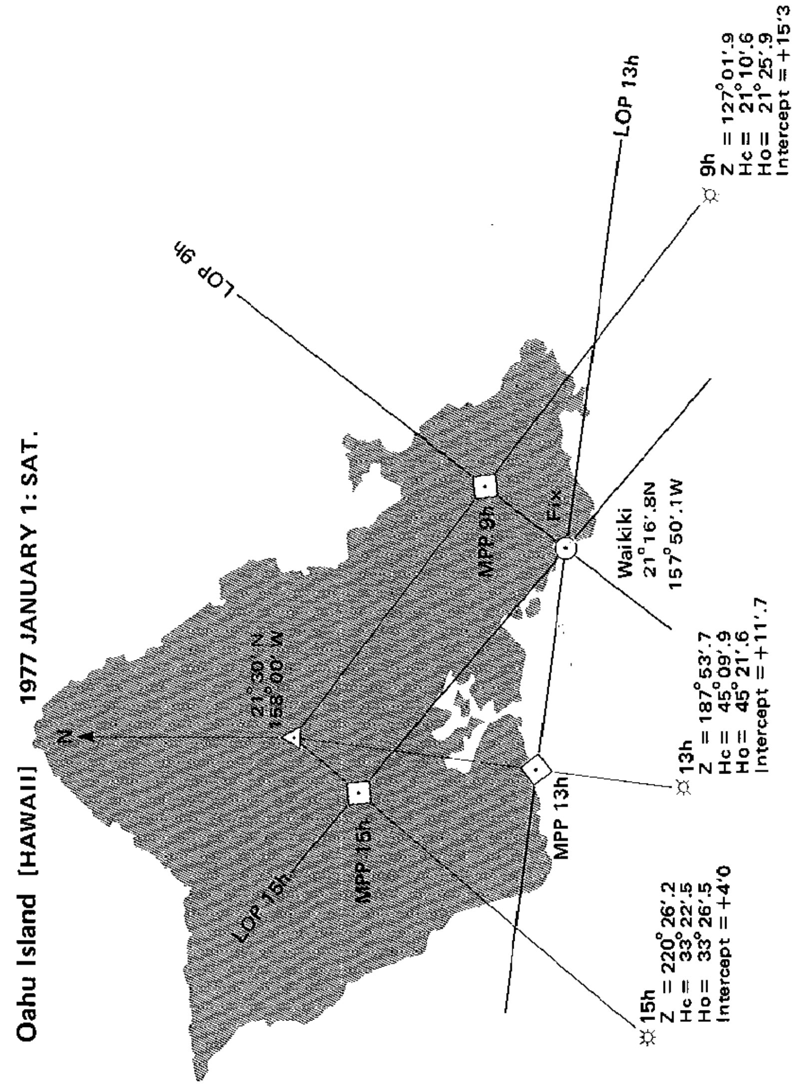


Fig. 7

RUNNING FIX

If the "FIX" must be made only by Sun sights, we can do it by allowing time intervals between the two sights as the Sun changes its azimuth in a day from east to west at a considerable speed.

In this case, the first LOP is advanced along the ship's course by the amount of the distance run between the two sights. The crossing point of the advanced LOP and the second LOP is the ship's position at the time of the second sight (Fig. 8).

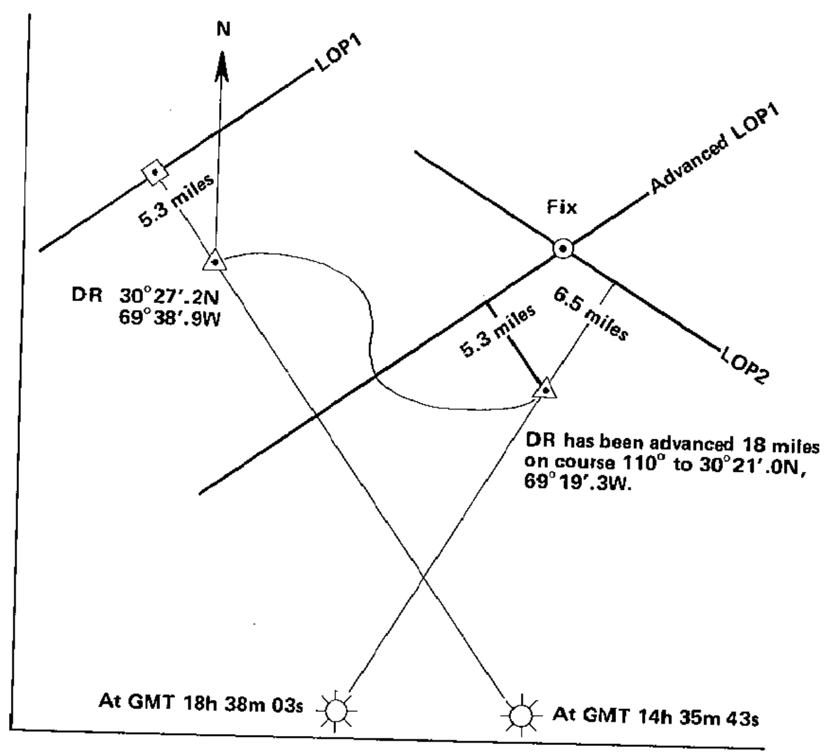


Fig. 8

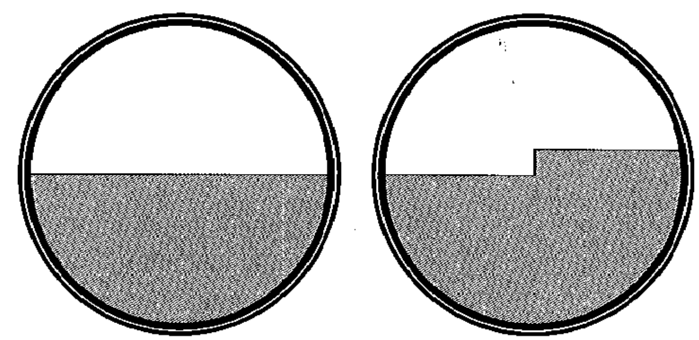
CHAPTER IV

Sextant Altitude Corrections – *From Nautical Almanac*

ALTITUDE CORRECTIONS FOR THE SUN

The corrections to be made for the Sun sight are (1) Index correction (2) Dip correction (3) Main correction and (4) Additional Refraction correction.

