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HP-65

NAVIGATION PAC 1

Addendum

HP-65 NAV PAC 1

This addendum contains information regarding two programs in the HP-65 NAV Pac 1.

Rhumbline Navigation (NAV1-09A). A fourth note should be added on p. 29: "This program gives incorrect results when computing distances due east or due west across the dateline. To obtain correct results, compute up to the dateline and then proceed on the other side."

Composite Sailing (NAV1-12A). The equations for λ_{v1} and λ_{v2} should contain the term sgn $(|\lambda_2 - \lambda_1| - 180)$ instead of sgn (L_{max}) so that the program will work correctly when the initial and final positions are on opposite sides of the dateline. A corrected version of the prerecorded magnetic card for this program is included in the magnetic card case or in this envelope. The corrected version is designated by a "B" following the program number: NAV1-12B. If it is enclosed in the envelope, replace the uncorrected card in the magnetic card case with the corrected version. The corrected listing is on the back side of this card.

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NAVIGATION PAC 1 INTRODUCTION

The HP-65 Navigation Pac I is a set of programs intended to assist the navigator by eliminating some of the more difficult calculations which he would normally perform. Using the prerecorded program cards contained in this pac the navigator will be able to reduce a sight to his most probable position with reference to nothing but the user instruction forms contained herein.

The programs of Navigation Pac I are grouped into three broad categories: piloting and dead reckoning, celestial navigation, and relative motion problems. The piloting programs include such programs as length conversions and propeller slip calculations as well as course planning and plotting aids such as great circle computations and rhumbline navigation. The celestial navigation programs include sextant altitude correction, a long-term almanac for sun and stars, a sight reduction table, and programs to reduce altitude intercepts to a most probable position. The remaining programs are specialized situations, such as collision avoidance, which are commonly solved on the maneuvering board or plotting sheet.

Many of the programs in this pac are designed to work together, sharing data through the storage registers, so that the user need only input new data and record final answers. Some program combinations are illustrated in the appendix.

USING THE KEYBOARD AND DATA FORMATTING

When running Navigation Pac I programs, only a few of the many keys on the HP-65 are actually used. The only keys you'll usually need are the number entry keys ([0] through [9] , [•] decimal point, [EEX] enter exponent, and [CHS] change sign), the five keys at the top labeled [A] through [E] , and the [R/S] key. In some cases it may be convenient to use the "to degrees, minutes, and seconds" key [→D.MS] to convert data before giving it to a program.

The angular notation most familiar to navigators is 110°58.'3, that is: degrees, minutes and tenths. Consequently, most of the programs in this pac accept and display angles in the form degrees, minutes and tenths (DDMM.m).* Azimuths and bearings are normally expressed only to the nearest tenth degree and are therefore expressed in the form D.d. Two programs were too complicated to include the capability of handling DDMM.m. These programs accept angles expressed in degrees, minutes and seconds (D.MS). Thus an angle of 35°28.'3 (35°28′18″) would be input in the form DDMM.m

*The lower case "m" indicates units one tenth as large as those indicated by the upper case "M".

as 3528.3 and in the form D.MS as 35.2818. If the angle is small, care must be taken that the digits are properly placed with respect to the decimal point (e.g., 9.'5 would be input in the form DDMM.m as 9.5 and in the form D.MS as .0930). Time, essentially an angular measure, is normally input in hours, minutes and seconds (H.MS).

RUNNING A PROGRAM

To run a program, pass the card through the lower slot as described on page 82. After the card has been run through the lower slot, it may be placed in the upper or window slot. Labels on the card will then identify the new functions of the A–E keys. Then input the data as indicated on the instruction form and press the appropriate lettered key to process the data. Although the symbols used for labels cannot replace the user instruction forms, they do serve to remind the user of the function of the corresponding key. In general the data may be input in any order, although it is recommended that the keys be pushed in order from left to right to avoid missing any. On the user instruction form, some data are preceded by large dots. These dots indicate that the corresponding data may be input in arbitrary order and that if one is entered incorrectly it may simply be reentered without restarting the entire problem. Programs which cannot accept data in arbitrary order have no dots on the user instruction form.

Usually programs may be run in any desired order but there are cases in which a particular order is important. Such cases are pointed out in the user instruction forms.

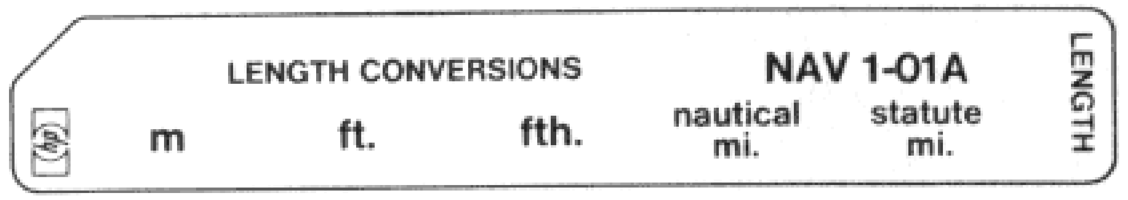
NAVIGATING WITH THE NAVIGATION PAC

It is sincerely hoped that navigational plots made with the aid of the HP-65 Navigation Pac will be easier to make and more accurate. Hopefully a navigator freed from the difficulties of evaluating complicated expressions will be able to spend more time insuring the safety of his ship.

ACKNOWLEDGMENTS

The Navigation Pac has benefitted immeasureably from the comments and suggestions of both professional and backyard navigators. We especially wish to thank Captain H.H. Shufeldt, USNR(Ret.), for his assistance in choosing important navigation problems to solve and rendering the text more comprehensible to the navigator. In addition we wish to extend our appreciation to Dr. Luis Alvarez for his sight reduction table and to John Benger for assisting with the presentation and for preparing practical examples.

NAV 1-01A
LENGTH CONVERSIONS



This program converts between various measures of length: metres, feet, fathoms, nautical miles, and statute miles.

Conversion Factors:

1 metre = 1 metre
1 foot = 0.3048 metres
1 fathom = 1.8288 metres
1 nautical mile = 1852 metres
1 statute mile = 1609.344 metres

Example 1:

Convert 16 metres to fathoms.

Solution:

16 [A] [C] ——→ 8.75

Example 2:

Convert 27 fathoms to feet

Solution:

27 [C] [B] ——→ 162.00

Example 3:

Convert 2.6 nautical miles to yards

Solution:

2.6 [D] [B] ——→ 15797.90
(first convert to feet)

3 [÷] ——→ 5265.97
(then divide by 3 to get yards)

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter LENGTH				
2	Key in one of the following				
	length in metres	l, m	A		0.00
	length in feet	l, ft.	B		0.00
	length in fathoms	l, fth.	C		0.00
	length in nautical miles	l, naut. mi.	D		0.00
	length in miles	l, mi.	E		0.00
3	Convert length to				
	metres or		A		l, m
	feet or		B		l, ft.
	fathoms or		C		l, fth.
	nautical miles or		D		l, naut. mi.
	miles		E		l, mi.

NAV 1-02A
SPEED, TIME, AND DISTANCE

SPEED,TIME, AND DISTANCE			NAV 1-02A
SPEED	TIME H.MS	TIME H.h	DISTANCE

This program finds a value for speed, time or distance when the other two are specified. The variable *time* may be expressed as H.MS or H.h.

Equations:

$$S = \frac{D}{t}$$

$$D = St$$

$$t = \frac{D}{S}$$

where

S = speed, distance units per hour

t = time, Hours.minutes-seconds or Hours.tenths

D = distance, any length unit

Example 1:

A vessel makes good 17.6 nautical miles in 45 minutes. What is her speed? (23.47 knots)

Solution:

17.6 [D] 0.45 [B] [A] ⟶ 23.47

Example 2:

At this speed how much longer will it take to cover 10 more miles? ($25^m 34^s$ or 0.43 hours)

Solution:

23.47 [A] 10 [D] [B] ⟶ 0.2534
0 [C] ⟶ 0.43

Example 3:

A vessel covers a measured mile in 343 seconds. What is her speed? (10.5 knots)

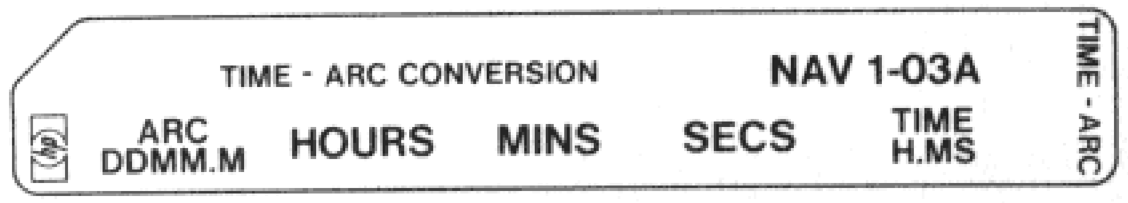
Solution:

343 [ENTER↑] 3600 [÷] [C] 1 [D] [A] ⟶ 10.50

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter S, T, D			
2	Key in two of the following			
	• Speed	S	[A]	0.00
	• Time in hours, minutes, and			
	seconds or	t, H.MS	[B]	0.0000
	in hours and tenths *	t, H.h	[C]	0.00
	• Distance	D	[D]	0.00
3	Compute remaining one			
	Speed		[A]	S
	Time in hours, minutes, and			
	seconds or		[B]	t, H.MS
	in hours and tenths		[C]	t, H.h
	Distance		[D]	D
*	To convert time in seconds to			
	H.h	t, sec	[↑]	t, sec
		3600	[÷]	t, H.h

NAV 1-03A

TIME-ARC CONVERSION



This program converts among arc and various representations for time. Angles are expressed as DDMM.m and time is expressed as H.h, M.m, S.s, or H.MS.

Conversion Factors:

1° of arc = 240 seconds
1 hour = 3600 seconds
1 minute = 60 seconds
1 second = 1 second

Example 1:

Convert $2^h 25^m 36^s$ to minutes. (145.6 minutes)

Solution:

2.2536 **E** **C** ⟶ 145.60

Example 2:

Convert $258^\circ 15'.6$ to time in H.MMSS. $(17^h 13^m 02^s)$

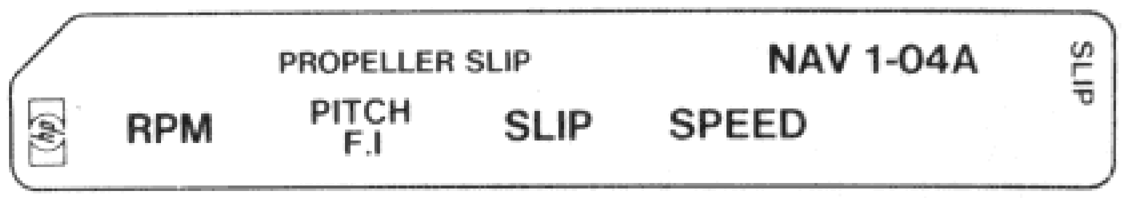
Solution:

25815.6 **A** **E** ⟶ 17.1302

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter TIME-ARC			
2	Key in one of the following			
	Arc	Arc, DDMM.m	A	0.
	Time in hours	t, hr	B	0.
	Time in minutes	t, min	C	0.
	Time in seconds	t, sec	D	0.
	Time in hours, minutes, and			
	seconds	t, H.MS	E	0.
3	Convert to			
	Arc or		A	Arc, DDMM.m
	Time in hours or		B	t, hr
	Time in minutes or		C	t, min
	Time in seconds or		D	t, sec
	Time in hours, minutes, and			
	seconds		E	t, H.MS

NAV 1-04A

PROPELLER SLIP



This program calculates a value for RPM, pitch, slip, or speed when the other three are specified. Pitch is input in the form feet and inches (FF.II). Thus a pitch of 9′3″ would be keyed in as 9.03.

Equation:

$$\text{Speed} = \frac{\text{RPM} \times \text{pitch} \times 60 \times (1 - \text{slip})}{6076}$$

Notes:

1. If zero slip is desired, enter a small number such as .001, because the program uses the value zero to decide whether an input has been made or the indicated item should be calculated.
2. An output for pitch such as 8.12 (8′12″) may result: it should be interpreted as 9′0″.

Example

A propeller having a pitch of 10 feet turns at 200 revolutions per minute. If there is 18% slip, what is the ship's speed? (16.19 knots)

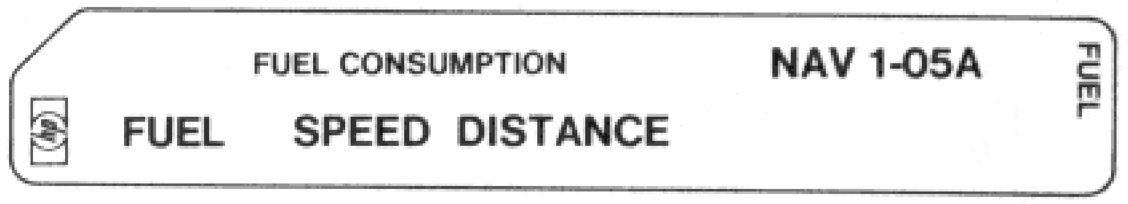
Solution:

200 [A] 10 [B] 18 [C] [D] ⟶ 16.19

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter SLIP		[ ] [ ]	
2	Key in three of the following		[ ] [ ]	
	RPM	RPM	[A] [ ]	0.00
	Pitch	pitch, FF.II	[B] [ ]	0.00
	Slip	slip, %	[C] [ ]	0.00
	Speed	speed, knots	[D] [ ]	0.00
3	Compute the remaining one		[ ] [ ]	
	RPM		[A] [ ]	RPM
	Pitch		[B] [ ]	pitch, FF.II
	Slip		[C] [ ]	slip, %
	Speed		[D] [ ]	speed, knots

NAV 1-05A

FUEL CONSUMPTION



This program solves for fuel consumption, speed, or distance run given the other two. Any convenient measuring unit may be used. The program is not valid near the vessel's hull speed or when the vessel starts to "plane."

Equations:

$$\frac{F_2}{F_1} = \left(\frac{S_2}{S_1}\right)^2 \left(\frac{D_2}{D_1}\right)$$

where

F_1 = fuel used at speed S_1 while travelling distance D_1

F_2 = fuel used at speed S_2 while travelling distance D_2

The above equation may be written in three forms:

$$F_2 = F_1 \left(\frac{S_2}{S_1}\right)^2 \frac{D_2}{D_1}$$

$$D_2 = D_1 \left(\frac{S_1}{S_2}\right)^2 \frac{F_2}{F_1}$$

$$S_2 = S_1 \sqrt{\frac{F_2}{F_1} \frac{D_1}{D_2}}$$

Note:

Fuel consumption in a given time t may be computed using this program. Although the distances D_1 and D_2 will be $S_1 t$ and $S_2 t$, they may be input simply as S_1 and S_2, because the time units will cancel out of the equation.

Example 1:

At 8 knots, 51 gallons of fuel are required to run 625 miles. The skipper wishes to run another 315 miles but does not want to use more than 20 gallons. What is his highest allowable speed? (7 knots)

Solution:

8 [B] 51 [A] 625 [C] 315 [C] 20 [A] [B] ⟶ 7.06

Example 2:

At 12 knots, 293 tons of fuel are required to steam 2097 miles. If the speed is increased to 15 knots, how many tons of fuel are required to steam the same distance? (457.8 tons) How many tons are required to steam 4282 miles at this new speed? (934.8 tons)

Solution:

12 [B] 293 [A] 2097 [C] 15 [B] 2097 [C] [A] ⟶ 457.81

12 [B] 293 [A] 2097 [C] 15 [B] 4282 [C] [A] ⟶ 934.84

Example 3:

It takes 1.5 gallons of diesel fuel to run 1 mile at 8 knots. What is the consumption if its speed is reduced to 5 knots? (.6 gal/mile) If its speed is increased to 15 knots? (5.3 gal/mile)

Solution:

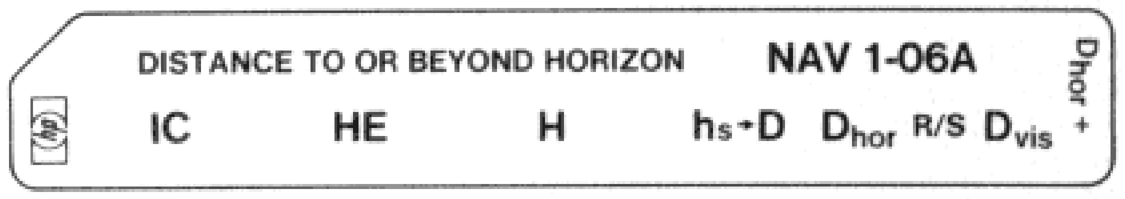
1.5 [A] 8 [B] 1 [C] 5 [B] 1 [C] [A] ⟶ 0.59

1.5 [A] 8 [B] 1 [C] 15 [B] 1 [C] [A] ⟶ 5.27

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter FUEL			
2	Key in all three values for con-			
	dition 1			
	• Fuel consumption	F_1	A	0.00
	• Speed	S_1	B	0.00
	• Distance	D_1	C	0.00
3	Key in *two* values for condition			
	2			
	• Fuel consumption	F_2	A	0.00
	• Speed	S_2	B	0.00
	• Distance	D_2	C	0.00
4	Compute *unknown* value for			
	condition 2			
	Fuel consumption or		A	F_2
	Speed or		B	S_2
	Distance		C	D_2

NAV 1-06A

DISTANCE TO OR BEYOND HORIZON



This program computes the distance to an object of known height whose base is obscured by the horizon and whose top subtends a sextant altitude hs with the horizon. The sextant altitude is corrected for index error and height of eye. Additional features are the calculation of the distance to the horizon for a given height of eye and the distance of visibility of an object of height H above sea level.