(1) Index error is the error of the sextant itself. This error can be checked by looking at the horizon with the sextant with its reading set at 0°00'.0. If the reflected image of the horizon in the horizon mirror does not form a straight line with the directly viewed horizon through the clear part, there exists an error caused by the lack of parallelism of the two mirrors. Then, move the index arm slowly until the horizon line is in alignment, and see how much the reading is off the "0". This amount should be added to or subtracted from the sextant reading depending on the direction of the error (Fig. 9).



Horizon in alignment

Horizon out of alignment
Index error present

Fig. 9

(2) Dip is the discrepancy in altitude reading due to the height of the observer's eye above sea level. If we could measure the altitude of a body with our eye at the sea water level this correction would not be necessary (Fig. 10).

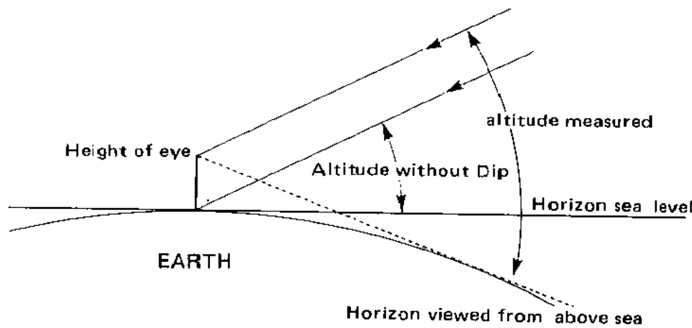


Fig. 10

This correction can be found in the Altitude Correction Tables of the Nautical Almanac (See Table 2on page20). We enter this table with the height of eye above sea level, in either feet or meters, to get the amount of correction. Otherwise, the correction can be simply calculated by NC-2 with the following formulas:

$$\text{Correction for dip} = -1'.76\sqrt{(\text{height of eye in meters})}$$
$$= -0'.97\sqrt{(\text{height of eye in feet})}$$

(3) Main correction consists of a) refraction, b) semidiameter and c) parallax.

a) Refraction is the difference between the actual altitude and apparent altitude due to the bending of the light passing through media of varying densities(Fig. 11).

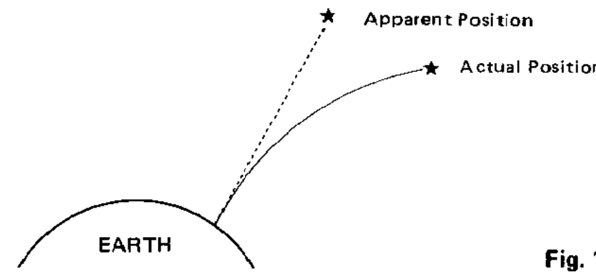


Fig. 11.

b) When measuring the altitude of the Sun or Moon by sextant it is customary to observe the upper or lower limb of the body because the center of the body cannot be easily judged. In this case the semi-diameter of the disk of the body must be subtracted from or added to the measured angle(Fig. 12).

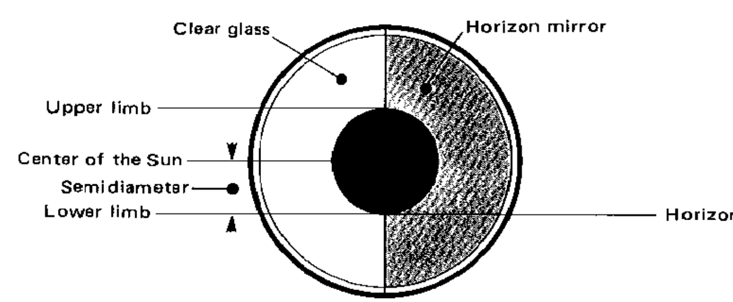


Fig. 12

c) Parallax is the difference in the apparent position of the body viewed from the surface of the earth and the center of the earth. While the angle must be measured from the center we can view the body only from the surface, and the difference must be adjusted (Fig. 13).

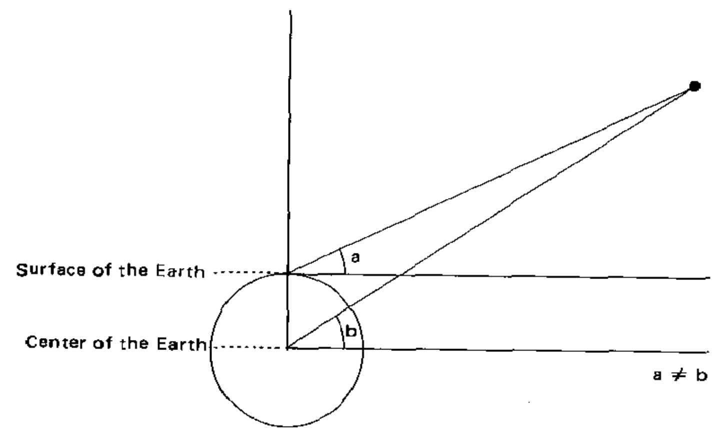


Fig. 13

The Nautical Almanac gives the Main Correction in the A2 and A3 ALTITUDE CORRECTION TABLES on the inside of its front cover, for the Sun, stars and planets. In these tables the main correction is given in total, without separating refraction, semidiameter and parallax corrections (See Table 3).

(4) Additional Refraction Correction

In the MAIN CORRECTION TABLES of the Nautical Almanac, the refraction correction is given based on standard atmospheric conditions, i.e., temperature 10°C, pressure 1010mb. Sometimes, an additional correction for nonstandard conditions is made from the A4 ADDITIONAL CORRECTIONS TABLE of the Nautical Almanac. Except for extreme temperature, pressure or low altitude, this correction is not usually applied.