Equations:

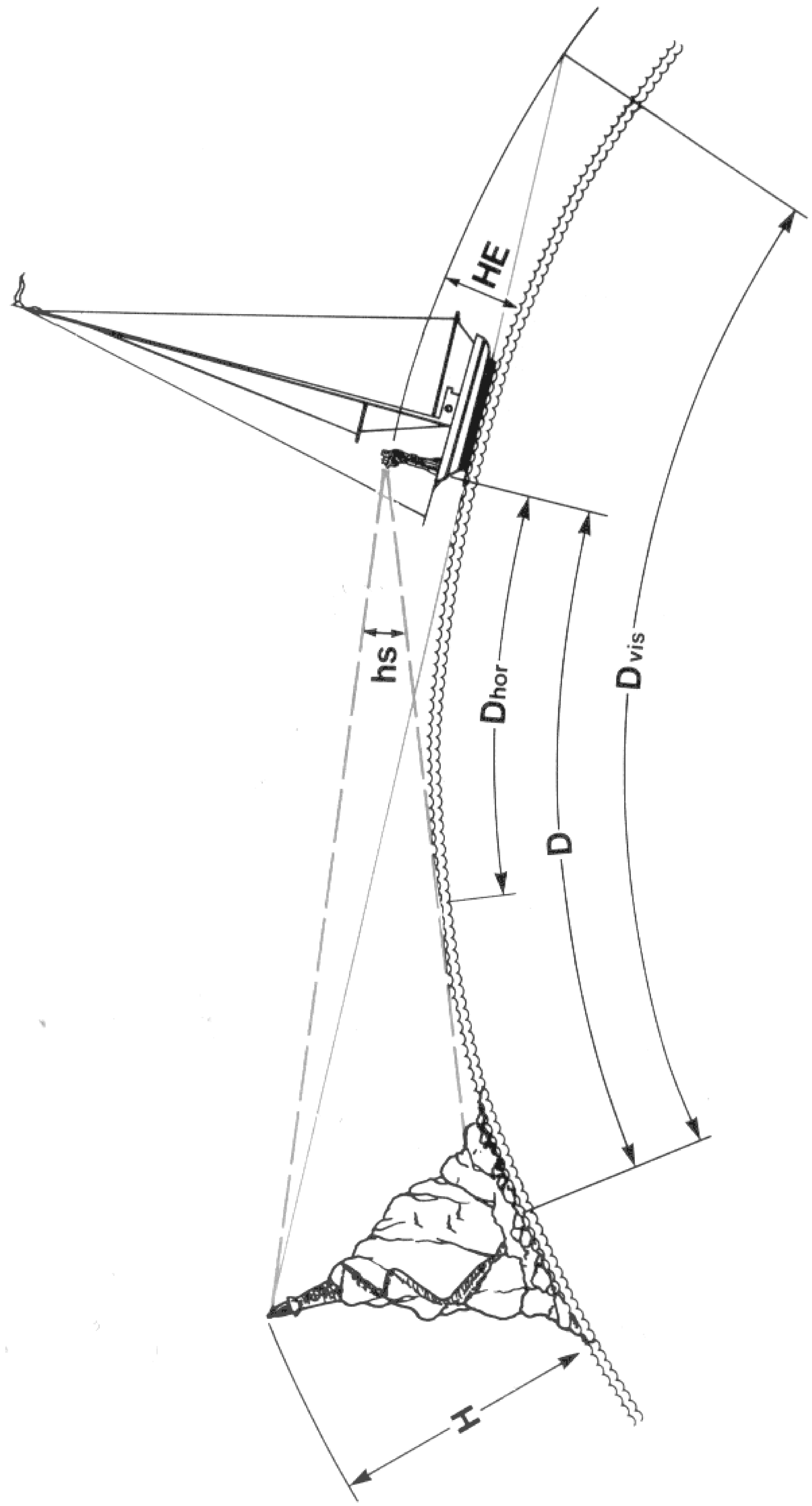
$$D = \sqrt{\left(\frac{\tan h_a}{2.46 \times 10^{-4}}\right)^2 + \frac{H-HE}{0.74736}} - \frac{\tan h_a}{2.46 \times 10^{-4}}$$

$$D_{hor} = 1.144\ \sqrt{HE}$$

$$D_{vis} = 1.144\ (\sqrt{HE} + \sqrt{H}\ )$$

where

- D = distance to object, nautical miles
- D_{hor} = distance to horizon, nautical mile.
- D_{vis} = distance of visibility, nautical mile
- H = height of object beyond horizon, feet
- HE = height of eye, feet
- $ha = hs + IC - 0.97\sqrt{HE}$
- hs = sextant altitude, DDMM.m
- IC = index correction, M.m



Example 1:

The height of eye of an observer is 9 feet above sea level, how far away is his horizon? (3.43 nautical miles)

Solution:

9 B E ⟶ 3.43

Example 2:

An observer "bobs" Farallon Light on the horizon and finds his height of eye to be 16 feet. The light is 358 feet above sea level. How far is the observer from the light? (26.22 nautical miles) (Accuracy is affected by abnormal refraction)

Solution:

16 B 358 C E R/S ⟶ 26.22

Example 3:

The top of a lighthouse, whose base is obscured by the horizon, is known to be 300 feet above sea level. It is found to have a sextant altitude of 25.'6 above the horizon. The height of eye is 20 feet and the sextant requires an index correction of +1.'3.

What is the distance to the lighthouse? (6.28 nautical miles)

What is the distance to the horizon? (5.12 nautical miles)

It has been determined that the luminous range of the light is "strong", now compute its visibility for the given height of eye. (24.93 nautical miles)

Solution:

1.3 A 20 B 300 C 25.6 D ⟶ 6.28

E ⟶ 5.12

R/S ⟶ 24.93

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter D_{hor} +				
2	Key in all of the following				
	• Index Correction	IC, M.m	A		
	• Height of eye	HE, ft.	B		
	• Height of object	H, ft.	C		
3	Key in sextant height and compute				
	Distance to object	hs, DDMM.m	D		D, naut. mi.
	Distance to horizon (optional)		E		D_{hor}, naut. mi.
	Distance of visibility (optional)		R/S		D_{vis}, naut. mi.

NAV 1-07A

DISTANCE BY HORIZON ANGLE AND DISTANCE SHORT OF HORIZON

DISTANCE BY HORIZON ANGLE DISTANCE SHORT OF HORIZON			NAV 1-07A		Dhor →
IC	HE	hs→D	H↓ hs→D	D↓ hs→H	

This program calculates the distance between an observer and an object when (1) the vertical angle between its waterline and the horizon has been observed from a known height of eye or (2) the object's height is known, together with its subtended angle.

This program also calculates the height of an object if its subtended angle and distance from the observer are known.

Equations:

$$D = \frac{HE}{\tan(hs + IC + .97\sqrt{HE})}$$

$$D = \frac{H}{\tan(hs + IC)}$$

where:

D = distance to object, feet

HE = height of eye, feet

IC = index correction, M.m

H = height of object, feet

hs = sextant altitude, DDMM.m

Note:

hs < 10′ may make D unreliable due to atmospheric conditions when vertical sextant altitude between object and horizon is taken.

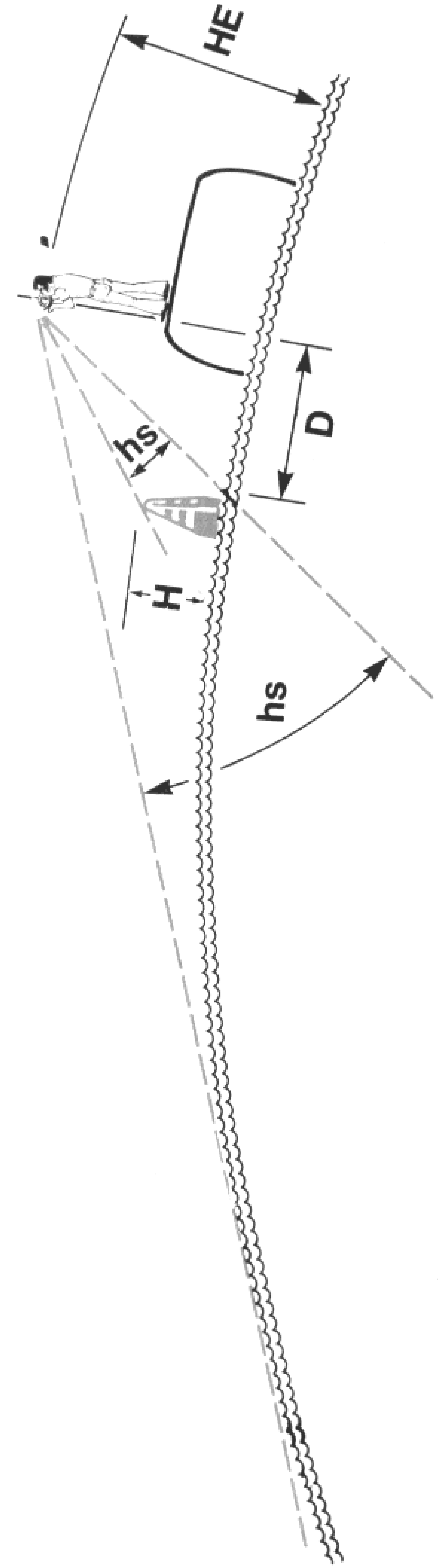
Example 1:

The sextant altitude between the waterline of a buoy and the horizon is found to be 21.′4. The observer has a height of eye of 22 feet and the sextant requires a +1.′7 index correction. How far is the observer from the buoy? (2735.25 feet or .45 nautical mile)

Solution:

1.7 [A] 22 [B] 21.4 [C] ⟶ 2735.25

[R/S] ⟶ 0.45



Example 2:

The sextant altitude subtended by the base and the top of a 41 foot light tower is 56.'2. The sextant requires a −1.'9 index correction. How far is the observer from the light tower? (2595.50 feet or .43 nautical mile)

Solution:

−1.9 **A** 41 [ENTER↑] 56.2 **D** ——→ 2995.50

R/S ——→ 0.43

Example 3:

A vessel is anchored 2015 feet from an observer. The sextant altitude between the vessel's waterline and truck of mast is 1°15.'2. There is no index error. How high is the truck of the mast above the waterline? (44 feet)

Solution:

0 **A** 2015 [ENTER↑] 115.2 **E** ——→ 44.08

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter D_{hor} –				
2	Key in the following				
	• Index correction	IC,M.m	A		IC,Mm
	• Height of eye	HE, ft.	R		HE, ft.
3	Key in sextant height and convert to distance				
	Sextant height	hs, DDMM.m	C		D, ft.
	Convert D to nautical miles (optional)		R/S		D, naut. mi.
4	Key in height of object and convert to distance				
	Height of object	H, ft.	↑		H, ft.
	Sextant height (angle subtended by object)	hs, DDMM.m	D		D, ft.
	Convert D to nautical miles (optional)		R/S		D, naut. mi.
5	Key in distance to object and convert to height				
	Distance	D, ft.	↑		D, ft.
	Sextant height	hs, DDMM.m	E		H, ft.

NAV 1-08A

DEAD RECKONING

DEAD RECKONING		NAV 1-08A
$L_i \uparrow \lambda_i$ D.MS	$\Delta t \uparrow C \uparrow S$	L R/S λ

This program calculates a ship's DR position given the ship's course, speed, and elapsed time from the last fix or DR position. The DR position is stored so that on subsequent legs just course, speed, and elapsed time need be entered to obtain the updated DR position. The program may be used for both small and large area DR problems. Because of the complexity of the equations used, it was impossible to allow this program to accept or display data in the form DDMM.m. Instead the program uses D.MS notation and forces four decimals to be displayed.

Equations:

The updated position (L, λ) is given by following a loxodrome (rhumbline) from the initial position (L_i, λ_i) for a distance determined by the speed and time.

$$L = L_i + \Delta t \frac{S \cos C}{60}$$

$$\lambda = \begin{cases} \lambda_i + \dfrac{180 \tan C\left(\ln \tan\left(45 + \dfrac{L_i}{2}\right) - \ln \tan\left(45 + \dfrac{L}{2}\right)\right)}{\pi}; & C \neq 90 \text{ or } 270 \\ \lambda_i - \Delta t \dfrac{S \sin C}{60 \cos L_i}; & C = 90 \text{ or } 270 \end{cases}$$

where:

L_i = initial latitude (N, positive; S, negative (CHS))

L = updated latitude

d_i = initial longitude (W, positive; S, negative (CHS))

λ = updated longitude

S = ship's speed, knots

C = ship's course

Δt = the time (H.MS) between initial and final positions.

Notes:

1. The program cannot follow a meridian over a pole.
2. The program loses accuracy and gets incorrect answers when within 0.5° of a pole.
3. The program may stop executing due to a machine limitation on courses 090 and 270. An unexpected display of zero will appear very soon after pressing **C**. Simply press **R/S** and the program will continue, computing the correct updated L and λ.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter DR				
2	Key in initial position				
	Latitude† (CHS for South)	L_i, D.MS	↑		L_i, D.MS
	Longitude (CHS for East)	λ_i, D.MS	A		L_i, D.d
3	Key in ship's way				
	Time spent on this course	Δt, H.MS	↑		Δt, H.MS
	Course*	C, D.d	↑		C, D.d
	Speed	S, knots	B		Δt, H.h
4	Compute new position				
	Latitude (– = S, + = N) th)		C		L, D.MS
	Longitude (– = E, + = W))		R/S		λ, D.MS
5	To continue the same course for				
	the same time, go to step 4. To				
	change the course, speed, or				
	time, go to step 3.				
*	If C = 090 or 270, the program				
	may halt prematurely when **C**				
	is pressed displaying 0.0000.				
	Pressing **R/S** will allow the				
	program to continue, and cor-				
	rect answers will be obtained.				
†	To convert DDMM.m to D.MS	DDMM.m	f	→D.MS	DDMM.SS
			EEX	2	1. 02
			÷		D.MS

Example 1:

A ship's last fix was L30°N, λ140°W. Where will she be after travelling for 2 hours at 12 knots on course 052°? (L30°14′47″N, λ139°38′08″)

Solution:

Enter DR

30 [ENTER↑] 140 [A] 2 [ENTER↑] 52 [ENTER↑]

12 [B] [C] ——→ 30.1447

[R/S] ——→ 139.3808

Example 2:

A vessel's position is L33°49.′1N, λ120°52.′0W at 1200. If she steams as shown, what is her position at each time?

Time	C	S	DR
1200			L33°49′06″N, λ120°52′00″W
1330	120°	15 knots	(L33°37′30″N, λ120°28′34″W)
1510	240°	15 knots	(L33°25′21″N, λ120°54′32″W)
1823	90°	17 knots	(L33°25′21″N, λ119°49′01″W)
1955	355°	20 knots	(L33°55′54″N, λ119°52′14″W)

Solution:

Enter DR

33.4906 [ENTER↑] 120.52 [A] 13.30 [ENTER↑]

12.00 [f⁻¹] [D.MS+] 120 [ENTER↑] 15 [B] [C] ——→ 33.3730

[R/S] ——→ 120.2834

15.10 [ENTER↑] 13.30 [f⁻¹] [D.MS+]

240 [ENTER↑] 15 [B] [C] ——→ 33.2521

[R/S] ——→ 120.5432

18.23 [ENTER↑] 15.10 [f⁻¹] [D.MS+]

90 [ENTER↑] 17 [B] [C] ——→ 0.0000

(Note 3)

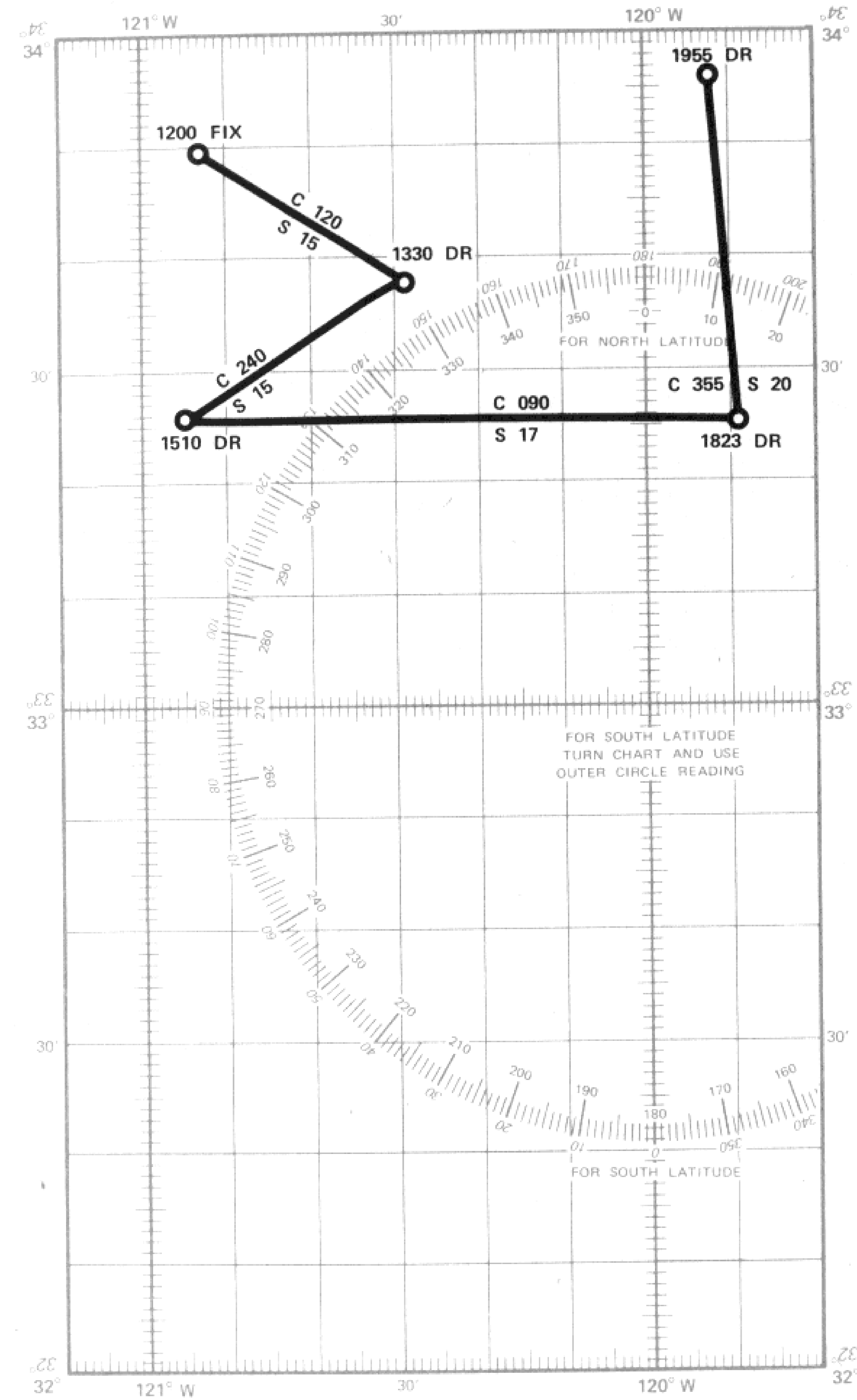
[R/S] ——→ 33.2521

[R/S] ——→ 119.4901

19.55 [ENTER↑] 18.23 [f⁻¹] [D.MS+]