A_2 ALTITUDE CORRECTION TABLES 10° – 90° – SUN

OCT.—MAR. SUN App. Alt.	Lower Limb	Upper Limb	APR.—SEPT. App. Alt.	Lower Limb	Upper Limb
° ′	′	′	° ′	′	′
9 34	+10·8	−21·5	9 39	+10·6	−21·2
9 45	+10·9	−21·4	9 51	+10·7	−21·1
9 56	+11·0	−21·3	10 03	+10·8	−21·0
10 08	+11·1	−21·2	10 15	+10·9	−20·9
10 21	+11·2	−21·1	10 27	+11·0	−20·8
10 34	+11·3	−21·0	10 40	+11·1	−20·7
10 47	+11·4	−20·9	10 54	+11·2	−20·6
11 01	+11·5	−20·8	11 08	+11·3	−20·5
11 15	+11·6	−20·7	11 23	+11·4	−20·4
11 30	+11·7	−20·6	11 38	+11·5	−20·3
11 46	+11·8	−20·5	11 54	+11·6	−20·2
12 02	+11·9	−20·4	12 10	+11·7	−20·1
12 19	+12·0	−20·3	12 28	+11·8	−20·0
12 37	+12·1	−20·2	12 46	+11·9	−19·9
12 55	+12·2	−20·1	13 05	+12·0	−19·8
13 14	+12·3	−20·0	13 24	+12·1	−19·7
13 35	+12·4	−19·9	13 45	+12·2	−19·6
13 56	+12·5	−19·8	14 07	+12·3	−19·5
14 18	+12·6	−19·7	14 30	+12·4	−19·4
14 42	+12·7	−19·6	14 54	+12·5	−19·3
15 06	+12·8	−19·5	15 19	+12·6	−19·2
15 32	+12·9	−19·4	15 46	+12·7	−19·1
15 59	+13·0	−19·3	16 14	+12·8	−19·0
16 28	+13·1	−19·2	16 44	+12·9	−18·9
16 59	+13·2	−19·1	17 15	+13·0	−18·8
17 32	+13·3	−19·0	17 48	+13·1	−18·7
18 06	+13·4	−18·9	18 24	+13·2	−18·6
18 42	+13·5	−18·8	19 01	+13·3	−18·5
19 21	+13·6	−18·7	19 42	+13·4	−18·4
20 03	+13·7	−18·6	20 25	+13·5	−18·3
20 48	+13·8	−18·5	21 11	+13·6	−18·2
21 35	+13·9	−18·4	22 00	+13·7	−18·1
22 26	+14·0	−18·3	22 54	+13·8	−18·0
23 22	+14·1	−18·2	23 51	+13·9	−17·9
24 21	+14·2	−18·1	24 53	+14·0	−17·8
25 26	+14·3	−18·0	26 00	+14·1	−17·7
26 36	+14·4	−17·9	27 13	+14·2	−17·6
27 52	+14·5	−17·8	28 33	+14·3	−17·5
29 15	+14·6	−17·7	30 00	+14·4	−17·4
30 46	+14·7	−17·6	31 35	+14·5	−17·3
32 26	+14·8	−17·5	33 20	+14·6	−17·2
34 17	+14·9	−17·4	35 17	+14·7	−17·1
36 20	+15·0	−17·3	37 26	+14·8	−17·0
38 36	+15·1	−17·2	39 50	+14·9	−16·9
41 08	+15·2	−17·1	42 31	+15·0	−16·8
43 59	+15·3	−17·0	45 31	+15·1	−16·7
47 10	+15·4	−16·9	48 55	+15·2	−16·6
50 46	+15·5	−16·8	52 44	+15·3	−16·5
54 49	+15·6	−16·7	57 02	+15·4	−16·4
59 23	+15·7	−16·6	61 51	+15·5	−16·3
64 30	+15·8	−16·5	67 17	+15·6	−16·2
70 12	+15·9	−16·4	73 16	+15·7	−16·1
76 26	+16·0	−16·3	79 43	+15·8	−16·0
83 05	+16·1	−16·2	86 32	+15·9	−15·9
90 00			90 00		

STARS AND PLANETS App. Alt.	Corr^n
° ′	′
9 56	−5·3
10 08	−5·2
10 20	−5·1
10 33	−5·0
10 46	−4·9
11 00	−4·8
11 14	−4·7
11 29	−4·6
11 45	−4·5
12 01	−4·4
12 18	−4·3
12 35	−4·2
12 54	−4·1
13 13	−4·0
13 33	−3·9
13 54	−3·8
14 16	−3·7
14 40	−3·6
15 04	−3·5
15 30	−3·4
15 57	−3·3
16 26	−3·2
16 56	−3·1
17 28	−3·0
18 02	−2·9
18 38	−2·8
19 17	−2·7
19 58	−2·6
20 42	−2·5
21 28	−2·4
22 19	−2·3
23 13	−2·2
24 11	−2·1
25 14	−2·0
26 22	−1·9
27 36	−1·8
28 56	−1·7
30 24	−1·6
32 00	−1·5
33 45	−1·4
35 40	−1·3
37 48	−1·2
40 08	−1·1
42 44	−1·0
45 36	−0·9
48 47	−0·8
52 18	−0·7
56 11	−0·6
60 28	−0·5
65 08	−0·4
70 11	−0·3
75 34	−0·2
81 13	−0·1
87 03	0·0
90 00	

App. Alt.	Additional Corr^n
1977 VENUS	
Jan. 1-Jan. 29	
0°	
47	+ 0·2′
Jan. 30-Feb. 26	
0°	
46	+ 0·3′
Feb. 27-Mar. 14	
0°	
11	+ 0·4′
41	+ 0·5
Mar. 15-Mar. 23	
0°	
6	+ 0·5′
20	+ 0·6
31	+ 0·7
Mar. 24-Apr. 19	
0°	
4	+ 0·6′
12	+ 0·7
22	+ 0·8
Apr. 20-Apr. 28	
0°	
6	+ 0·5′
20	+ 0·6
31	+ 0·7
Apr. 29-May 13	
0°	
11	+ 0·4′
41	+ 0·5
May 14-June 8	
0°	
46	+ 0·3′
June 9-July 23	
0°	
47	+ 0·2′
July 24-Dec. 31	
0°	
42	+ 0·1′
MARS	
Jan. 1-Nov. 12	
0°	
60	+ 0·1′
Nov. 13-Dec. 31	
0°	
41	+ 0·2′
75	+ 0·1

Table 3.