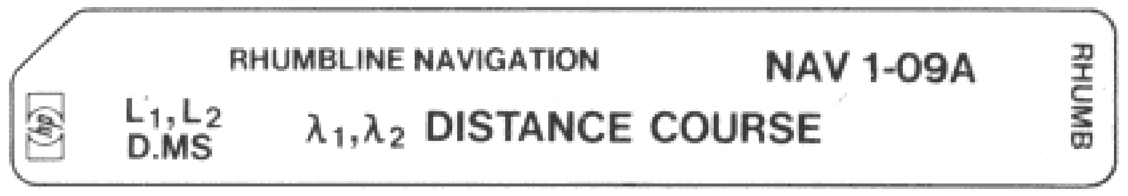
355 [ENTER↑] 20 [B] [C] ——→ 33.5554

[R/S] ——→ 119.5214



NAV 1-09A

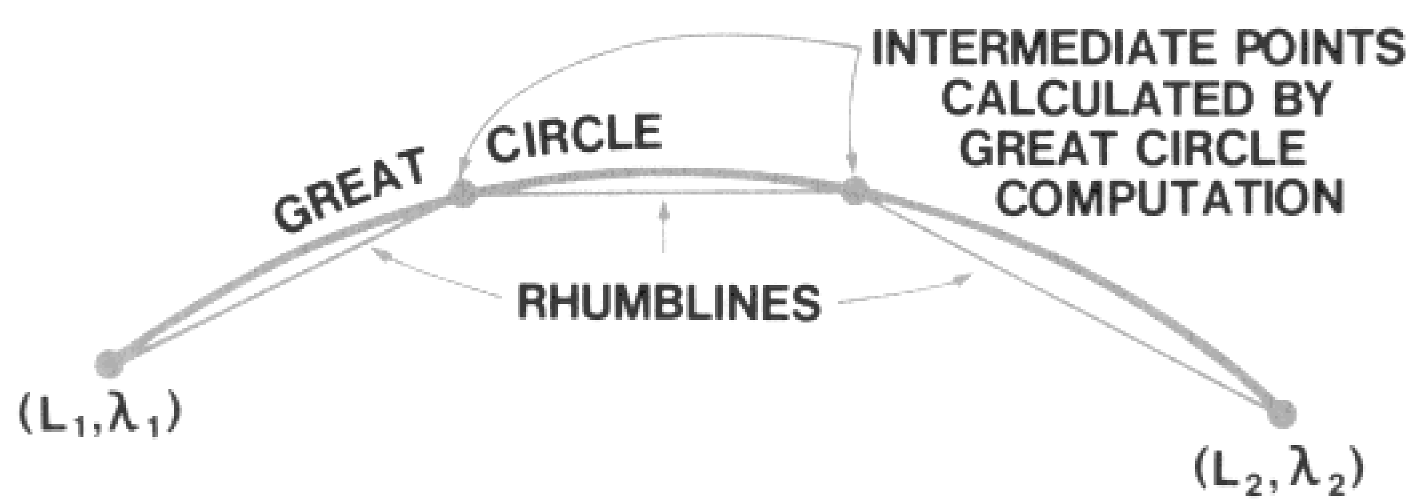
RHUMBLINE NAVIGATION



This program accepts the coordinates of two points on the globe and calculates the rhumbline course C and distance D between them. The program inputs are latitude and longitude of the initial point (L_1, λ_1) and latitude and longitude of the final point (L_2, λ_2) in degrees, minutes, and seconds. The program outputs are heading in degrees and distance in nautical miles.

Since the rhumbline is the constant heading path between points on the globe, it forms the basis of short distance navigation. In low and mid latitudes the rhumbline is sufficient for virtually all course and distance calculation which navigators encounter. However, as distance increases or at high latitudes the rhumbline ceases to be an efficient track since it is not the shortest distance between points.

The shortest distance between points on a sphere is the great circle. However, in order to steam great circles, an infinite number of heading changes are necessary. Since it is impossible to calculate an infinite number of headings at an infinite number of points, several rhumblines may be used to approximate a great circle. The more rhumblines that are used the closer to the great circle distance the sum of the rhumbline distances will be. The Great Circle Computation program may be used to calculate intermediate heading change points which can be linked by rhumblines.



Equations:

$$C = \tan^{-1} \frac{\pi(\lambda_1 - \lambda_2)}{180(\ln\tan(45 + \frac{1}{2}L_2) - \ln\tan(45 + \frac{1}{2}L_1))}$$

$$D = \begin{cases} 60(\lambda_2 - \lambda_1)\cos L; \cos C = 0 \\ 60\,\dfrac{(L_2 - L_1)}{\cos C}; \text{otherwise} \end{cases}$$

where:

(L_1, λ_1) = position of initial point

(L_2, λ_2) = position of final point

D = rhumbline distance

C = rhumbline course

Notes:

1. No course should pass through either the south or north pole.
2. Errors in distance calculations may be encountered as cos C approaches zero.
3. Accuracy deteriorates for very short legs.

4 *

Example 1:

What is the distance and course from L35°24.'2N, λ125°02.'6W to L41°09.'2N, λ147°22.'6E? (4135.6 nautical miles, 274.°8)

Solution:

Enter: RHUMB

35.2412 **A** 125.0236 **B** 41.0912 **A**

147.2236 [CHS] **B** **C** ⟶ 4135.60

D ⟶ 274.79

Example 2:

What course should be sailed to travel a rhumbline from L2°13.'7S, λ179°07.'9E to L5°27.'4N, λ179°24'.6W? (10°7) What is the distance? (469.3 natical miles)

Solution:

Enter: RHUMB

2.1342 [CHS] **A** 179.0754 [CHS] **B**

5.2724 **A** 179.2436 **B** **C** ⟶ 469.31

D ⟶ 10.73

* This program gives incorrect results when computing distances due east or west across the dateline. To obtain ... the dateline and then proceed on the other side.

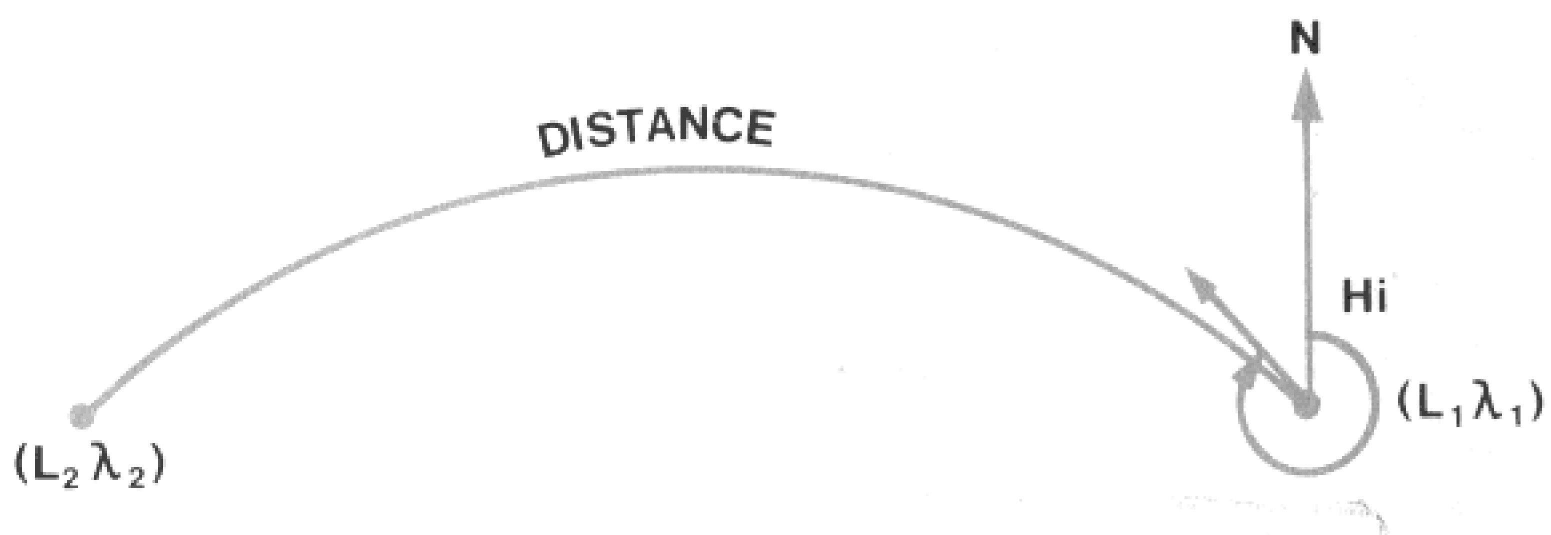
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter RHUMB				
2	Key in				
	Initial position				
	• Latitude* (CHS for South)	L_1, D.MS	A		L_1, D.d
	• Longitude (CHS for East)	λ_1, D.MS	B		λ_1, D.d
	Final position				
	• Latitude (CHS for South)	L_2, D.MS	A		L_2, D.d
	• Longitude (CHS for East)	λ_2, D.MS	B		λ_2, D.d
3	Compute				
	• Distance		C		D, naut. mi.
	• Course		D		C, D.d
4	To continue the course, return				
	to step 2 and input a new final				
	position				
*	To convert DDMM.m to D.MS	DDMM.m	f	→D.MS	DDMM.SS
			EEX	2	1. 02
			÷		D.MS

NAV 1-10A
GREAT CIRCLE NAVIGATION

GREAT CIRCLE NAVIGATION		NAV 1-10A	
L_1, L_2	λ_1, λ_2	DISTANCE	COURSE

GC NAV

This program computes the great circle distance between two points and computes the initial heading from the first point. Coordinates are input in the form DDMM.m. Outputs are distance in nautical miles and initial heading in D.d.



Equations:

$$D = 60 \cos^{-1} [\sin L_1 \sin L_2 + \cos L_1 \cos L_2 \cos(\lambda_2 - \lambda_1)]$$

$$H_i = \cos^{-1} \left[\frac{\sin L_2 - \sin L_1 \cos(D/60)}{\sin(D/60) \cos L_1} \right]$$

where

L_1, λ_1 = coordinates of initial point

L_2, λ_2 = coordinates of final point

D = distance from initial to final point

H_i = initial heading from initial to final point

Notes:

1. Truncation and round off errors occur when the source and destination are very close together (1 mile or less).
2. Do not use coordinates located at diametrically opposite sides of the earth.
3. Do not use latitudes of +90° or −90°.
4. Do not try to compute initial heading along a line of longitude ($L_1 = L_2$).

Example:

What is the distance and initial great-circle heading from L33°53.3′S, λ18°23.1′E to L40°27.1′N, λ73°49.4′W? (6762.72 nautical miles, 304°.5)

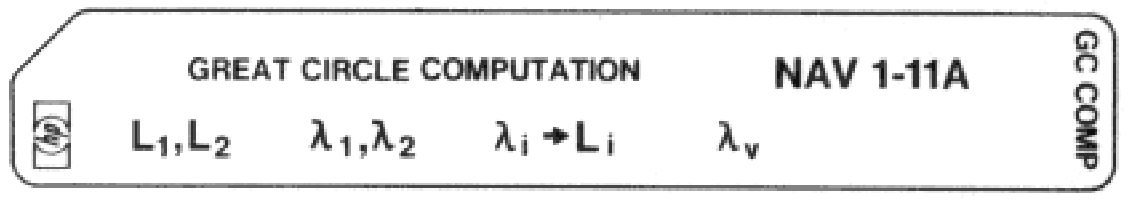
Solution:

3353.3 [CHS] [A] 1823.1 [CHS] [B]
4027.1 [A] 7349.4 [B] [C] ——→ 6762.72
[D] ——→ 304.48

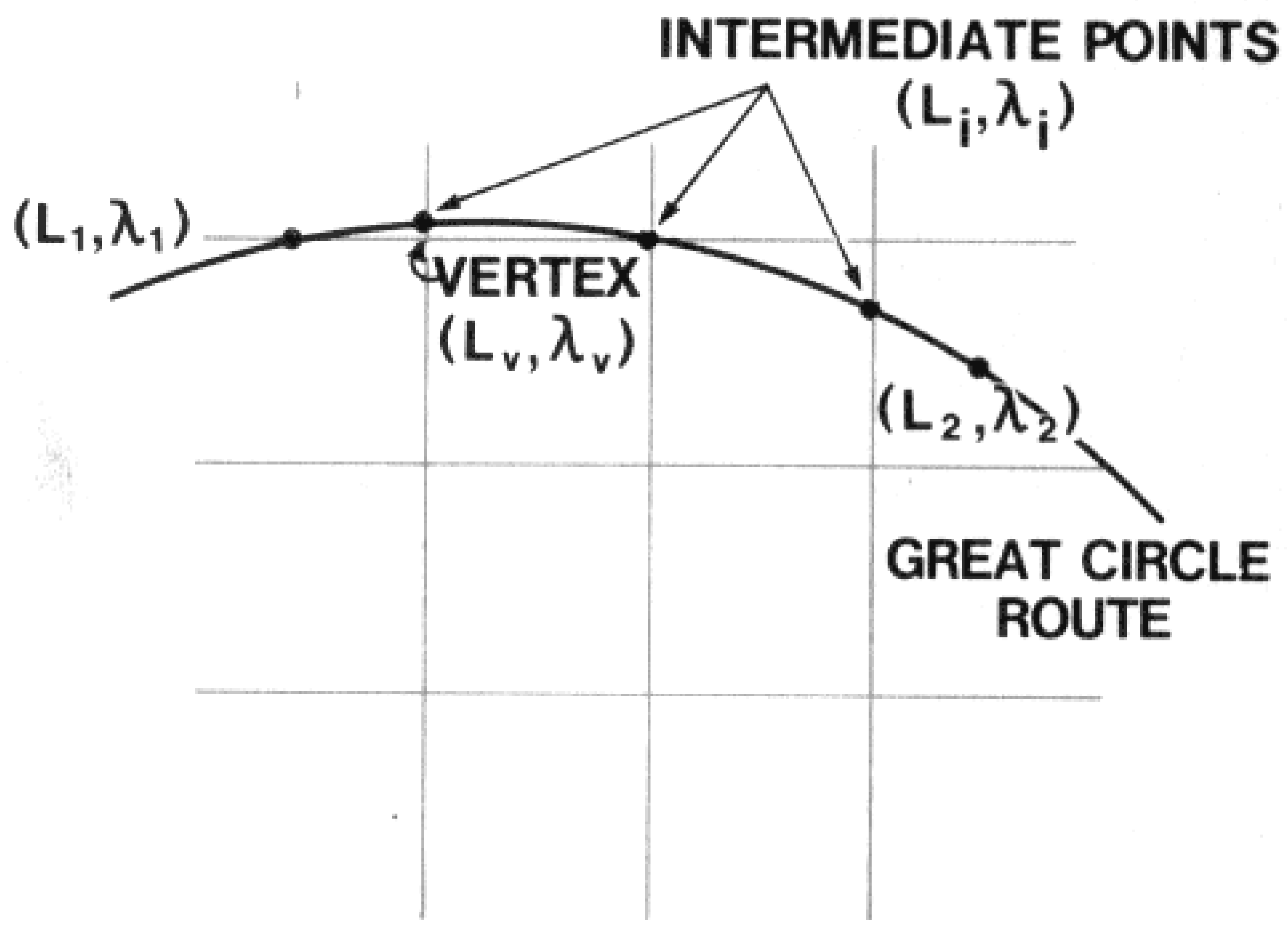
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter GC NAV			
2	Key in			
	Initial position			
	• Latitude ([CHS] for South)	L_1, DDMM.m	A	L_1, D.d
	• Longitude ([CHS] for East)	λ_1, DDMM.m	B	λ_1, D.d
	Final position			
	• Latitude ([CHS] for South)	L_2, DDMM.m	A	L_2, D.d
	• Longitude ([CHS] for East)	λ_2, DDMM.m	B	λ_2, D.d
3	Compute			
	Distance		C	D, naut. mi.
	Initial heading		D	H_i, D.d
4	For new case, return to step 2			
	(note: if the new initial position			
	is the final position of the pre-			
	vious great circle, enter only the			
	new final position)			

NAV 1-11A

GREAT CIRCLE COMPUTATION



This program computes the latitude corresponding to a specified longitude on a great circle passing through two given points. The program may be run alone or in conjunction with GC NAV which enables it to compute the longitude of the vertex of the great circle.



Equations:

$$L_i = \tan^{-1}\left[\frac{\tan L_2 \sin(\lambda_i - \lambda_1) - \tan L_1 \sin(\lambda_i - \lambda_2)}{\sin(\lambda_2 - \lambda_1)}\right]$$

$$\lambda_v = \lambda_1 - \sin^{-1}\left[\frac{\cos H_i}{\sin(\cos^{-1}(\sin H_i \cos L_1))}\right]$$

where

(L_1, λ_1) = coordinates of initial point

(L_2, λ_2) = coordinates of final point

H_i = initial heading from initial to final point

(L_i, λ_i) = coordinates of intermediate point

λ_v = longitude of vertex

Notes:

1. The program does not compute along lines of longitude ($\lambda_1 = \lambda_2$).
2. There is another vertex at $\lambda = \lambda_v + 180$.
3. Equator crossings are at $\lambda = \lambda_v \pm 90°$.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter GC COMP		[ ] [ ]	
2	Key in		[ ] [ ]	
	Initial position		[ ] [ ]	
	• Latitude (CHS for South)	L_1, DDMM.m	[A] [ ]	L_1, D.d
	• Longitude (CHS for East)	λ_1, DDMM.m	[B] [ ]	λ_1, D.d
	Final position		[ ] [ ]	
	• Latitude (CHS for South)	L_2, DDMM.m	[A] [ ]	L_2, D.d
	• Longitude (CHS for East)	λ_2, DDMM.m	[B] [ ]	λ_2, D.d
3	Key in intermediate longitude		[ ] [ ]	
	and compute intermediate lat-		[ ] [ ]	
	itude	λ_i, DDMM.m	[C] [ ]	L_i, DDMM.m
4	Repeat step 3 as desired		[ ] [ ]	
			[ ] [ ]	
	OR		[ ] [ ]	
			[ ] [ ]	
1	Run GC NAV		[ ] [ ]	
2	Enter GC COMP		[ ] [ ]	
3	Compute		[ ] [ ]	
	Longitude of vertex		[D] [ ]	λ_v, DDMM.m
	Latitude of vertex	λ_v, DDMM.m	[C] [ ]	L_v, DDMM.m
4	Key in intermediate longitude		[ ] [ ]	
	and compute intermediate		[ ] [ ]	
	latitude	λ_i, DDMM.m	[C] [ ]	L_i, DDMM.m
5	Repeat step 4 as desired		[ ] [ ]	

Example:

A ship is proceeding from Manila to Los Angeles. The captain wishes to use great-circle sailing from L12°45!2N, λ124°20!1E, off the entrance to San Bernardino Strait, to L33°48!8N, λ120°07!1W, five miles south of Santa Rosa Island.