DIP Ht. of Eye	Corr^n	Ht. of Eye
m	′	ft.
2·4	−2·8	8·0
2·6	−2·9	8·6
2·8	−3·0	9·2
3·0	−3·1	9·8
3·2	−3·2	10·5
3·4	−3·3	11·2
3·6	−3·4	11·9
3·8	−3·5	12·6
4·0	−3·6	13·3
4·3	−3·7	14·1
4·5	−3·8	14·9
4·7	−3·9	15·7
5·0	−4·0	16·5
5·2	−4·1	17·4
5·5	−4·2	18·3
5·8	−4·3	19·1
6·1	−4·4	20·1
6·3	−4·5	21·0
6·6	−4·6	22·0
6·9	−4·7	22·9
7·2	−4·8	23·9
7·5	−4·9	24·9
7·9	−5·0	26·0
8·2	−5·1	27·1
8·5	−5·2	28·1
8·8	−5·3	29·2
9·2	−5·4	30·4
9·5	−5·5	31·5
9·9	−5·6	32·7
10·3	−5·7	33·9
10·6	−5·8	35·1
11·0	−5·9	36·3
11·4	−6·0	37·6
11·8	−6·1	38·9
12·2	−6·2	40·1
12·6	−6·3	41·5
13·0	−6·4	42·8
13·4	−6·5	44·2
13·8	−6·6	45·5
14·2	−6·7	46·9
14·7	−6·8	48·4
15·1	−6·9	49·8
15·5	−7·0	51·3
16·0	−7·1	52·8
16·5	−7·2	54·3
16·9	−7·3	55·8
17·4	−7·4	57·4
17·9	−7·5	58·9
18·4	−7·6	60·5
18·8	−7·7	62·1
19·3	−7·8	63·8
19·8	−7·9	65·4
20·4	−8·0	67·1
20·9	−8·1	68·8
21·4		70·5

Ht. of Eye	Corr^n
m	′
1·0	−1·8
1·5	−2·2
2·0	−2·5
2·5	−2·8
3·0	−3·0
See table ←	
m	
20	−7·9
22	−8·3
24	−8·6
26	−9·0
28	−9·3
30	−9·6
32	−10·0
34	−10·3
36	−10·6
38	−10·8
40	−11·1
42	−11·4
44	−11·7
46	−11·9
48	−12·2
ft.	
2	−1·4
4	−1·9
6	−2·4
8	−2·7
10	−3·1
See table ←	
ft.	
70	−8·1
75	−8·4
80	−8·7
85	−8·9
90	−9·2
95	−9·5
100	−9·7
105	−9·9
110	−10·2
115	−10·4
120	−10·6
125	−10·8
130	−11·1
135	−11·3
140	−11·5
145	−11·7
150	−11·9
155	−12·1

Table 2.

HOW TO FIND THE ALTITUDE CORRECTIONS

In the Computation of Intercept in Chapter III, we had the sextant altitude correction of +12′.0 which then was not explained. How to find this correction in the Nautical Almanac is explained here.

Problem (1): The sextant reading of the lower limb of the Sun sight is 28°20′.5 on Jan. 1, 1977. The sextant reads 0′.5 too low because of the index error. The height of eye above sea level is 3 meters. Find the sextant altitude corrections.

	SOURCE	
Sextant Reading		28°20′.5
Index correction	Check the sextant	+0′.5
Dip for height of eye 3m	Nautical Almanac (Table 2)	–3′.0
Apparent altitude		28°18′.0
Main correction for 28°18′.0	Nautical Almanac (Table 3)	+14′.5
		28°32′.5

Total correction: (+0′.5–3′.0+14′.5 = 12′.0).Note that the main correction table should be entered with apparent altitude.

ALTITUDE CORRECTIONS FOR STARS AND PLANETS

The sextant altitude corrections for stars and planets are much the same as for the Sun. Use A2 AltitudeCorrection Tables STARS AND PLANETS of Nautical Almanac for main correction. Make sure the additional correction in the same table is applied for Venus and Mars.

ALTITUDE CORRECTIONS FOR THE MOON

Use Altitude Correction Tables –MOON of Nautical Almanac. (Pages xxxiv-xxxv). When upper limb is observed, subtract 30′0 after the main correction is made. Then make LU correction by the LU correction table. The HP factor required to enter this table is found in the Moon table of the daily pages. More altitude correction examples are found in Nautical Almanac on Page 259.

CHAPTER V

Identification of Unknown Star

If we know the altitude and bearing of a star, and want to find out what star it is, NC-2 is used in the following manner.

Problem: At GMT19h32m16s on Jan. 1, 1977 an unknown star is observed at altitude 62°36′.3 and approximate azimuth 72°T. The ship's DR position is 12°40′N 152°22′E.

Required: Identity of the star

Key	Display	
[LOP]	H 0.	
72	H 72.	
[◉]	d 0.	
62.363	d 62.363	
[◉]	L 0.	
12.40 [N/E]	L 12.40	
[◉]	A 19.286	. . . . Approximate declination
[◉]	Ξ 332.206	. . . . Approximate local hour angle

Then compute the following in ARC mode.

Local hour angle of star (LHA)	332°20′.6	
Subtract DR longitude of ship	−152°22′.0E	*1
Greenwich hour angle of star (GHA)	179°58′.6	
Subtract GHA Aries for 19h32m16s (GHA) Jan. 1, 1977	−34°24′.1	*2
Sidereal hour angle of star (SHA)	145°34′.5	*3

Entering Star table on Pages 268–273 of the Nautical Almanac with SHA 145°34′.5 and DEC 19°28′.6N, the star with the closest values is found to be α bootis (SHA 146°20′.8 DEC N19°17′.9), another name of which is Arcturus, star No. 37. In the event that a reasonably close match of the computed SHA and DEC values cannot be found in the Star table, it is possible that the body observed was actually a planet, and the SHA values of the four navigational planets at the bottom of the STARS table of the daily pages should also be checked.

*1 Add if longitude is west.
*2 See Chapter II for how to find GHA.
*3 If the answer becomes negative, add 360° to get SHA.
If the answer is greater than 360°, subtract 360°.

PART TWO : DIGITAL NAVIGATION BY NC-2
CHAPTER I

Dead Reckoning and Piloting by NC-2

TAMAYA NC-2 ASTRO-NAVIGATION CALCULATOR can be used effectively in solving the other most important navigation problems. Explanations with examples are given in this chapter.

DEAD RECKONING

[DR] Dead Reckoning mode computes the latitude and longitude of the point of arrival.

Problem 1		Key	Display	Answer
Departure Point Lat.	32°30'.6N	[DR-WP]	L 0.	D.R. Lat. 30°34'.2N
Departure Point Long.	118°36'.2W	32.306 [N/E]	L 32.306	D.R. Long. 123°36'.0W
Course	245°30'	[⊙]	II 0.	
Distance	280.8 miles	118.362 [S/W]	II −118.362	
		[⊙]	c 0.	
		245.3	c 245.3	
		[⊙]	d 0.	
		280.8	d 280.8	
		[⊙]	L 30.342	
		[⊙]	II −123.360	
		[⊙] REPEAT	L and II	

COURSE AND DISTANCE

[CD] Course and Distance mode computes the course and distance from the departure point to the arrival point.

Problem 2		Key	Display	Answer
Departure Point Lat.	35°22'.4N	[CD]	L 0.	Course made good
Departure Point Long.	125°08'.2W	35.224 [N/E]	L 35.224	203°32'.8
Arrival Point Lat.	17°45'.2S	[⊙]	II 0.	distance 3477.1 miles
Arrival Point Long.	149°30'.0W	125.082 [S/W]	II −125.082	
		[⊙]	L 0.	
		17.452 [S/W]	L −17.452	
		[⊙]	II 0.	
		149.30 [S/W]	II −149.30	
		[⊙]	c 203.328	
		[⊙]	d 3477.1	
		[⊙] REPEAT	c and d	

Principle

The principle of DR and CD calculation is Mercator Sailing. Accuracy is lost when the course approaches near 090° and 270°, so the program automatically switches to Mid-latitude Sailing, thus assuring accurate program for all circumstances. The course obtained by Mercator Sailing is a rhumb line. Appearing as a straight line on the Mercator chart it makes the same angle with all meridians it crosses. The main advantage of a rhumb line is that it maintains constant true direction. A ship following rhumb line between two points will not change a certain course. With the exception of very high latitudes (over 89°59'.5), NC-2 is good virtually for all course and distance computation.

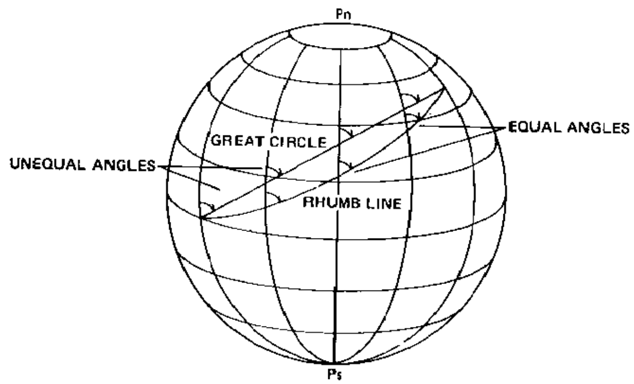
GREAT CIRCLE SAILING

[GC] Great Circle Sailing mode computes the great circle distance between two points and also the initial course from the departure point.

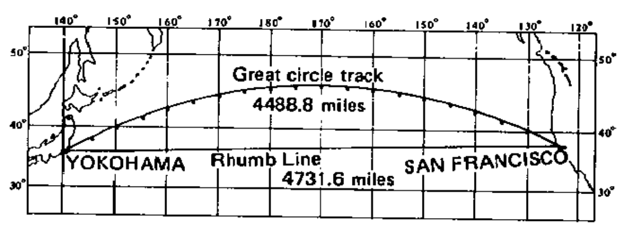
Problem 3		Key	Display	Answer
Departure Point Lat.	37°50'.8N	[GC]	L 0.	Great circle distance
Departure Point Long.	122°25'.5W	37.508 [N/E]	L 37.508	4488.8 miles
	(San Francisco)	[⊙]	II 0.	
Arrival Point Lat.	34°52'.0N	122.255 [S/W]	II −122.255	Initial great circle course
Arrival Point Long.	139°42'.0E	[⊙]	L 0.	302°37'.9
	(Yokohama)	34.520 [N/E]	L 34.520	
		[⊙]	II 0.	
		139.420 [N/E]	II 139.420	
		[⊙]	d 4488.8	
		[⊙]	c 302.379	
		[⊙] REPEAT	d and c	

COMPARISON OF RHUMB LINE AND GREAT CIRCLE

Great Circle and Rhumb Line on the Earth's Surface.



Great Circle and Rhumb Line on the Mercator Chart.



CHAPTER II

Navigating Through Current and Wind by NC-2

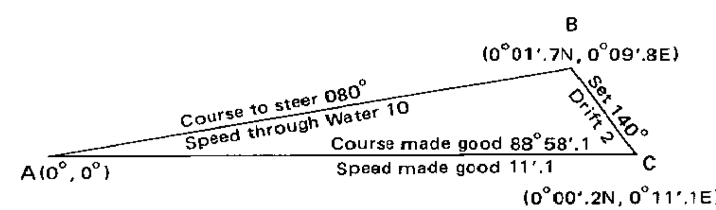
Problem 1: Finding course and speed made good through a current.

A ship on course 080°, speed 10 knots, is steaming through a current having a set of 140° and drift of 2 knots.

Compute (1) Course made good and (2) speed made good.

The problem can be solved by NC-2 in the DR·MP and CD modes by substituting speeds for distances as follows:

a. In DR·MP mode, key lat. 0°, long. 0° for point A.
b. Key course 80° and distance (speed) 10.
c. Values for point B are found to be 0°01'.7N, 0°09'. 8E. Still in DR·MP mode, key these point B values followed by course (set) 140° and distance (drift) 2 to get values for point C: 0°00'.2N, 0°11'.1E.
d. Change NC-2 to CD mode and key lat. 0°, long. 0° for point A and lat. 0°00'.2N, long. 0°11'.1E for point C. Answers are found to be course 88°58'1, distance (speed) 11.1.