Required:

(1) The initial great-circle heading. (50°3)

(2) The great-circle distance. (6185.88 nautical miles)

(3) The latitude and longitude of the vertex. (L41°21!1N, λ160°34!0W)

(4) The latitude at λ180°. (39°41!6N)

Solution:

Enter: GC NAV

1245.2 [A] 12420.1 [CHS] [B] 3348.8 [A]

12007.1 [B] [C] ——→ 6185.88

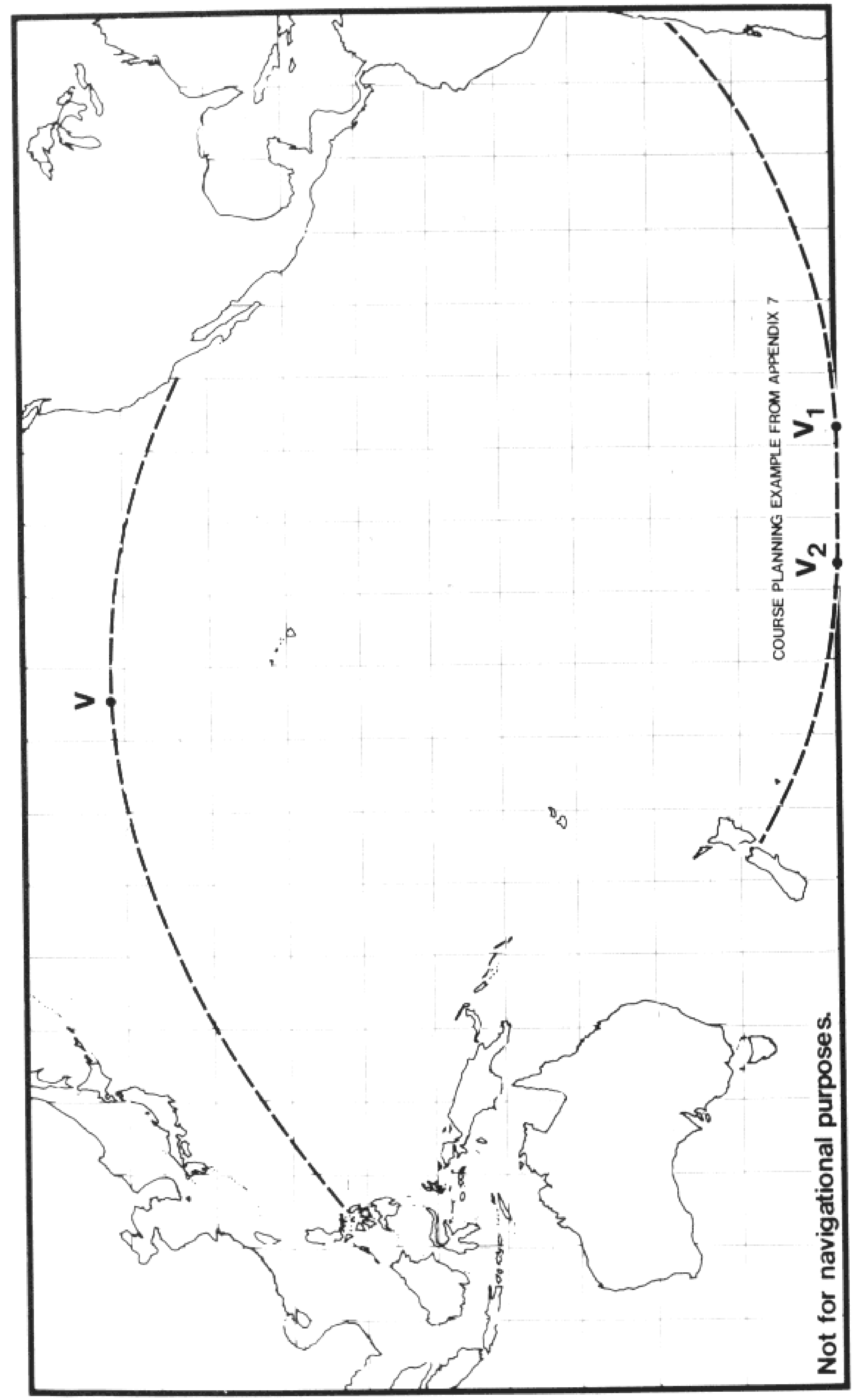
[D] ——→ 50.32

Enter: G.C. PLOT

[D] ——→ 16034.0

[C] ——→ 4121.1

18000 [C] ——→ 3941.6



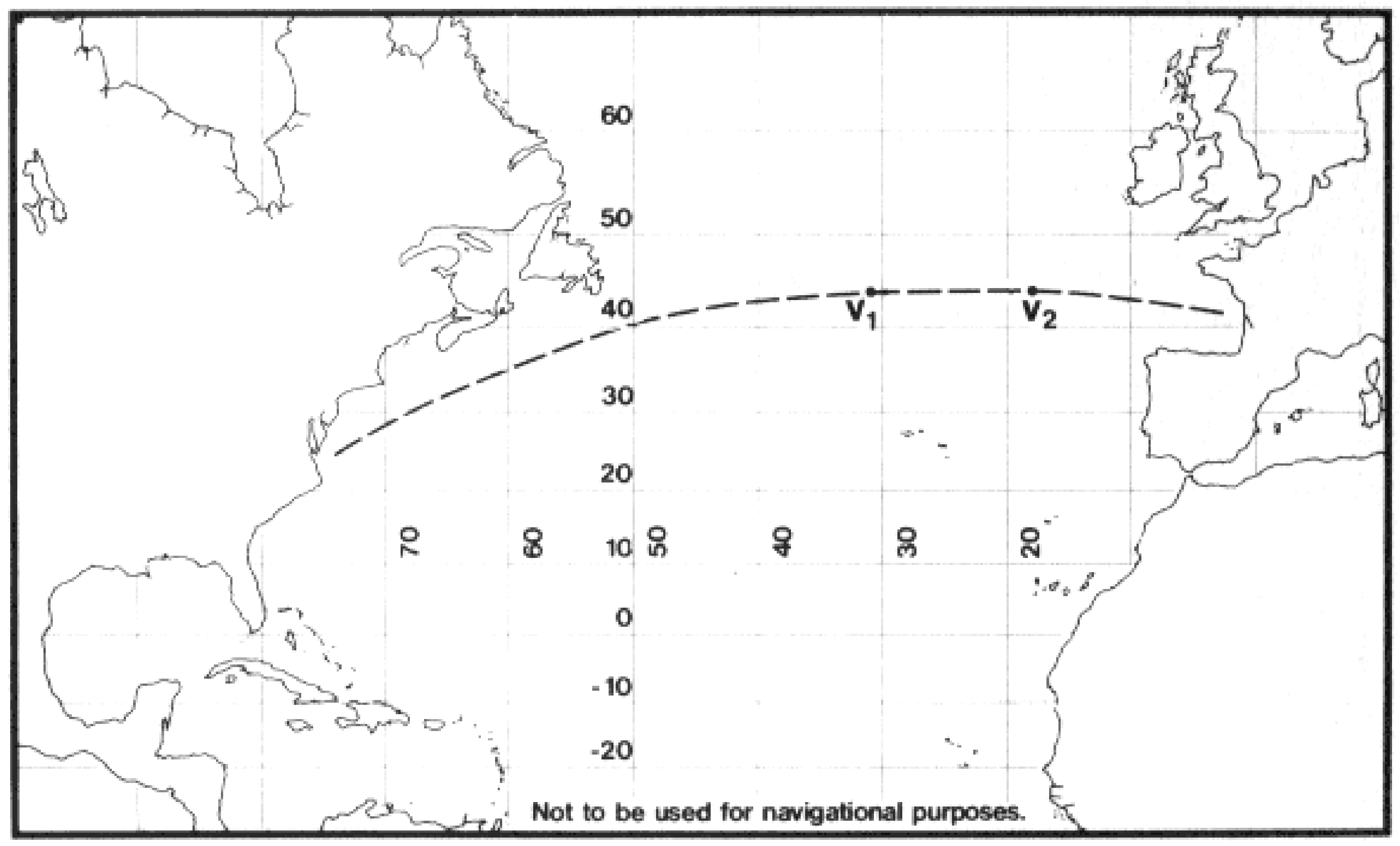
NAV 1-12A

COMPOSITE SAILING

COMPOSITE SAILING NAV 1-12A COMPSAIL

L_1, L_2 λ_1, λ_2 Lmax λ_{v1} R/S λ_{v2}

When the great circle would carry a vessel to a higher latitude than desired, a modification of great-circle sailing, called composite sailing, may be used to good advantage. The composite track consists of a great circle from the point of departure and tangent to the limiting parallel, a course line along the parallel, and a great circle tangent to the limiting parallel and through the destination. This program computes, for each of two points, the longitude at which a great circle through the point is tangent to some limiting parallel.



Equations:

$$\lambda_{v1} = \lambda_1 + \cos^{-1}\left(\frac{\tan L_1}{\tan L_{max}}\right) \mathrm{sgn}(\lambda_2 - \lambda_1)\ \mathrm{sgn}(L_{max})$$

$$\lambda_{v2} = \lambda_2 + \cos^{-1}\left(\frac{\tan L_2}{\tan L_{max}}\right) \mathrm{sgn}(\lambda_1 - \lambda_2)\ \mathrm{sgn}(L_{max})$$

where

(L_1, λ_1) = initial position

(L_2, λ_2) = final position

(L_{max}, λ_{v1}) = point at which limiting parallel is met

(L_{max}, λ_{v2}) = point at which limiting parallel is left

$$\mathrm{sgn}(x) = \begin{cases} +1 ; x \geq 0 \\ -1 ; x < 0 \end{cases}$$

Example:

A ship leaves Baltimore bound for Bordeaux (Royan), France. The captain desires to use composite sailing from L36°57.'7N, λ75°42.'2W one mile south of Chesapeake Light to L45°39.'1N, λ1°29.'8W, near the entrance to Grande Passe de l'Ouest, limiting the maximum latitude to 47°N.

Required.

(1) The longitude at which the limiting parallel is reached. (λ_{v1} = 30°16.'1)

(2) The longitude at which the limiting parallel should be left. (λ_{v2} = 18°56.'9)

Solution:

Enter: COMPSAIL

3657.7 [A] 7542.2 [B] 4539.1 [A]

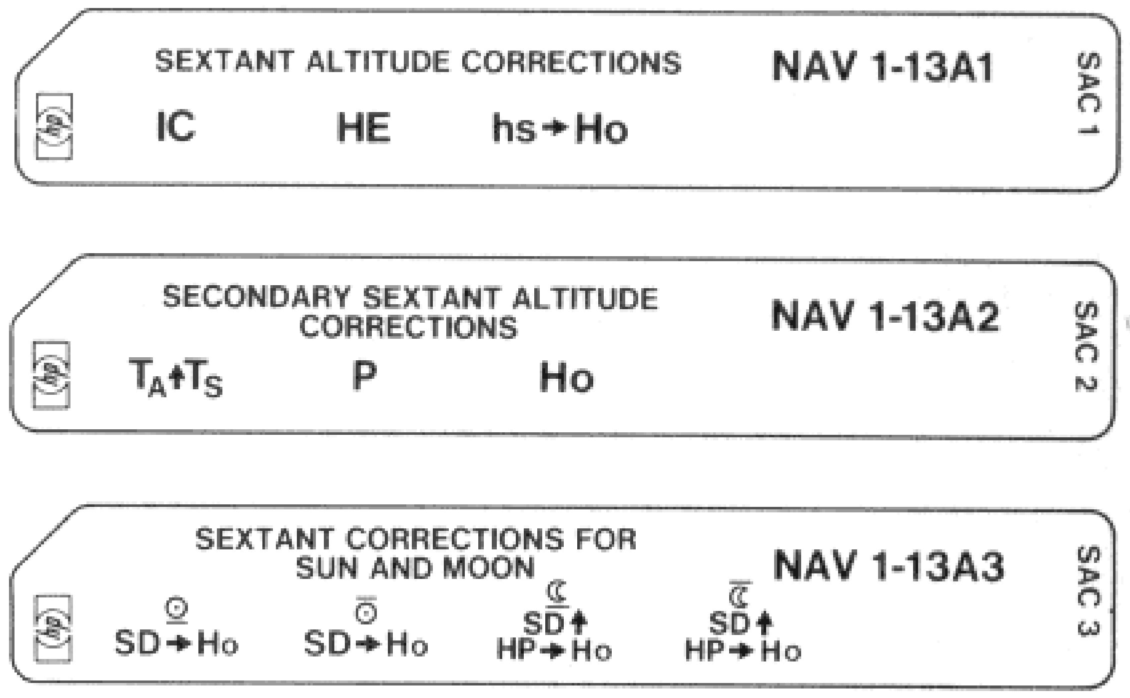
129.8 [B] 4700 [C] [D] ——→ 3016.1

[R/S] ——→ 1856.9

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter COMP SAIL			
2	Key in			
	Initial position			
	• Latitude ([CHS] for South)	L_1, DDMM.m	A	L_1, D.d
	• Longitude ([CHS] for East)	λ_1, DDMM.m	B	λ_1, D.d
	Final position			
	• Latitude ([CHS] for South)	L_2, DDMM.m	A	L_2, D.d
	• Longitude ([CHS] for East)	λ_2, DDMM.m	B	λ_2, D.d
	Latitude of limiting parallel	L_{max}, DDMM.m	C	L_{max}, D.d
3	Compute			
	Longitude at which limiting			
	parallel is met		D	λ_{v1}, DDMM.m
	Longitude at which limiting			
	parallel is left		R/S	λ_{v2}, DDMM.m

NAV 1-13A1,2,3

SEXTANT ALTITUDE CORRECTIONS



This set of programs is used to correct sextant readings. The first card applies index correction, height of eye correction, and mean refraction correction. The second card corrects for sea-air temperature difference and abnormal air temperature and pressure. The third card allows almanac entries for semi-diameter of sun and moon and corrects for geocentric parallax (moon only). If an almanac is not available for determination of the sun's SD, key in zero and the program will automatically use 16′.

Equations:

Card 1:

$$ha_1 = hs + IC - D$$

$$Ho = ha_1 - Rm$$

where

- hs = uncorrected sextant reading
- ha_1 = apparant altitude (also called h_r, rectified altitude)
- Ho = fully corrected sextant altitude
- IC = index correction
- D = dip of horizon = $0'.97\sqrt{HE}$
- HE = height of eye in feet
- Rm = mean refraction

$$= \begin{cases} 23'.6 - 8'.36 \ln(ha); & ha < 7^\circ \\ 0'.97 \cot(ha) - 0'.0011 \cot^3(ha); & ha \geq 7^\circ \end{cases}$$

Card 2:

$$ha = ha_1 + S$$

$$Ho = ha - Rm \frac{510}{460 + T_A} \frac{P}{29.83}$$

where

- ha_1 = apparent altitude from card 1
- $S = 0'.11\ (T_A - T_S)$ = sea-air temperature difference correction
- T_S = Temperature of sea, °F
- T_A = Temperature of air, °F
- P = atmospheric pressure, inches of mercury

Card 3:

$$Ho = Ho_{old} \pm SD + HP \cos(Ho_{old})$$

where

- Ho_{old} = Ho from card 1 or 2
- SD = semi-diameter of sun or moon
- HP = horizontal parallax of moon

Example 1:

hs = 10°36′.3

IC = +1′.5

HE = 23 feet

Solution:

Enter: SAC1

1.5 **A** 23 **B** 1036.3 **C** ——→ 1028.1

Example 2:

Same as above except $T_A = 85^\circ$, $T_S = 40^\circ$, P = 28.00 in. Hg

Solution:

Enter: SAC1

1.5 **A** 23 **B** 1036.3 **C** ——→ 1028.1

Enter: SAC2

85 [ENTER↑] 40 **A** 28 **B** **C** ——→ 1033.6

Example 3:

The upper limb of the sun is observed with a marine sextant having an IC of +1'.0, from a height of eye of 45 feet. The hs is 32°47'.9. What is Ho if the sun's SD is 18'.5? (32°22'.4)

Solution:

Enter: SAC1

1 **A** 45 **B** 3247.9 **C** ——————→ 3240.9

Enter SAC3

18.5 **B** ——————→ 3222.4

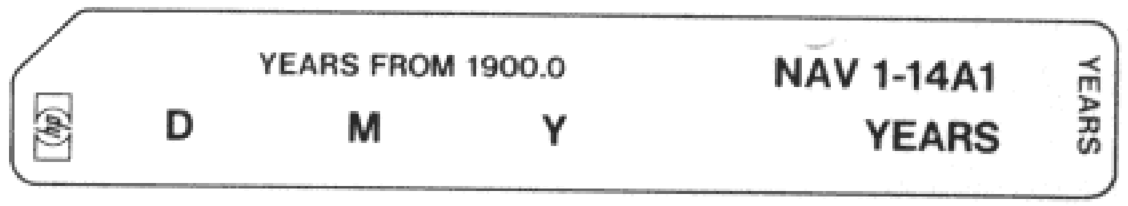
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter SAC 1			
2	Key in constants			
	• Index correction	IC, M.m	A	IC, M.m
	• Height of eye	HE, ft.	B	HE, ft.
3	Key in sextant height and com-			
	pute corrected altitude	hs, DDMM.m	C	Ho, DDMM.m
4	For additional sights, return to			
	step 3.			