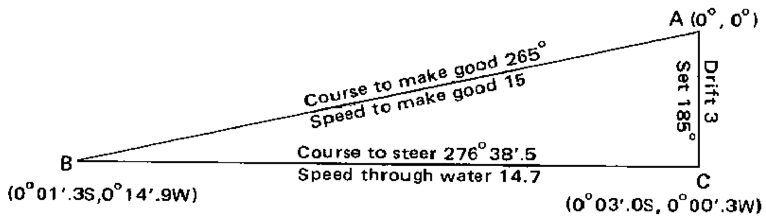


Answer (1) 88°58'.1
(2) 11.1 knots

Problem 2: Finding the course to steer and the speed to use to make good a given course and speed through a current.

The captain desires to make good a course of 265° and a speed of 15 knots through a current having a set of 185° and a drift of 3 knots.

Compute (1) the course to steer and (2) the speed to use.



This problem also can be solved by NC-2 in the [CR-MP] and [CD] modes by using speeds in lieu of distances as in Problem 1:

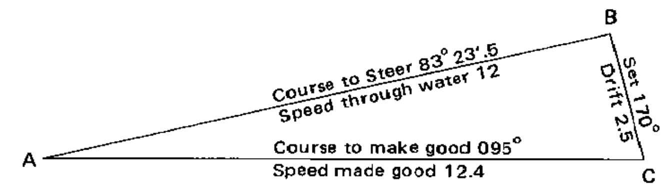
a. In [CR-MP] mode, key lat. 0°, long. 0° for point A.
b. Key course 265° and distance (speed) 15.
c. Values for point B are found to be 0°01'.3S, 0°14'.9W.
d. Still in [CR-MP] mode, again key lat. 0°, long. 0° for point A, then key course (set) 185° and distance (drift) 3 to get values for point C: 0°03'.0S, 0°00'.3W.
e. Change NC-2 to [CD] mode and key lat. 0°03'.0S, long. 0°00'.3W for point C and lat. 0°01'.3S, long. 0°14'.9W for point B. Answers are found to be course 276°38'5, distance (speed) 14.7.

Answer (1) 276°38'.5
(2) 14.7 knots

Problem 3: Finding the course to steer at a given speed to make good a given course through a current.

The captain desires to make good a course of 095° through a current having a set of 170° and drift of 2.5 knots, using a speed of 12 knots.

Compute (1) the course to steer and (2) the speed made good.



This problem can be solved by NC-2 using the following formulas.

$$\sin\alpha = \frac{SC \sin DC}{SB}$$

$$ST = \frac{SB \sin(180 - \alpha - DC)}{\sin DC}$$

Where

α = Ship's course correction angle
DC = direction of current relative to intended course
SB = speed of ship in knots through water
SC = speed of current in knots
ST = the actual ship speed made good

$$\sin\alpha = \frac{2.5 \times \sin(170 - 95)}{12} = 0.201234547 \quad {*1}$$

$$\alpha = 11.365 \quad {*2}$$

$$ST = \frac{12 \times \sin(180 - 11.365 - 75)}{\sin 75} = 12.40155402 \quad {*1}$$

Course to steer = 095° − 11°36'.5 = 83°23'.5

Answer (1) 83°23′.5 (2) 12.4 knots

*1 The multiplication and division in these cases must be made in [N] mode. We will get wrong answers if these computation are made in [ARC] mode. The best key sequence for the ST computation in this problem is: [ARC] 180-11.365-75 [=] [sin] [N] [×] 12 [÷] 75 [sin] [=].

*2 When we know that sin α = x , cos α = x or tan α = x and want to find the value of α by inverse trigonometric function the key sequence on NC-2 is x [arc] [sin] , x [arc] [cos] or x [arc] [tan].

Note: The current problems are taken from H.O. Pub. No. 9, American Practical Navigator by Bowditch. Slight differences in answers are due to the fact that Bowditch shows graphic solutions on a plane surface, whereas in Problems 1 and 2 the NC-2 utilizes the Mercator Sailing method based on a spherical surface.

Problem 4: Finding direction and speed of true wind.

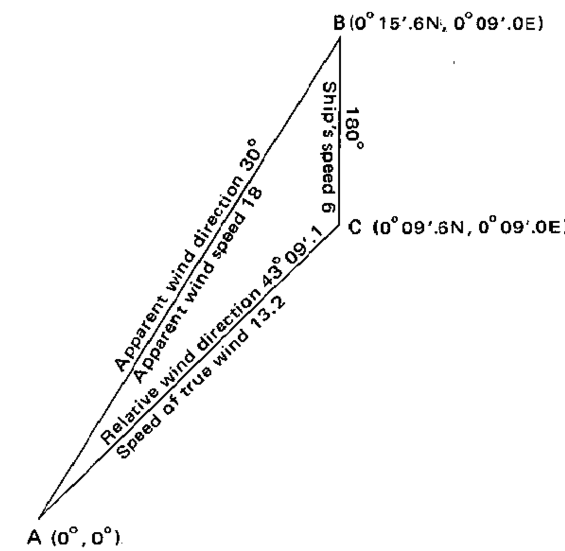
A ship is on a course of 115° at a speed of 6 knots. The apparent wind is blowing from 30° off the starboard bow (30° relative bearing) and its apparent speed is 18 knots.

Compute (1) the relative wind direction, (2) the true wind direction, and (3) speed of the true wind.

This problem can be solved by NC-2 in the [DR-MP] and [CD] modes by substituting speeds for distances, and using relative bearings and directions:

a. In [DR-MP] mode, key lat. 0°, long. 0° for point A.
b. Key course (relative direction from which apparent wind is blowing) 30° and distance (apparent wind speed) 18.
c. Values for point B are found to be 0°15′.6N, 0°09′.0E. Still in [DR-MP] mode, key these point B values followed by 180° (this value is the same for all such problems) and distance (speed) 6 to get values for point C: 0°09′.6N, 0°09′.0E.
d. Change NC-2 to [CD] mode and key lat. 0°, long. 0° for point A and lat. 0°09′.6N, long. 0°09′.0 E for point C. Answers are found to be relative wind direction 43°09′.1, speed of true wind 13.2. True wind direction is the relative direction plus the true heading, or 43°09′.1 + 115° = 158°09′.1.

Answers (1) 43°09′.1 (2) 158°09′1 (3) 13.2 knots



CHAPTER III

Glossary of Useful Mathematics for Navigation

LENGTH CONVERSIONS

1 meter	=	3.281 feet
1 foot	=	0.3048 meters
1 nautical mile	=	1,852 meters
1 nautical mile	=	6,076.1 feet
1 nautical mile	=	1.1507 statute miles

TEMPERATURE AND PRESSURE CONVERSIONS

Fahrenheit temperature: $F = \frac{9}{5}C + 32^\circ$

Celsius temperature: $C = \frac{5}{9}(F - 32^\circ)$

Inches of mercury $= \frac{\text{Millibars pressure}}{33.86}$

SPEED, TIME AND DISTANCE

$S = \frac{D}{T} \qquad T = \frac{D}{S} \qquad D = ST$

S = speed in knots
T = elapsed time in hours
D = distance in nautical miles

$S = \frac{60D}{T} \qquad T = \frac{60D}{S} \qquad D = \frac{ST}{60}$

S = speed in knots
T = elapsed time in minutes
D = distance in nautical miles

$S = \frac{3600D}{T} \qquad T = \frac{3600D}{S} \qquad D = \frac{ST}{3600}$

S = speed in knots
T = elapsed time in seconds
D = distance in nautical miles

DISTANCE OFF AN OBJECT BY A SINGLE BEARING

From Fig. A

D abeam $= R \tan B_1$

D abeam = distance in nautical miles to object when the ship drew abeam

R = distance in nautical miles run till object drew abeam

B_1 = observed relative bearing of object

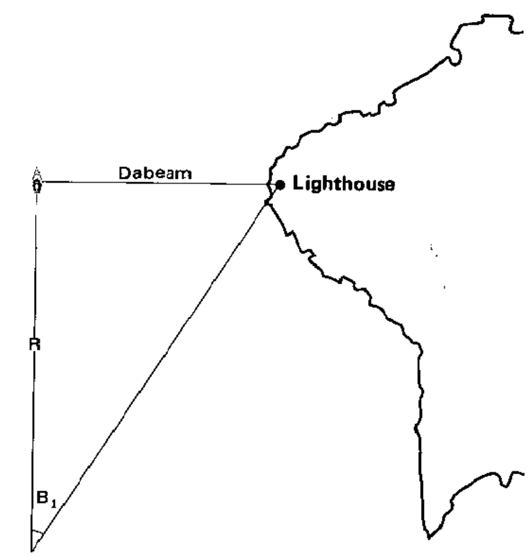


Fig. A

DISTANCE OFF AN OBJECT BY TWO BEARINGS

From Fig. B

$$D_2 = \frac{R \sin B_1}{\sin (B_2 - B_1)}$$

$$D \text{ abeam} = D_2 \sin B_2$$

$$D_1 = \frac{D \text{ abeam}}{\sin B_1}$$

B_1 = first relative bearing of object
B_2 = second relative bearing of object
R = distance in nautical miles run between bearings
D_1, D_2 = distance in nautical miles to object at time of first and second bearings.

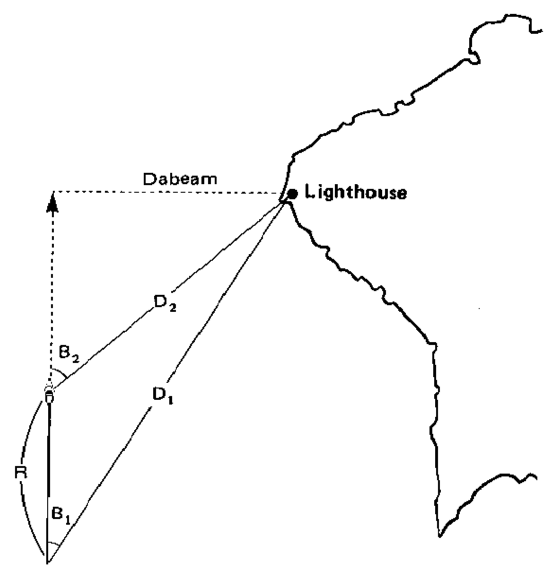


Fig. B

APPLICATION OF MARINE SEXTANT IN MEASURING DISTANCE

From Fig. C

$$D = \sqrt{\left(\frac{\tan \alpha}{0.000246}\right)^2 + \frac{H-h}{0.74736}} - \frac{\tan \alpha}{0.000246}$$

$$D \text{ hor} = 1.144\sqrt{h}$$

$$D \text{ vis} = 1.144\,(\sqrt{h} + \sqrt{H}\,)$$

where

D = distance to object in nautical miles
D hor = distance to horizon in nautical miles
D vis = distance of visibility in nautical miles
H = height of object beyond horizon in feet
h = height of the observer's eye in feet above sea level
α = corrected sextant vertical angle
(make corrections for Dip and Index error.
Dip is $-\,0.'97\sqrt{h \text{ in feet}}$)

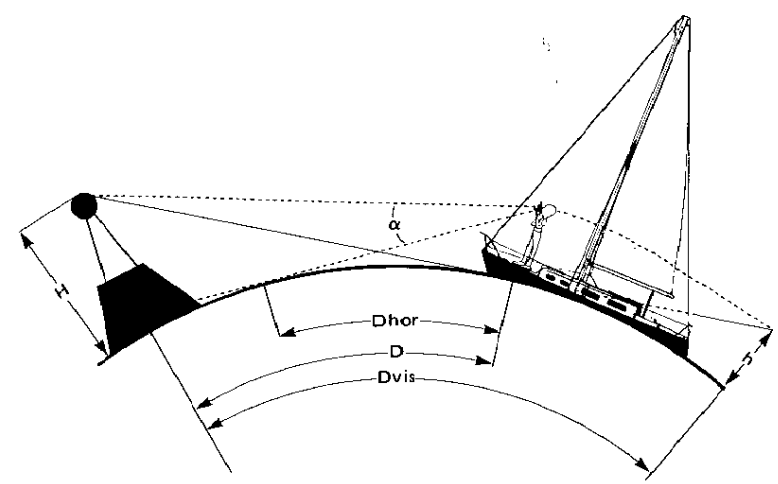


Fig. C

From Fig. D

$$D = \frac{h}{\tan(\alpha_1 + 0'.97\sqrt{h})} \quad {*1}$$

$$D = \frac{H}{\tan \alpha_2}$$

where
- D = distance to object in feet above sea level.
- H = height of object in feet.
- h = height of eye in feet above sea level.
- α_1 = vertical angle between object's waterline and the horizon, corrected for index error only.
- α_2 = vertical angle between top of the object and its waterline, corrected for index error only.