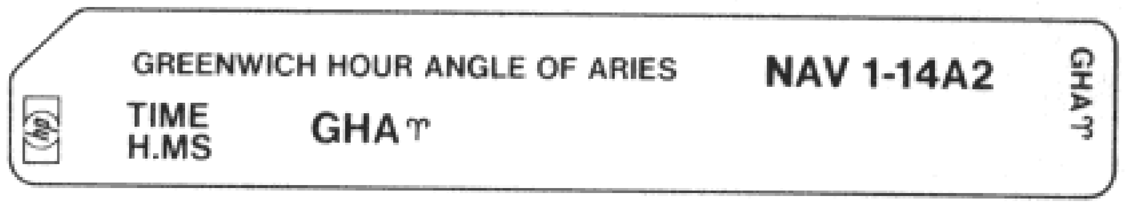
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	First run SAC 1			
2	Enter SAC 2			
3	Key in constants			
	• Temperature			
	of air	T_a, °F	↑	T_a, °F
	of water*	T_s, °F	A	T_a, °F
	• Air pressure	P, in. Hg	B	P, in. Hg
4	Apply S to ha stored by SAC 1			
	and compute corrected sextant			
	altitude		C	Ho, DDMM.m
*	If T_s is not known use $T_s = T_a$			
	and the refinements will be			
	applied to the mean refraction			
	correction only			

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	First run SAC 1 or SAC 1 and			
	SAC 2			
2	Enter SAC 3			
3	Key in semidiameter of ⊙ (If			
	unknown key in 0) and compute			
	Ho corrected for observation of			
	lower limb of sun	SD, M.m	A	Ho, DDMM.m
	or			
	for observation of upper limb of			
	sun	SD, M.m	B	Ho, DDMM.m
	OR			
3	Key in			
	Semidiameter of ☾ and	SD, M.m	↑	SD, M.m
	Horizontal parallax of ☾ and			
	compute Ho corrected for			
	observation of lower limb of			
	moon	HP, M.m	C	Ho, DDMM.m
	or			
	for observation of upper limb of			
	moon	HP, M.m	D	Ho, DDMM.m

NAV 1-14A

LONG-TERM ARIES ALMANAC





This set of programs is used to compute the Greenwich Hour Angle of the first point of Aries (the vernal equinox) which is the celestial reference point from which Sidereal Hour Angle is measured. The program also stores the time in years from 1900.0 for the star almanac and the time in days from 12^h GMT 1 Jan 1974 for the sun almanac.

Equations:

The number of days from 1900.0 (0^h GMT 31 Dec 1899) to day D month M year Y is given by

$$\text{days} = 31(M-1) + D + (M>2)\left(-[.4M+2.3] + 1 - \left[\frac{r+3}{4}\right]\right) + 365r + \left[\frac{r+3}{4}\right] + 4\left[\frac{Y-1900}{4}\right]$$

where

$$r = 4 \times \text{Frac}\left(\frac{Y-1900}{4}\right) \text{, see footnote}$$

$$(M>2) = \begin{cases} 1; M>2 \\ 0; M \leqslant 2 \end{cases}$$

$[x]$ = largest integer not greater than x

The number of years, therefore, is

$$Y.y = \frac{\text{days}}{365.25}$$

*Thus $\left[\frac{r+3}{4}\right] = \begin{cases} 0; \text{leap year} \\ 1; \text{non-leap year} \end{cases}$

The long term Aries almanac is based on the fact that due to the Earth's precession, the vernal equinox moves westward through 360° in about 25785 years at a rate of

$$\frac{360°}{25785} = 0.0139617$$

degrees per year. Due to the Earth's motion about the sun, then, the equinox should move 360.0139617 degrees in GHA in a year. A calendar year is slightly longer than a tropical year (365.25 days versus 365.2421988 days) so the vernal equinox moves only

$$\frac{365.2421988 \times 360.0139617}{365.25} = 360.0062724$$

degrees per tropical year. Thus in a calendar year, ♈ moves 0.461358 minutes of arc farther than it does in a tropical year. The long term ♈ almanac corrects for this motion every four years by adding 1.845432 minutes (0.0307572 degrees). Due to the Earth's rotation on its axis, ♈ moves

$$360 + \frac{360.0139617}{365.25} = 360.9856645$$

degrees per day or 15.04106935 degrees per hour. Thus in terms of the time in hours, years from 1900.0, and number of four-year periods since 1900, we can write

$$\text{GHA } ♈ = 0.030757\,n + 360.00627 \times 4\,\text{Frac}\left[\frac{Y.y}{4}\right] + 15.041069\,H.h + 98.2204$$

where

n = number of leap years from 1900

Y.y = years from 1900.0

H.h = time of day

98.2204 = value for GHA ♈ at 0^h on 31 Dec 1899 which makes program most correct in 1974

Example 1:

Compute GHA ♈ for GMT $13^h02^m49^s$ on 7 Aug 1950. (151°11.′4)

Solution:

Enter: YEARS

7 **A** 8 **B** 1950 **C** **E** ——————→ 50.6

Enter: GHA ♈

13.0249 **A** **B** ——————→ 15111.4

Example 2:

Compute GHA ♈ for GMT $1^h12^m07^s$ on 6 Jun 1974. (272°06.′2)

Solution:

Enter: YEARS

6 **A** 6 **B** 1974 **C** **E** ——————→ 74.4

Enter: GHA ♈

1.1207 **A** **B** ——————→ 27206.2

Example 3:

Compute GHA ♈ for GMT $17^h59^m42^s$ on 30 May 1980. (158°19.′9)

Solution:

Enter: YEARS

30 **A** 5 **D** 1980 **C** **E** ——————→ 80.4

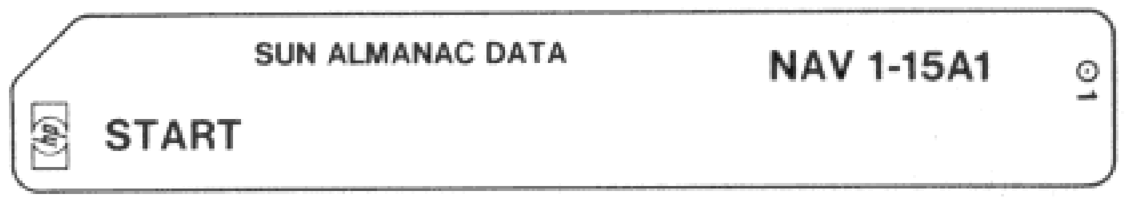
Enter: GHA ♈

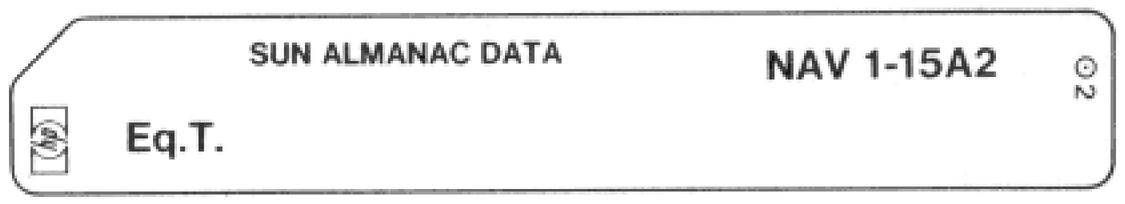
17.5942 **A** **B** ——————→ 15819.9

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter YEARS			
2	Key in the date			
	• Day	Day, D	A	Day
	• Month	Month, M	B	Month
	• Year	Year, Y	C	Year
3	Compute			
	Years from 1900.0		E	Y.y
4	Enter GHA ♈			
5	Key in			
	Time of day	t, H.MS	A	t, H.h
6	Compute			
	GHA ♈		B	GHA ♈, DDMM.m

NAV 1-15A

1974-1975 SUN ALMANAC





This program computes the sidereal hour angle and declination of the sun and stores them for use by the Almanac Positions program. This program also computes the Equation of Time which is used with the declination by the Sunrise, Sunset, and Twilight program.

The program is based on a 1974 ephemeris and will give positions with increasing error if used for other years. For 1975 no errors greater than 0'.5 have been found.

Equations:

Let

D# = 365.25 (Y.y − 74) − 1.5 = day number from GMT noon on 1 January 1974

The Sun's mean anomaly is given by

$$\theta = 0.9856 \left(D\# + \frac{T}{24} \right)$$

The Equation of Time is

$$\text{Eq. T.} = -1.842 \sin(\theta - 3.41) - 2.482 \sin(2\theta + 20.38) - 0.079 \sin(3\theta + 17) - 0.055 \sin(4\theta + 40) - 0.003 \sin(5\theta + 41)$$

The Sun's Greenwich Hour Angle is

$$\text{GHA}\odot = \left(0.5 + \frac{T}{24}\right) 360 + \text{Eq. T.}$$

and its declination is

$$\text{DEC}\odot = 0.379 - 23.267 \cos(\theta + 10.274) - 0.381 \cos(2\theta + 7.4) - 0.171 \cos(3\theta + 29.7) - 0.008 \cos(4\theta + 26) - 0.003 \cos(5\theta + 95)$$

Example 1:

Find the Sun's position and the Equation of Time on 3 Nov 1975 at $12^h00^m00^s$. (Almanac GHA 4°06'.0, DEC 14°57'.3S Eq.T. 16^m24^s HP-65 GHA 4°06'.2, DEC 14°57'.0S, Eq.T. 16^m25^s)

Solution:

Enter YEARS

3 [A] 11 [B] 1975 [C] [E] ——→ 75.84

Enter GHA ♈

12 [A] [B] ——→ 22207.5

Enter ⊙1

[A]

Enter ⊙2

[A] ——→ 0.1625

Enter SHA

[B] ——→ 406.2

[C] ——→ -1457.0

Note that a partial solar eclipse occurs on this date.

Example 2:

Find the Sun's position on 21 Jun 1974 at $19^h38^m40^s$. (SHA 269°57'.4, DEC 23°26'.5)

Solution:

Enter YEARS

21 [A] 6 [B] 1974 [C] [E] ——→ 74.5

Enter GHA ♈

19.3840 [A] [B] ——→ 20417.0

Enter ⊙1

[A]

Enter ⊙2

[A] ——→ -0.0142

Enter SHA

[A] ——→ 26957.4

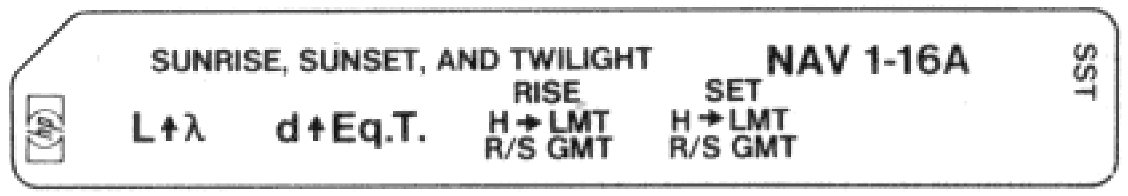
[C] ——→ 2326.5

Note the Sun is crossing the solstitial colure.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	First run ARIES ALMANAC		[ ] [ ]	
2	Enter ⊙1		[ ] [ ]	
3	Compute		[A] [ ]	
4	Enter ⊙2		[ ] [ ]	
5	Compute		[A] [ ]	Eq.T., H.MS
6	Run ALMANAC POSITIONS to		[ ] [ ]	
	finish problem		[ ] [ ]	

NAV 1-16A

SUNRISE, SUNSET, AND TWILIGHT



This program computes the local mean time and Greenwich mean time at which the sun will be at altitude H from either horizon. Inputs are observer's position, the declination of the sun, the Equation of Time, and the desired altitude. The values used for d and Eq. T. may be approximate values from *The Nautical Almanac* or they may be supplied automatically by the Sun Almanac program. The GMT output may be less than zero or greater than 24 indicating a change of date.

Equations:

$$\mathrm{LMT}_{\mathrm{RISING}} = -\cos^{-1}\left[\frac{\sin H - \sin L \sin d}{\cos L \cos d}\right] + 12 - \mathrm{Eq.\,T.}$$

$$\mathrm{LMT}_{\mathrm{SETTING}} = +\cos^{-1}\left[\frac{\sin H - \sin L \sin d}{\cos L \cos d}\right] + 12 - \mathrm{Eq.\,T.}$$

$$\mathrm{GMT} = \mathrm{LMT} + \frac{\lambda}{15}$$

$$H = \begin{cases} -50'.0 & \text{; sun rises or sets} \\ -6^\circ 0' & \text{; civil twilight begins or ends} \\ -12^\circ 0' & \text{; nautical twilight begins or ends} \\ -18^\circ 0' & \text{; astronomical twilight begins or ends} \end{cases}$$

Example:

Compute the time of sunrise on 25 December 1974 at L19°30′ N, λ 155° W. ($6^h 31^m$)

Solution:

Enter: YEARS

25 **A** 12 **B** 1974 **C** **E** ——→ 74.98

Enter: GHA ♈

7 **A** **B** ——→ 19824.8

Enter: ⊙1

A

Enter: ⊙2

A ——→ 0.0008

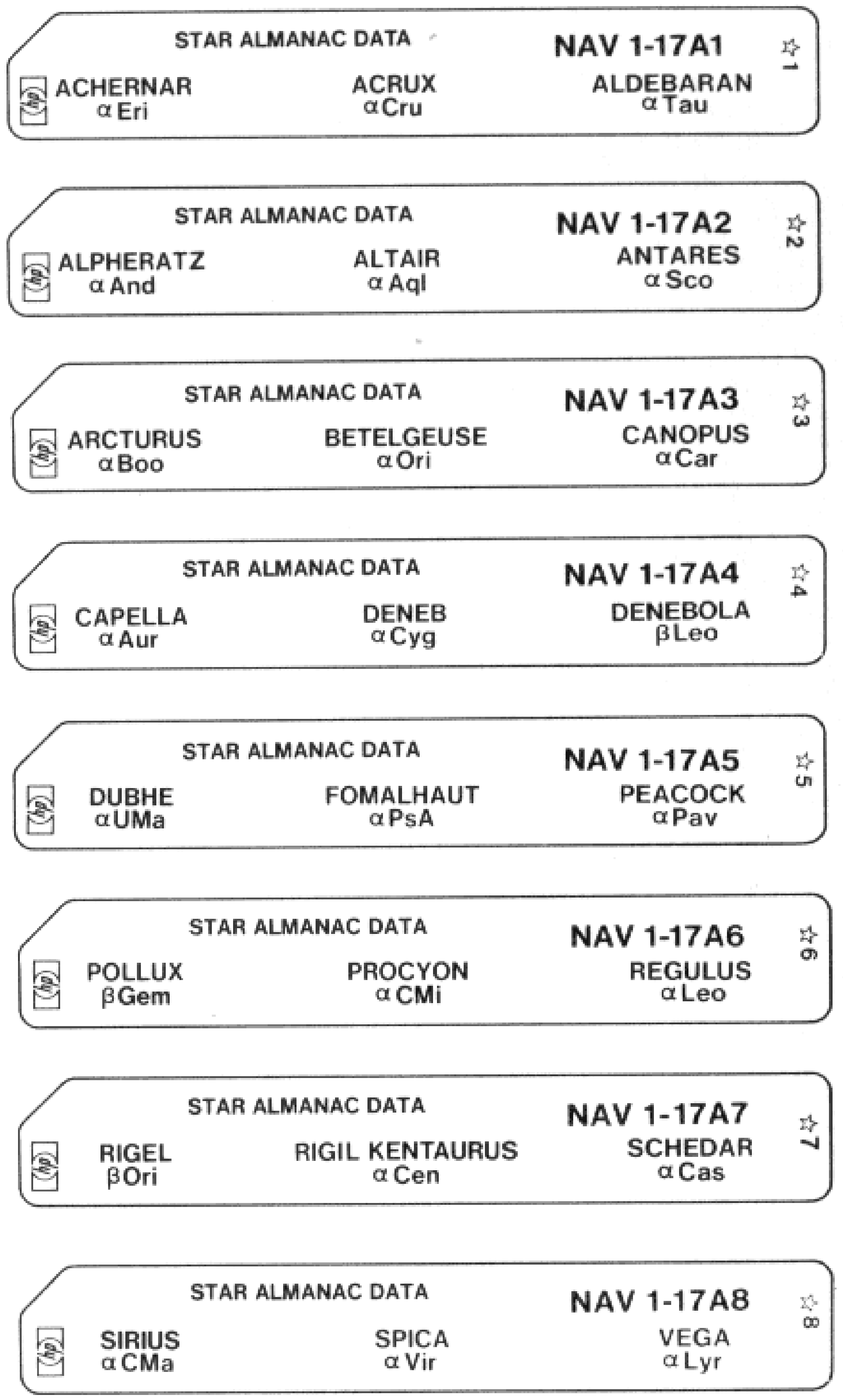
Enter: SST

1930 [ENTER↑] 15500 **A** 50 [CHS] **C** ——→ 6.3058

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter SST			
2	Key in			
	• Observer's position			
	Latitude ([CHS] for South)	L, DDMM.m	↑	L, DDMM.m
	Longitude ([CHS] for East)	λ, DDMM.m	A	L, D.d
	• Sun parameters near time of			
	desired phenomenon			
	Declination	d, DDMM.m	↑	d, DDMM.m
	Equation of Time	Eq.T., H.MS	B	Eq.T., H.h
3	Key in desired altitude and			
	compute			
	Time rising Sun reaches H from			
	Eastern horizon	H, DDMM.m	C	LMT, H.MS
	Compute corresponding GMT			
	(optional)	LMT, H.MS	R/S	GMT. H.MS
4	Key in desired altitude and			
	compute			
	Time setting Sun reaches H			
	from Western horizon	H, DDMM.m	D	LMT, H.MS
	Compute corresponding GMT			
	(optional)	LMT, H.MS	R/S	GMT, H.MS
	or			
1	First run SUN ALMANAC			
	near time of desired phenom-			
	enon			
2	Key in observer's position			
	Latitude ([CHS] for South)	L, DDMM.m	↑	L, DDMM.m
	Longitude ([CHS] for East)	λ, DDMM.m	A	L, D.d
3	Continue with step 3 or 4 above			

NAV 1-17A

LONG-TERM STAR ALMANAC



This set of programs stores the position of any of 24 stars into the registers for use by the Almanac Positions program. Each card contains data for three stars: SHA(1900), ΔSHA (annual correction), DEC(1900), and ΔDEC (annual correction). The 1900 positions were obtained by working backwards from the 1956 positions in *Bowditch*, Appendix X. Appendix 6 of this manual contains the 1900 positions of 38 navigational stars with instructions for making more star cards.

Example:

Set up the calculator to compute the position of Arcturus on 2 Jun 1950 at GMT $4^h 10^m 35^s$.

Solution:

Enter: YEARS

2 **A** 6 **B** 1950 **C** **E** ⟶ 50.42

Enter: GHA ♈

4.1035 **A** **B** ⟶ 31242.9

Enter: ★ 2

A ⟶ −0.3

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	First run ARIES ALMANAC			
2	Enter one of eight star cards			
	NAVI – 17A1 to NAVI – 17A8			
3	Select a star			
	First star or		A	ΔDEC, M.m
	Second star or		C	ΔDEC, M.m
	Third star		E	ΔDEC, M.m
4	Run ALMANAC POSITIONS			

NAV 1-18A
ALMANAC POSITIONS

POSITION OF SUN AND STARS				NAV 1-18A1
SHA	GHA	DEC	HA→RA	SHA

RELATIVE POSITION OF SUN AND STARS				NAV 1-18A2
L	λ	LHA	DEC	LHA

These programs are run after the Aries Almanac and either the Sun Almanac or a star data card. They compute the position of the Sun or selected star on the celestial sphere. The first card computes SHA, GHA and DEC and allows conversion of hour angle to right ascension. The other card accepts the observer's DR position and computes the LHA and DEC of the Sun or star, storing appropriate data for use by the Sight Reduction Table program.

Equations:

The position of a star on a given date is

$$SHA = SHA\ (1900.0) + Y.y\ \Delta SHA$$

$$DEC = DEC\ (1900.0) + Y.y\ \Delta DEC$$

$$GHA = GHA\ \Upsilon + SHA$$

$$LHA = GHA - \lambda$$

where

- Y.y = number of years from 1900.0
- SHA = Sidereal hour angle
- ΔSHA = annual correction to SHA
- GHA = Greenwich hour angle
- LHA = Local hour angle
- DEC = Declination
- ΔDEC = annual correction to DEC
- λ = observer's longitude

Example 1:

Compute the position of Arcturus on 2 Jun 1950 at GMT $4^h 10^m 35^s$. (SHA 146°39'.0, GHA 99°21'.9, DEC 19°26'.3N)

Solution:

Enter: YEARS

2 **A** 6 **B** 1950 **C** **E** ⟶ 50.42

Enter: GHA ♈

4.1035 **A** **B** ⟶ 31242.9

Enter: ★ 3

A ⟶ -0.3

Enter: SHA

A ⟶ 14639.0

B ⟶ 9921.9

C ⟶ 1926.3

Example 2:

Compute the relative position of Betelgeuse at GMT $5^h 0^m 0^s$ on 3 Mar 1974 at L40N, λ128W. (LHA 19°09'.2, DEC 7°24'.2)

Solution:

Enter: YEARS

3 **A** 3 **B** 1974 **C** **E** ⟶ 74.17

Enter: GHA ♈

5 **A** **B** ⟶ 23535.7

Enter: ★ 3

C ⟶ 0.0

Enter: LHA

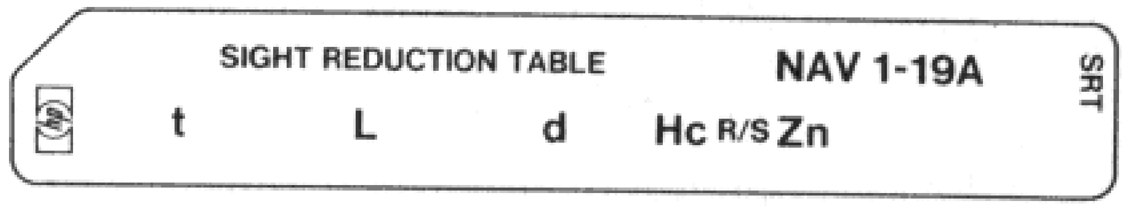
4000 **A** 12800 **B** **C** ⟶ 1909.2

D ⟶ 724.2

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	First run ARIES ALMANAC			
	and the SUN DATA or a STAR			
	DATA program			
2	Enter SHA			
3	Compute any or all of the			
	following			
	• Sidereal Hour Angle		A	SHA, DDMM.m
	Convert to Right Ascension			
	(optional)		D	RA, H.MS
	• Greenwich Hour Angle		B	GHA, DDMM.m
	Convert to hours of Right			
	Ascension (optional)		D	Hours, H.MS
	• Declination		C	DEC, DDMM.m
	Convert to degrees, minutes,			
	and seconds	DEC, DDMM.m	R/S	DEC, D.MS
5	Enter LHA (optional)			
6	Key in observer's position			
	• Latitude (CHS for South)	L, DDMM.m	A	L, D.d
	• Longitude (CHS for East)	λ, DDMM.m	B	λ, D.d
7	Compute			
	Local Hour Angle		C	LHA, DDMM.m
	Declination		D	DEC, DDMM.m
	or			
2	Enter LHA			
	Key in observer's position			
3	• Latitude (CHS for South)	L, DDMM.m	A	L, D.d
	• Longitude (CHS for East)	λ, DDMM.m	B	λ, D.d
4	Compute			
	Local Hour Angle		C	LHA, DDMM.m
	Declination		D	DEC, DDMM.m

NAV 1-19A

SIGHT REDUCTION TABLE

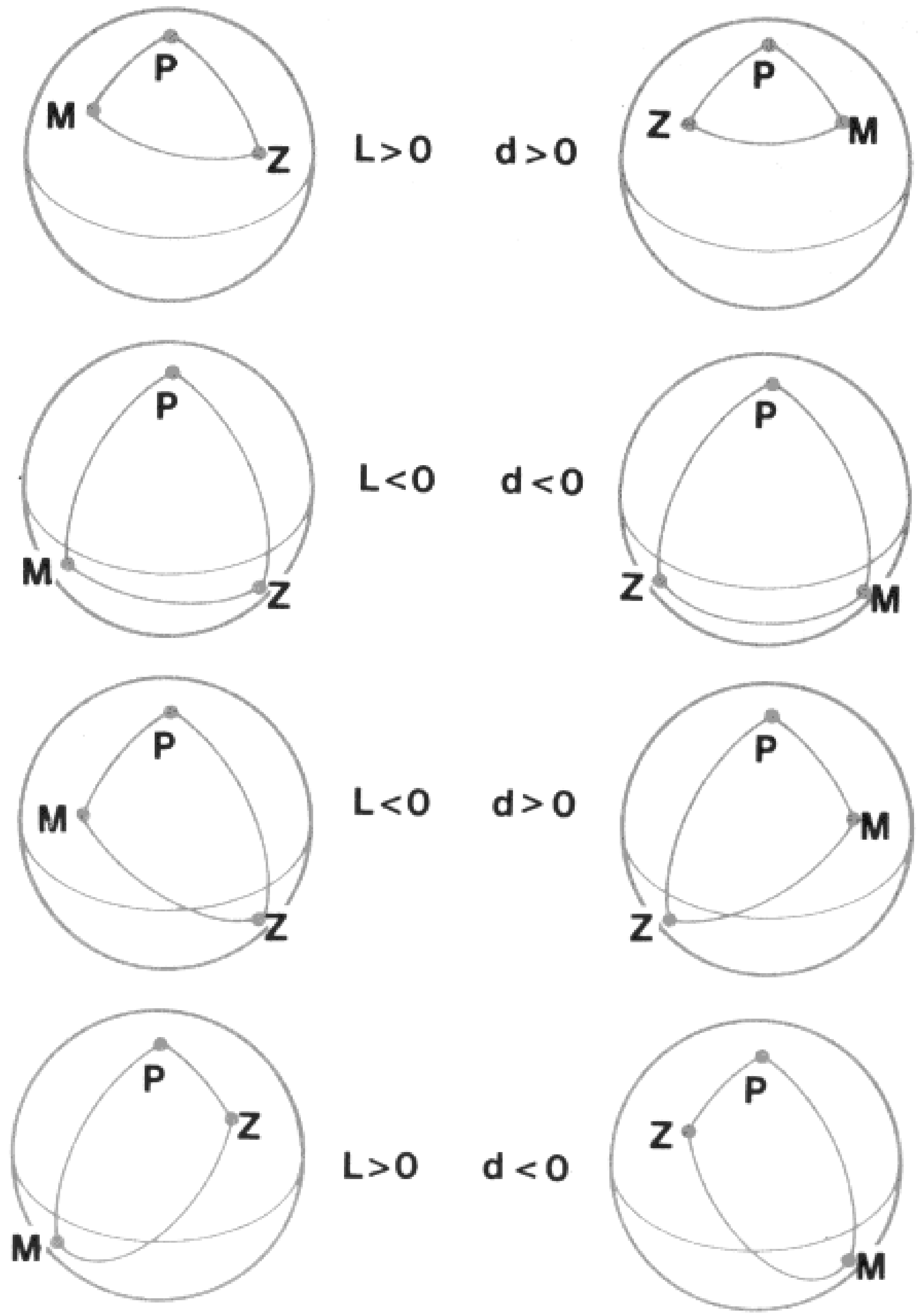


This program calculates the computed altitude Hc and azimuth Zn of a celestial body given the observer's latitude and the local hour angle and declination of the body. The program may be used alone to replace HO214, etc., or it may be used in conjunction with the long term almanac programs and the most probable position program to reduce a star sight to an MPP. The program considers all eight navigational triangles always using the north pole as the elevated pole.

THE EIGHT COMBINATIONS OF t,L AND d

OBJECT WEST OF OBSERVER — **OBJECT EAST OF OBSERVER**

tE — **tW**



$$Hc = (90-p) = \sin^{-1}\ [\sin d \sin L + \cos d \cos L \cos t]$$

The smallest angle from North to the arc ZM is given by

$$Z = \cos^{-1}\left[\frac{\sin d - \sin L \sin Hc}{\cos Hc \cos L}\right]$$

and the azimuth is

$$Zn = \begin{cases} Z\ ;\ tE\ (\sin t < 0) \\ 360 - Z\ ;\ tW\ (\sin t > 0) \end{cases}$$

where

d = declination of body

L = latitude of observer

t = local hour angle

Note:

This program may also be used for star identification by entering observed azimuth in place of local hour angle and observed altitude in place of declination. The outputs are then declination and local hour angle instead of altitude and azimuth. The star may be identified by comparing this computed declination to the list of stars in *The Nautical Almanac.*

Example 1:

Compute the altitude and azimuth of the Sun if its LHA is 333°01.'9W and its declination is 12°28.'1S. The assumed latitude is 34°11.'1S. (Hc = 57°16.'0, Zn = 055.°0)

Solution:

Enter: SRT

33301.9 [A] 3411.1 [CHS] [B]

1228.1 [CHS] [C] [D] ⟶ 5716.0

[R/S] ⟶ 55.0

Example 2:

Compute the altitude and azimuth of Regulus if its LHA is 36°39′.3W and its declination is 12°12′.7N. The assumed latitude is 33°30′N (Hc = 50°24′.4, Zn = 246°.3)

Solution:

Enter: SRT

3639.3 [A] 3330 [B]

1212.7 [C] [D] ——→ 5024.4

[R/S] ——→ 246.3

Example 3:

Compute the altitude and azimuth of Alpheratz if its LHA is 311°04′.5W and its declination is N28°56′.3. The assumed latitude is 34°50′N (Hc = 48°26′.9, Zn = 084°.1)

Solution:

Enter: SRT

31104.5 [A] 3450 [B] 2856.3 [C] [D] ——→ 4826.9

[R/S] ——→ 84.1

Example 4:

Compute the altitude of ♄ (Saturn) if its LHA is 55°53′.1W and its declination is 6°56′.9N. The assumed latitude is 38°39′S. (Hc = 21°03′.2, Zn = 298°.3)

Solution:

Enter: SRT

5553.1 [A] 3839 [CHS] [B]

656.9 [C] [D] ——→ 2103.2

[R/S] ——→ 298.3

Example 5:

Compute the altitude and azimuth of the moon if its LHA is 2°39′.9W and its declination 13°51′.1N. The assumed latitude is 33°20′N. (Hc = 70°22′.1, Zn = 187°.7)

Solution:

Enter: SRT

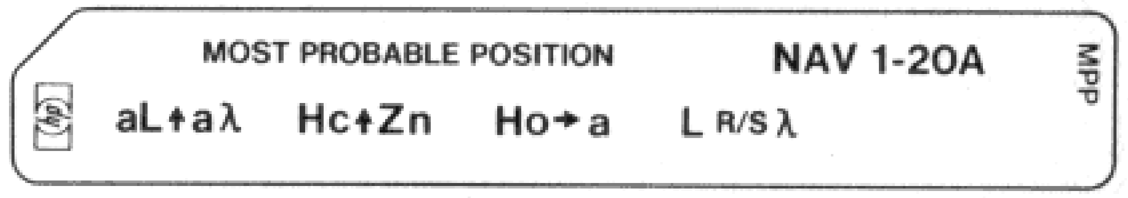
239.9 [A] 3320 [B] 1351.1 [C] [D] ——→ 7022.1

[R/S] ——→ 187.7

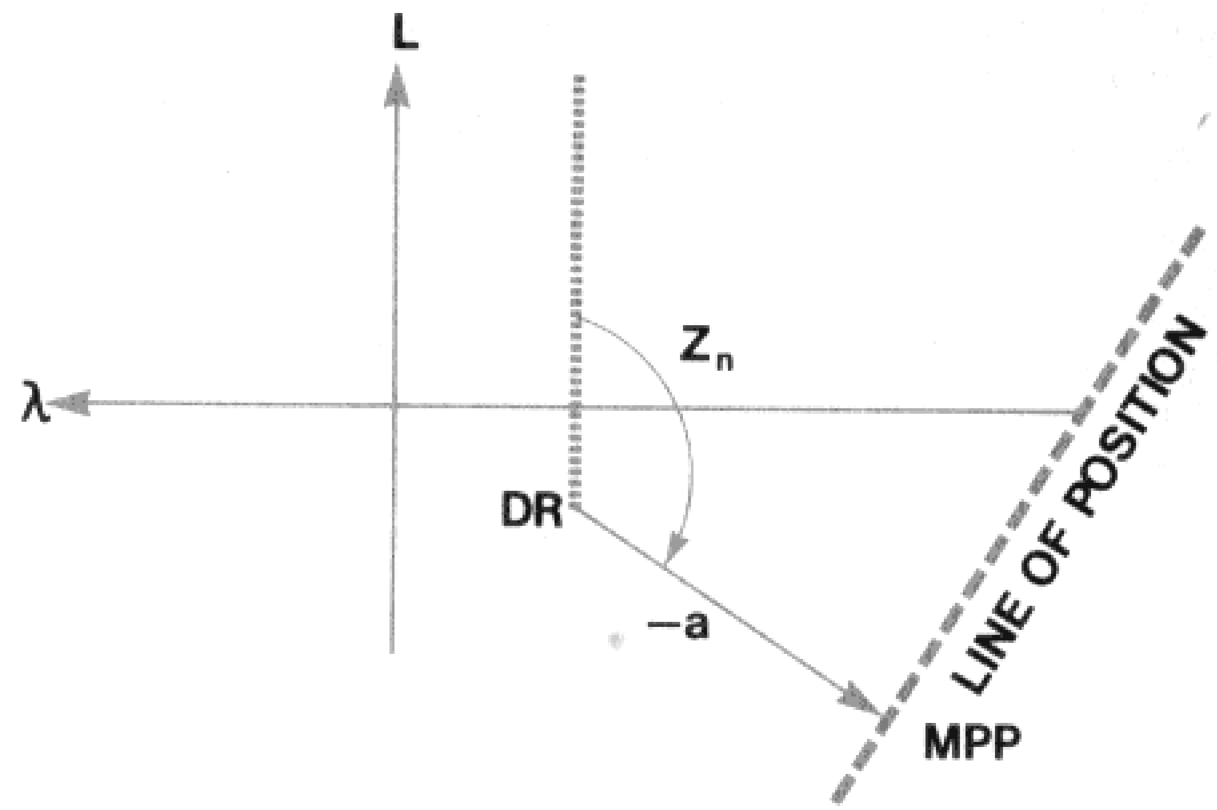
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter SRT			
2	Key in			
	• Local Hour Angle	t, DDMM.m	A	t, D.d
	• Latitude of observer	L, DDMM.m	B	L, D.d
	• Declination of star	d, DDMM.m	C	d, D.d
3	Compute			
	Altitude		D	Hc, DDMM.m
	Azimuth		R/S	Zn, D.d
	OR			
1	First run ARIES ALMANAC			
	and the SUN or a STAR			
	ALMANAC			
2	Enter SRT			
3	Compute			
	Altitude		D	Hc, DDMM.m
	Azimuth		R/S	Zn, D.d

NAV 1-20A

MOST PROBABLE POSITION



This program computes the most probable position from a single observation of a celestial object by dropping a perpendicular from the dead reckoning position to the line of position of the object. Inputs are the observer's position (DR), Hc and Zn of the object, and the object's corrected sextant height. If this card is run after the Aries and star almanacs and the sight reduction table, only the corrected sextant height need be input, because the other programs will have stored all necessary data.