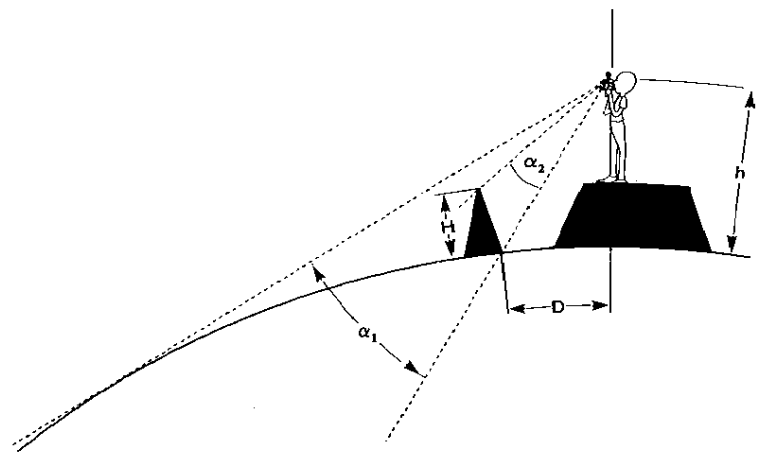
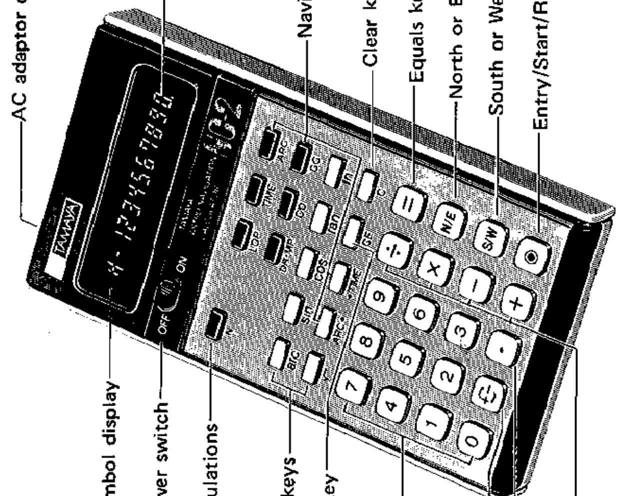


Fig. D

*1 The reciprocal computation procedures (x $\boxed{\div}\boxed{=}\boxed{=}$ for 1/x) can be used for this problem.

APPENDIX : EXPLANATION OF NC-2 ASTRO-NAVIGATION CALCULATOR



EXPLANATION OF MODE SELECTORS AND KEYS

NAVIGATION MODE KEYS

LOP — mode key calculates the Altitude and Azimuth of the Sun, Moon, planets and the stars to obtain a Line of Position in celestial navigation.

DR-MP — mode key calculates the Dead Reckoning and Most Probable Position.

CD — mode key calculates the Course and Distance by Mercator Sailing and Mid-latitude Sailing.

GC — mode key calculates the Initial Course and Distance by Great-circle Sailing.

TIME — mode key makes the hours, minutes, seconds calculation.

ARC — mode key makes the degrees, minutes and 1/10 minutes calculation.

ARC← — mode key converts the hours, minutes and seconds into degrees, minutes and 1/10 minutes.

→TIME — mode key converts the degrees, minutes and 1/10 minutes into hours, minutes and seconds.

FUNCTIONS KEYS

arc: Key for converting sin, cos and tan to $\sin^{-1}$, $\cos^{-1}$ and, $\tan^{-1}$ functions.

sin cos tan: Trigonometric function keys

ln: Natural logarithmic function key

$\sqrt{\ }$ **:** Square root calculation key

OTHER KEYS

C — Clears all the calculation registers, error etc. Resumes the beginning of the program in CD, DR-MP, LOP, GC, TIME, ARC.

CE — Clears only displayed register.

0 → 9 — Numeral keys to enter a number.

• — Designates the decimal point of a set number.

× ÷ + − — Sets the order of each function.

= — Completes the addition, subtraction, multiplication, division functions.

+/− — Inverts the sign of a displayed number.

N/E — Designates North in latitude and East in longitude.

S/W — Designates South in latitude and West in longitude.

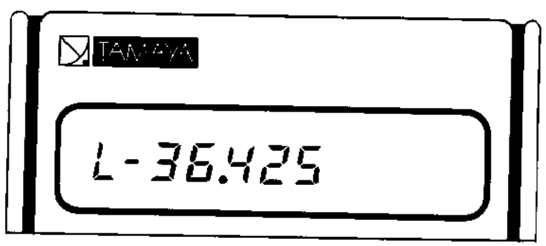
◉ — Enters a number, starts the programmed calculation and recalls the memory.

off ▭ on
Power switch. — When the power switch is slid to "ON" position the calculator is powered, automatically cleared and ready for operation by normal calculation mode.

N — Clears the navigation modes and sets the normal calculation mode.

EXPLANATION OF DIALOGUE SYMBOLS AND INDICATORS

Dialogue system makes the operation very easy by telling you at each step what data to feed in. The answers are also accompanied by the symbols which specify the meaning.



Ex. Latitude 36°42′.5S

NC-2 ASTRO-NAVIGATION CALCULATOR

INPUT/OUTPUT DIALOGUE

LOP ▼	DR.MP CD GC ▼	TIME ▼	ARC ▼	MODE / MEANING
H				Local Hour Angle
d				declination
A				Computed Altitude
Ξ				Azimuth
L	L			Latitude
	//			longitude
	c			course (Azimuth)
	d			distance (Intercept)
		h		hour
			d	degree

– sign after L indicates South latitude

– sign after // indicates West longitude

E : Overflow error symbol

– : minus symbol

The wise Navigator uses all reliable aids available to him, and seeks to understand their uses and limitations. He learns to evaluate his various aids when he has means for checking their accuracy and reliability, so that he can adequately interpret their indications when his resources are limited. He stores in his mind the fundamental knowledge that may be needed in an emergency. Machines may reflect much of the *SCIENCE* of Navigation, but only a competent human can practice the *ART* of Navigation.

– from H.O. Pub. No.9 American Practical Navigator by Bowditch –