Equations:

$$\lambda = \lambda_1 - \frac{-a \sin Zn}{\cos L_1}$$

$$L = L_1 - a \cos Zn$$

where

L_1, λ_1 = coordinates of observer's DR

L, λ = coordinates of MPP

a = Hc − Ho = altitude intercept (− = Towards, + = Away)

Hc = computed altitude of object

Ho = corrected sextant height

Zn = Azimuth of object

Example:

A navigator determines his DR to be L40°12′S, λ159°57′E. He observes Procyon at $9^h 40^m 59^s$ GMT to be 11°11.′3 above the horizon. The computed altitude is 10°57.′0 at 73°4. What is his MPP? (L40°07.′9S, λ160°14.′9E)

Solution:

Enter: MPP

4012 [CHS] [ENTER↑] 15957 [CHS] [A]

1057.0 [ENTER↑] 73.4 [B] 1111.3 [C] ——→ −14.3

(14.3 miles Toward)

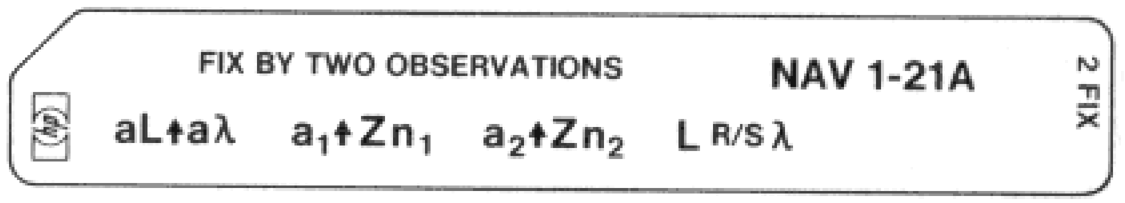
[D] ——→ −4007.9

[R/S] ——→ −16014.9

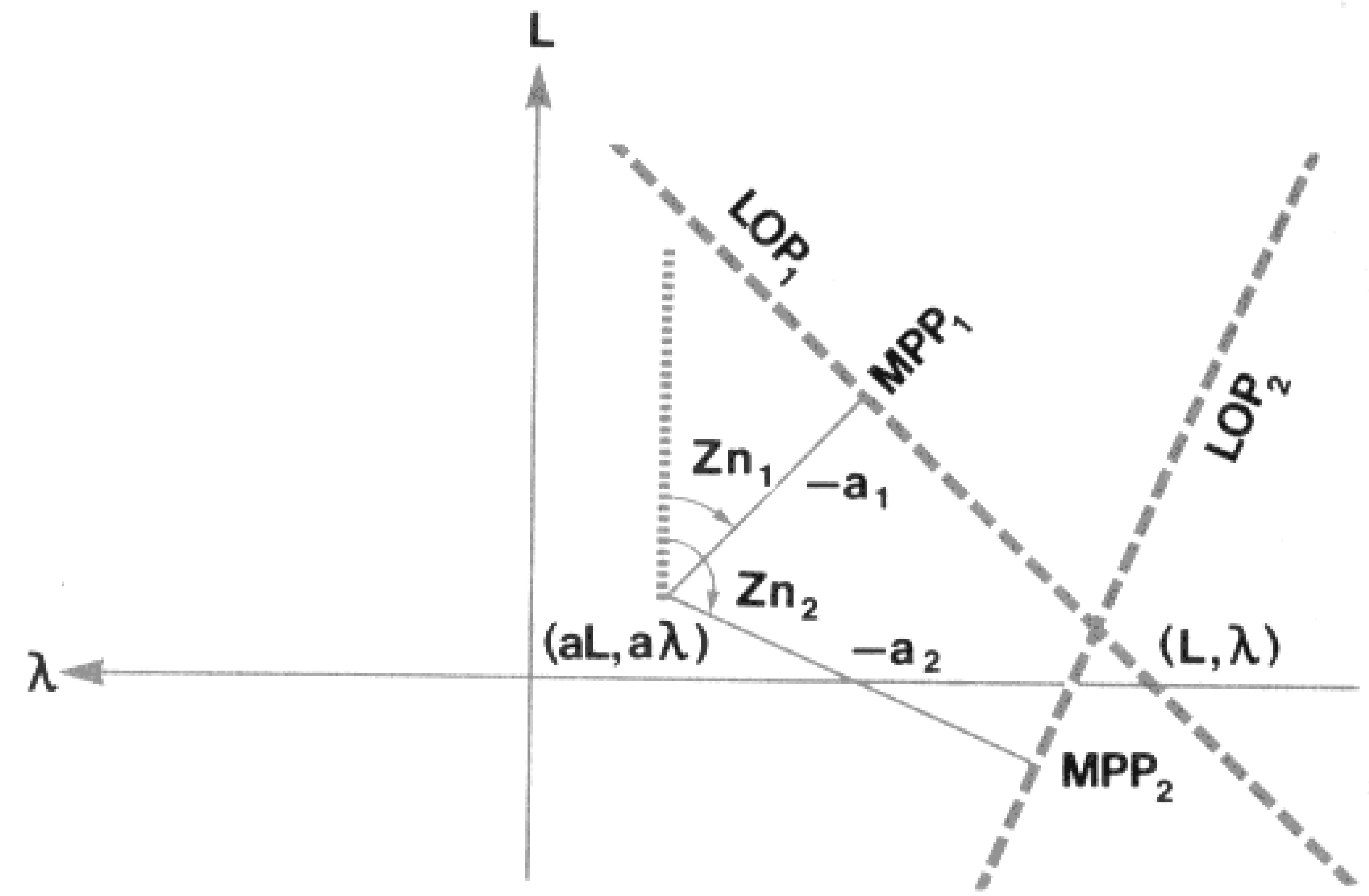
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter MPP			
2	Key in			
	• Observer's position			
	Latitude ([CHS] for South)	aL, DDMM.m	↑	aL, DDMM.m
	Longitude ([CHS] for East)	aλ, DDMM.m	A	aL, D.d
	• Computed star sight			
	Computed Altitude	Hc, DDMM.m	↑	Hc, DDMM.m
	Azimuth	Zn, D.d	B	Hc, D.d
3	Key in observed altitude and			
	compute			
	altitude intercept (+ = A, − = T)	Ho, DDMM.m	C	a, M.m
4	Compute location of MPP			
	Latitude (− = S, + = N)		D	L, DDMM.m
	Longitude (− = E, + = W)		R/S	λ, DDMM.m
	OR			
1	First run ARIES ALMANAC,			
	the SUN or STAR ALMANAC,			
	LHA, and SRT			
2	Enter MPP			
3	Key in observed altitude and			
	compute altitude intercept	Ho, DDMM.n	C	a, M.m
	Compute location of MPP			
	Latitude (− = S, + = N)		D	L, DDMM.m
	Longitude (− = E, + = W)		R/S	λ, DDMM.m

NAV 1-21A

FIX BY TWO OBSERVATIONS



This program accepts the observer's dead reckoning position and intercepts and azimuths for observations of any two celestial bodies and computes the coordinates of the intersection of the lines of position of the two bodies. Inputs and outputs are expressed in the form DDMM.m or D.d as appropriate. The intercepts and azimuths for the two bodies may have been obtained as intermediate outputs when solving for the most probable positions resulting from each of the two sights.



Equations:

$$L = aL - \Delta L_1 + \tan Zn_1 \left[\frac{\Delta L_2 - \Delta L_1 - \Delta\lambda_1 \tan Zn_1 + \Delta\lambda_2 \tan Zn_2}{\tan Zn_2 - \tan Zn_1} - \Delta\lambda_1 \right]$$

$$\lambda = a\lambda + \frac{\Delta L_2 - \Delta L_1 - \Delta\lambda_1 \tan Zn_1 + \Delta\lambda_2 \tan Zn_2}{(\tan Zn_2 - \tan Zn_1)\cos aL}$$

where

$\Delta L_1 = a_1 \cos Zn_1$

$\Delta\lambda_1 = a_1 \sin Zn_1$

$\Delta L_2 = a_2 \cos Zn_2$

$\Delta\lambda_2 = a_2 \sin Zn_2$

Example:

Pollux, Spica and Vega are observed from L42°31'.8N, λ171°28'.6E. Pollux's intercept is 13.8 miles away at 288°.3 and Vega's is 6 miles toward at 65°.8. What is the position of the fix (L42°21'.6N, λ171°43'.7E)

Solution:

Enter: 2 FIX

4231.8 [ENTER↑] 17128.6 [CHS] [A] 13.8 [ENTER↑]
288.3 [B] 6 [CHS] [ENTER↑] 65.8 [C] [D] ——→ 4221.60
[R/S] ——→ −17143.73

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter 2 FIX				
2	Key in				
	• Assumed position				
	Latitude ([CHS] for South)	aL, DDMM.m	↑		aL, DDMM.m
	Longitude ([CHS] for East)	aλ, DDMM.m	A		aL, D.d
	• Celestial body #1				
	Altitude difference ([CHS] for				
	Toward)	a_1, M.m	↑		a_1, M.m
	Azimuth	Zn_1, D.d	B		$\Delta\lambda_1$, M.m
	• Celestial body #2				
	Altitude difference ([CHS] for				
	Toward)	a_2, M.m	↑		a_2, M.m
	Azimuth	Zn_2, D.d	C		$\Delta\lambda_2$, M.m
3	Compute				
	Latitude (− = S, + = N)		D		L, DDMM.m
	Longitude (− = E, + = W)		R/S		λ, DDMM.m

NAV 1-22A

FIX BY THREE OBSERVATIONS

FIX BY THREE OBSERVATIONS NAV 1-22A 3 FIX

$L_1 \uparrow \lambda_1$ $L_2 \uparrow \lambda_2$ $L_3 \uparrow \lambda_3$ L R/S λ

This program computes the coordinates of a fix obtained from observations of three celestial bodies. Inputs are the three vertices of the triangle formed by the LOP's. The resulting fix is the centroid of the triangle.

Notes:

1. This program will not work if the triangle straddles the dateline.
2. If the bodies are not well distributed in azimuth, it may be advisable to plot an exterior fix.

Equations:

$$L = \frac{L_1 + L_2 + L_3}{3}$$

$$\lambda = \frac{\lambda_1 + \lambda_2 + \lambda_3}{3}$$

Example:

On a set of observations on three stars, the Fix by Two Observations program gave three positions: L_1 40°25'.63S, λ_1 160°21'.85E; L_2 40°22'.40S, λ_2 160°20'.58E; L_3 40°25'.83S, λ_3 160°14'.53E. What is the best fix based on these three two-star fixes? (L40°24'.62S, λ160°18'.98E)

Solution:

Enter: 3 FIX

4025.63 [CHS] [ENTER↑] 16021.85 [CHS] [A]
4022.40 [CHS] [ENTER↑] 16020.58 [CHS] [B]
4025.83 [CHS] [ENTER↑] 16014.53 [CHS] [C] ⟶ -4024.62
[R/S] ⟶ -16018.98

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter 3 FIX			
2	Key in vertices			
	• Vertex 1			
	Latitude ([CHS] for South)	L_1, DDMM.m	[↑]	L_1, DDMM.m
	Longitude ([CHS] for East)	λ_1, DDMM.m	[A]	L_1, D.d
	• Vertex 2			
	Latitude ([CHS] for South)	L_2, DDMM.m	[↑]	L_2, DDMM.m
	Longitude ([CHS] for East)	λ_2, DDMM.m	[B]	L_2, D.d
	• Vertex 3			
	Latitude ([CHS] for South)	L_3, DDMM.m	[↑]	L_3, DDMM.m
	Longitude ([CHS] for East)	λ_3, DDMM.m	[C]	L_3, D.d
3	Compute most probable position			
	Latitude (– = S, + = N)		[D]	L, DDMM.m
	Longitude (– = E, + = W)		[R/S]	λ, DDMM.m

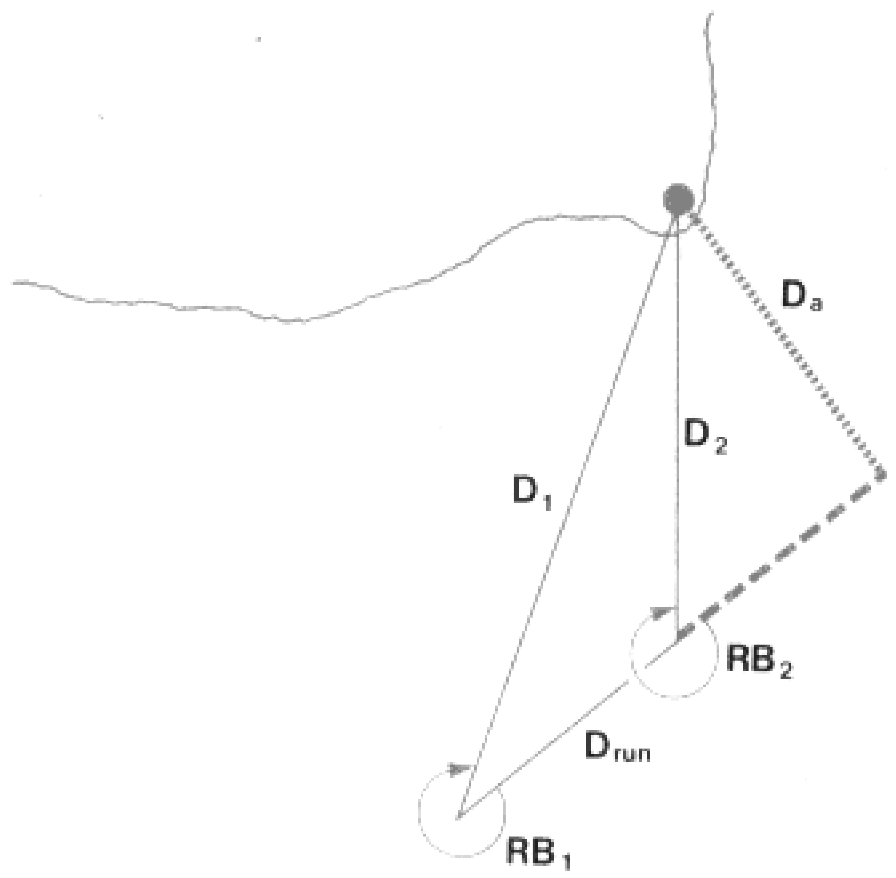
NAV 1-23A

DISTANCE OFF AN OBJECT BY TWO BEARINGS

DISTANCE OFF AN OBJECT BY TWO BEARINGS — NAV 1-23A — DIST

$RB_1 \uparrow RB_2$ | D_{run} | $S \uparrow t$ | D_a | D_1 R/S D_2

To determine the distance off an object as a vessel passes it, observe two bearings on the bow and note the distance run between bearings. The program calculates the distance off the object when it is abeam and at the time of the first and second bearings.



Equations:

$$D_2 = \frac{\sin RB_1}{\sin (RB_2 - RB_1)} D_{run}$$

$$D_{abeam} = \left| D_2 \sin RB_2 \right|$$

$$D_1 = \left| \frac{D_{abeam}}{\sin RB_1} \right|$$

where

RB_1 = First relative bearing

RB_2 = Second relative bearing

D_{run} = St = Distance run

S = speed of vessel

t = time in minutes

D_1, D_2 = Distance at time of first or second bearing

D_a = Distance when abeam

Example 1:

A lighthouse bears –026° (26° counterclockwise) at 1130 and –051° at 1140. Our speed is 15 knots. How far will we be off the light when it is abeam? (2 nautical miles). How far off were we at 1130 and 1140? (4.6 and 2.6 nautical miles).

Solution:

26 [CHS] [ENTER↑] 51 [CHS] [A]

15 [ENTER↑] 10 [C] [D] ⟶ 2.02

[E] ⟶ 4.60

[R/S] ⟶ 2.59

Example 2:

A buoy is sighted bearing 015° on the bow, after a 3 mile run it bears 105°. What was its distance when abeam? (0.75 nautical miles) miles)

Solution:

15 [ENTER↑] 105 [A] 3 [B] [D] ⟶ 0.75

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter DIST				
2	Key in				
	• Bearings				
	at t_1	RB_1, D.d	↑		RB_1, D.d
	at t_2	RB_2, D.d	A		RB_1, D.d
	• Distance run				
	Distance	D_{run}, naut. mi.	B		D_{run}, naut. mi.
	or				
	Speed and	S, knots	↑		S, knots
	Time between bearings	t, M.m	C		D_{run}, naut. mi.
3	Compute				
	• Distance when abeam		D		D_a, naut. mi.
	• Distance				
	at time t_1		E		D_1, naut. mi.
	at time t_2		R/S		D_2, naut. mi.

NAV 1-24A
VECTOR ADDITION

VECTOR ADDITION			NAV 1-24A		VECTOR
$B_1 \uparrow r_1$	$B_2 \uparrow r_2$	$\vec{r}_1 + \vec{r}_2$	$\vec{r}_1 - \vec{r}_2$	$\vec{r}_2 - \vec{r}_1$	

This program will compute the sum or difference of two vectors in polar form. It can be used to solve a large number of relative motion problems.

Example 1:

The apparent wind is from 040° relative at 15 knots. Our speed is 5 knots. What is the true relative wind? (11.62 knots at 236°.05 (from 56°.05))

Solution:

220 [ENTER↑] 15 [A] 0 [ENTER↑] 5 [B] [C] ——→ 11.62

[R/S] ——→ 236.05 (direction of wind)

180 [−] ——→ 56.05 (direction wind comes from)

Example 2:

A vessel fixes her position at the beginning and end of a 23 minute run at 8 knots on heading 030°. She made good 4 nautical miles but her true course was 041°. What is the current? (3 knots, 71°.6)

Solution:

30 [ENTER↑] 8 [A] 41 [ENTER↑]

4 [ENTER↑] 23 [÷] 60 [×] [B] [E] ——→ 3.00

[R/S] ——→ 71.59

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter VECTOR			
2	Key in vectors			
	• Vector 1			
	bearing	B_1, D.d	[↑]	B_1, D.d
	magnitude	r_1	[A]	0.00
	• Vector 2			
	bearing	B_2, D.d	[↑]	B_2, D.d
	magnitude	r_2	[B]	0.00
3	Compute			
	• Sum			
	Magnitude		[C]	$\lvert\vec{r}_1 + \vec{r}_2\rvert$
	Bearing		[R/S]	B, D.d
	• Difference $\vec{r}_1 - \vec{r}_2$			
	Magnitude		[D]	$\lvert\vec{r}_1 - \vec{r}_2\rvert$
	Bearing		[R/S]	B, D.d
	• Difference $\vec{r}_2 - \vec{r}_1$			
	Magnitude		[E]	$\lvert\vec{r}_2 - \vec{r}_1\rvert$
	Bearing		[R/S]	B, D.d
	Note: Continued pressing of			
	R/S causes alternate display of			
	magnitude and bearing.			

NAV 1-25A
VELOCITY TO CHANGE RELATIVE POSITION

VELOCITY TO CHANGE RELATIVE POSITION				NAV 1-25A	REL POS
g COURSE SPEED	M 1 BEARING↑ DISTANCE	M 2 BEARING↑ DISTANCE	Δt H.MS	COURSE R/S SPEED	

This program may be used when it is desired to change position relative to another vessel whose course and speed are known. The program computes the course and speed necessary to complete the maneuver in a specified time. Bearings may be relative or true.

Equations:

$$\vec{em} = \frac{\vec{GM}_2 - \vec{GM}_1}{\Delta t} + \vec{eg}$$

where

$\vec{em}$ = velocity of maneuvering vessel (M)

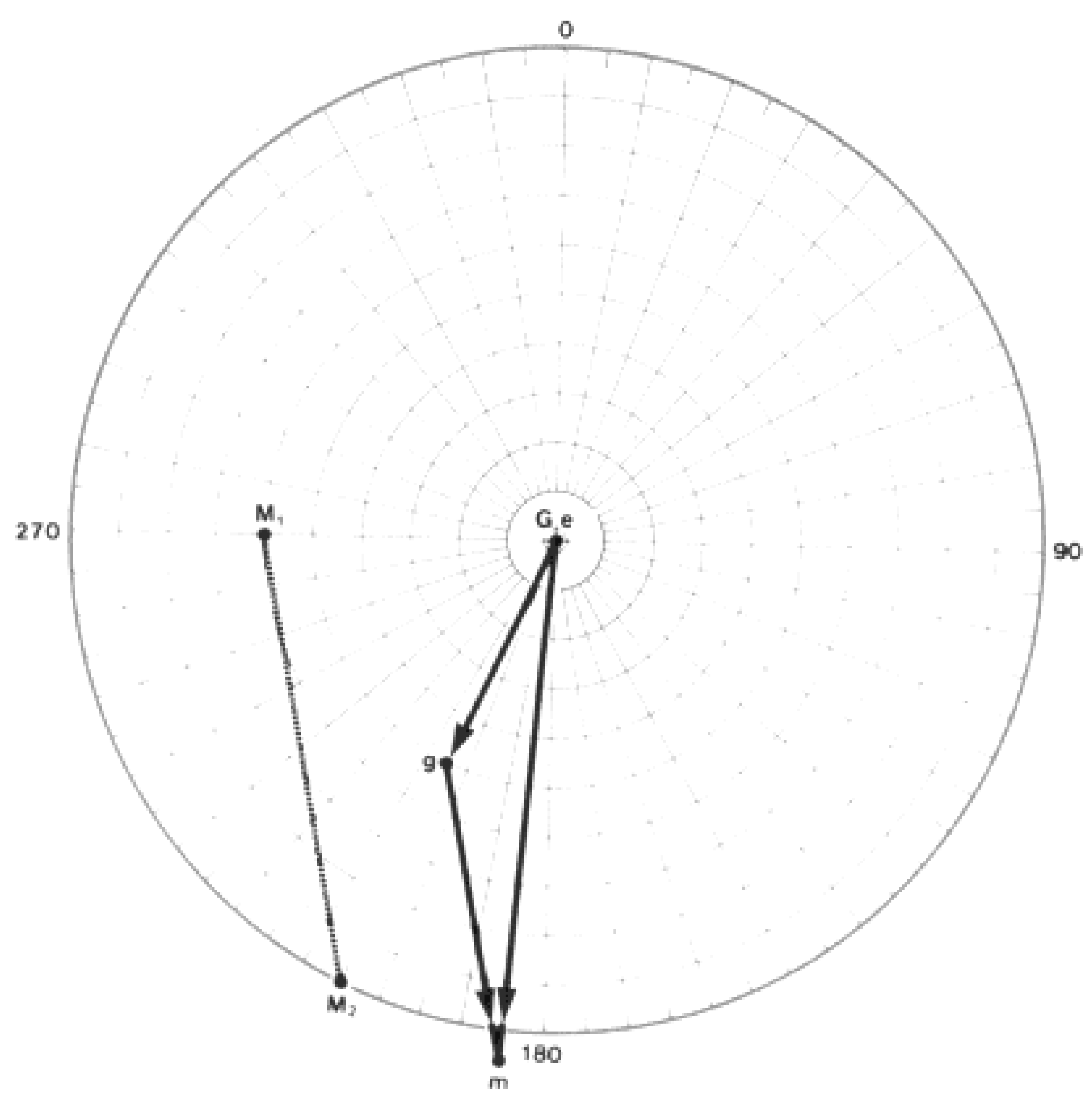
$\vec{eg}$ = velocity of guide vessel (G)

$\vec{GM}_1$ = position of M relative to G at time t_1

$\vec{GM}_2$ = position of M relative to G at time t_2

Δt = time for maneuver

The vector symbol $\vec{a}$ represents magnitude and angle simultaneously.



Example:

The guide is on course 205° true, speed 10 knots. We wish to change position from 12 miles due west of the guide to 20 miles dead ahead (0° relative) in 1.5 hours. What is our course and speed? (185°, 21.2 knots)

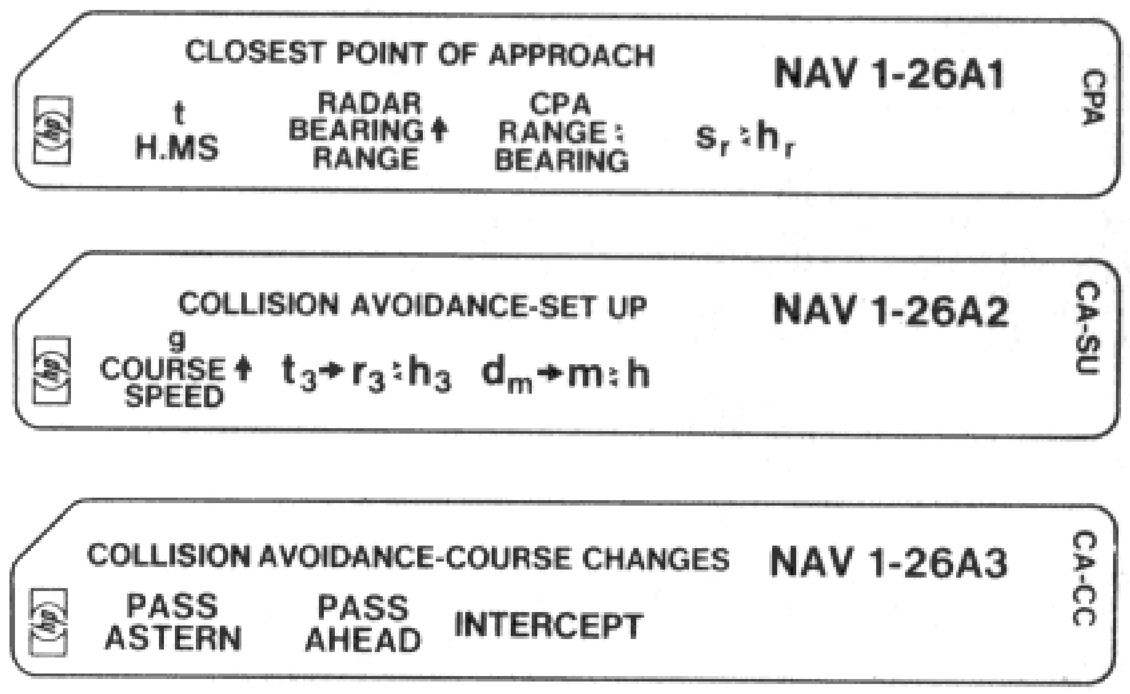
Solution:

205 [ENTER↑] 10 [A] 270 [ENTER↑] 12 [B]
0 [ENTER↑] 20 [C] 1.30 [D] [E] ——→ 185.03
[R/S] ——→ 21.23

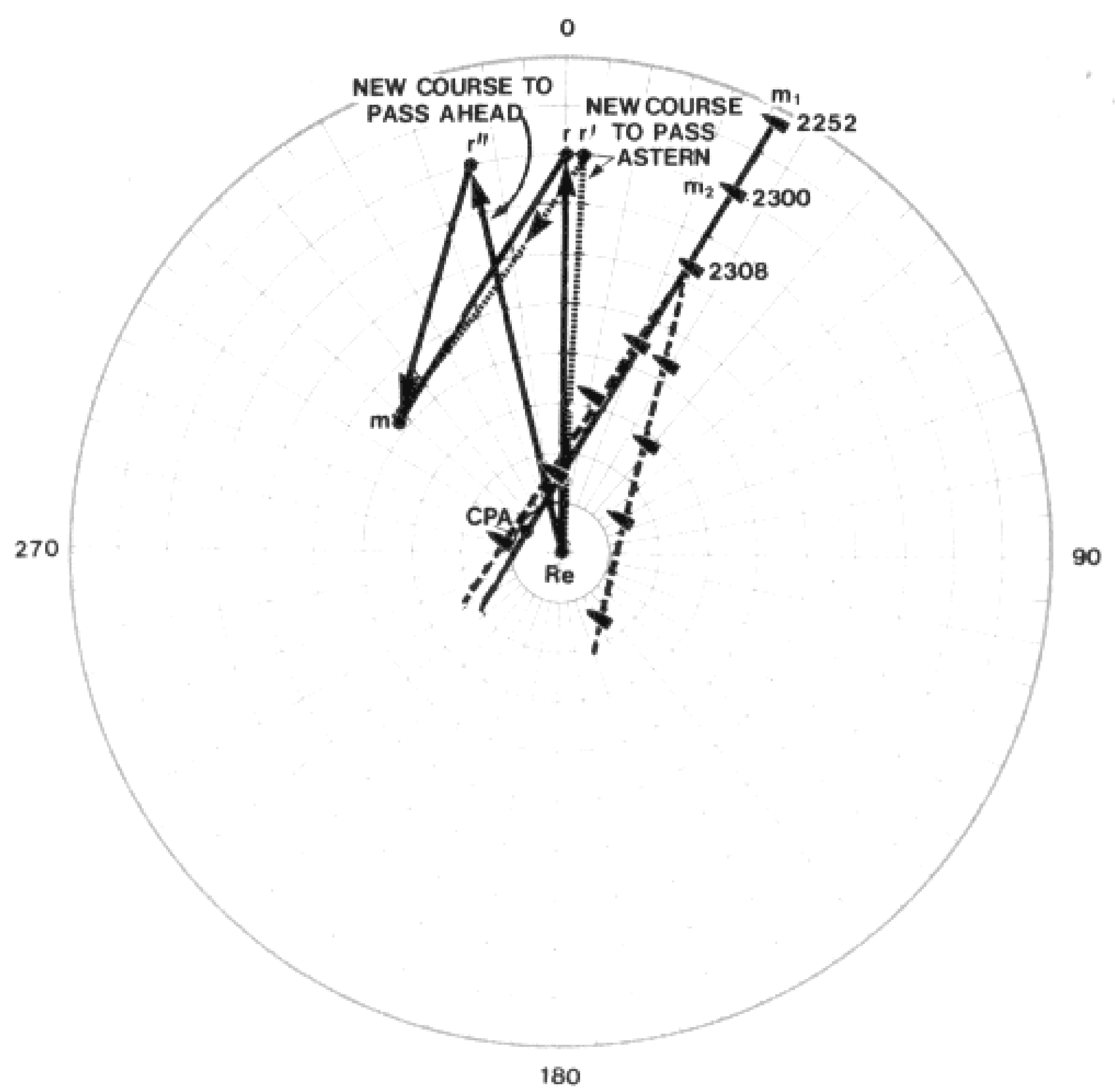
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter REL POS			
2	Key in G's way			
	Course	C, D.d	↑	C, D.d
	Speed	S, knots	A	90 – C, D.d
3	Key in relative positions and			
	time allowed			
	• M_1			
	Bearing	B_1, D.d	↑	B_1, D.d
	Distance	RM_1, naut. mi.	B	0.00
	(If entered bearing was relat-			
	ive)		R/S	– C
	• M_2			
	Bearing	B_2, D.d	↑	B_2, D.d
	Distance	RM_2, naut. mi.	C	0.00
	(If entered bearing was relat-			
	ive)		R/S	– C
	• Time allowed for maneuver	Δt, H.MS	D	Δt, H.h
4	Compute M's way to complete			
	maneuver			
	Course		E	C, D.d
	Speed		R/S	S, knots

NAV 1-26A

MANEUVERING RELATIVE TO ANOTHER VESSEL



This program computes the course change necessary to come within distance D of a ship having range r_1 and bearing B_1 at time t_1 and range r_2 and bearing B_2 at time t_2. The course change is applied at a specific time t_3. Intermediate outputs are range and bearing of CPA, relative speed and heading of the other ship, range and bearing of other ship at t_3, and actual speed and heading of other ship. The final outputs are course change and new heading to pass ahead, pass astern, or intercept.



Equations:

Card 1:

Let $\vec{r}_1 = r_1 \angle B_1$ = the range and true bearing of target at t_1

$\vec{r}_1 = r_2 \angle B_2$ = the range and true bearing of target at t_2

$\vec{r}_{CPA} = r_{CPA} \angle B_{CPA}$ = the range and true bearing of target at t_{CPA}

Then the bearing of the CPA is

$$B_{CPA} = \tan^{-1} \frac{r_2 \cos B_2 - r_1 \cos B_1}{r_1 \sin B_1 - r_2 \sin B_2}$$

and the range of the CPA is

$$r_{CPA} = r_2 \cos (B_{CPA} - B_2)$$

The relative motion $\overrightarrow{rm} = rm \angle h_r$ is given by

$$\overrightarrow{rm} = \frac{\vec{r}_2 - \vec{r}_1}{t_2 - t_1} \times \frac{1 \text{ mile}}{2025 \text{ yd.}}$$

Card 2:

Let C = course of our ship

$S = er$ = speed of our ship

t_3 = time at which course change will be executed

$\vec{r}_3 = r_3 \angle B_3$

θ = change to relative heading to intercept

$h_r + \theta$ = relative heading to intercept

ϕ = change to $(h_r + \theta)$ to pass at distance D

D = desired miss distance

$\overrightarrow{em} = em \angle h$ = speed and heading of target ship

Then $\vec{r}_3 = \vec{r}_2 + \overrightarrow{rm}(t_3 - t_2) \times 2025$

$$\phi = \sin^{-1} \frac{D}{r_3}$$

$$\overrightarrow{em} = \overrightarrow{er} + \overrightarrow{rm} = S \angle C + rm \angle h_r$$

$$\theta = B_3 + 180 - h_r$$

Card 3:

Let

$$\beta = \begin{cases} \theta + \phi \text{ to pass astern} \\ \theta - \phi \text{ to pass ahead} \\ \theta \text{ to intercept} \end{cases}$$

α = new course at time t_3

Then $$\alpha = h_r + \beta + 180 - \sin^{-1}\left(\frac{em}{er} \sin (h - h_r - \beta)\right)$$

Example:

Part 1: At 2252 a ship observes a target 29,100 yards away at 026° true. At 2300, the position of the target is 24,000 yards at 025° What is the CPA? (2380 yards at 301°) What is the relative speed of the target? (18.97 knots at 211°)

Solution:

Card 1:

22.52 [A] 26 [ENTER↑] 29100 [B] 23.00 [A]

25 [ENTER↑] 24000 [B] [C] ——→ 2380.24 (range of CPA)

[g] [x⇄y] ——→ 300.69 (bearing of CPA)

[D] ——→ 18.97 (relative speed)

[g] [x⇄y] ——→ 210.69 (relative heading)

Part 2: Our course is 24 knots at 000°. We wish to change course at 2308 so that we will pass 3000 yards astern of the target.

Solution:

Card 2:

0 [ENTER↑] 24 [A] 23.08 [B] ——→ 18911.25 (range at t_3)

[g] [x⇄y] ——→ 23.46 (bearing at t_3)

3000 [C] ——→ 12.36 (his speed)

[g] [x⇄y] ——→ -51.53 (his heading)

Part 3: What course should we steer to pass astern? (002°) Ahead? (346°) Intercept? (354°)

Solution:

Card 3:

[A] ——→ 2.002 (come starboard 2° to heading 002 to pass astern)

[B] ——→ -14.346 (come port 14° to heading 346 to pass ahead)

[C] ——→ -6.354 (come port 6° to heading 354 to intercept)

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter CPA				
2	Key in				
	• $Time_1$	t_1, H.MS	A		t_1, H.h
	• Relative $position_1$				
	Bearing	B_1, D.d	↑		B_1, D.d
	Range	r_1, yards	B		B_1, D.d
3	Key in				
	• $Time_2$	t_2, H.MS	A		t_2, H.h
	• Relative $position_2$				
	Bearing	B_2, D.d	↑		B_2, D.d
	Range	r_2, yards	B		B_2, D.d
4	Compute				
	Closest point of approach		C		r_{CPA}, yards
5	Display				
	Bearing of CPA (optional)		g	x⇄y	B_{CPA}, D.d
6	Compute				
	Relative velocity (rm)		D		rm, knots
7	Display				
	Relative heading		g	x⇄y	h_r, D.d

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter CA - SU				
2	Key in R's way				
	Course	C, D.d	↑		C, D.d
	Speed	S, knots	A		100C + S/1000
3	Key in				
	Time when course will be				
	changed	t_3, H.MS	B		r_3, yards
4	Display				
	Bearing at t_3 (optional)		g	x⇄y	B_3, D.d
5	Key in desired CPA and com-				
	plete speed of target	D, yards	C		em, knots
6	Display				
	M's heading (optional)		g	x⇄y	h, D.d

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter CA - CC				
2	Output				
	• Course change and new				
	course to pass astern		A		ΔC. CCC *
	• Course change and new				
	course to pass ahead		B		ΔC. CCC
	• Course change and new				
	course to intercept		C		ΔC. CCC
*	This display is a combination				
	of two numbers, thus – 23.058				
	is read "come port 23° to a new				
	course of 058."				

APPENDIX

Appendix 1

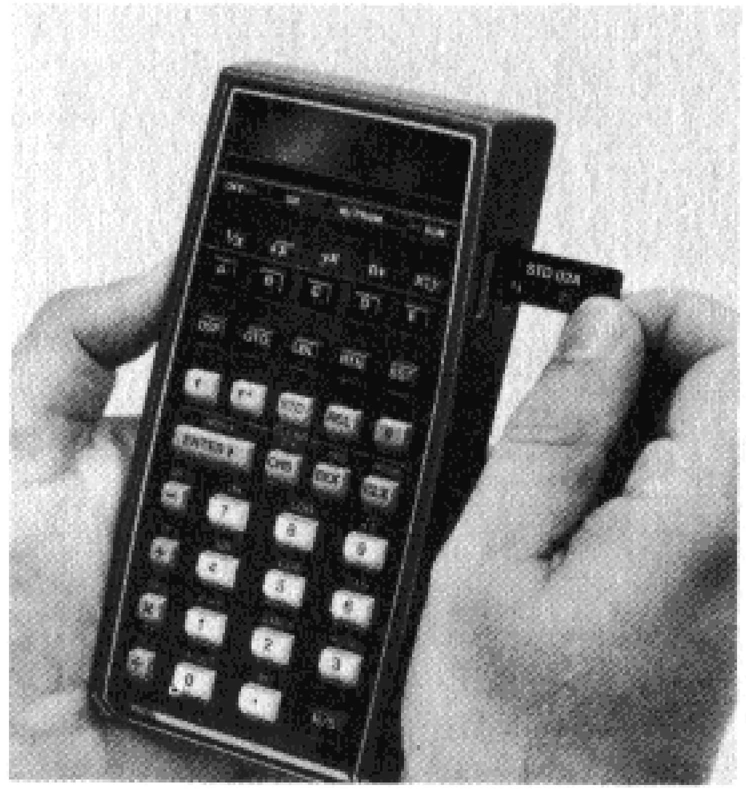
ENTERING A PROGRAM

From the card case supplied with this application pac, select a program card.

Set W/PRGM-RUN switch to RUN.

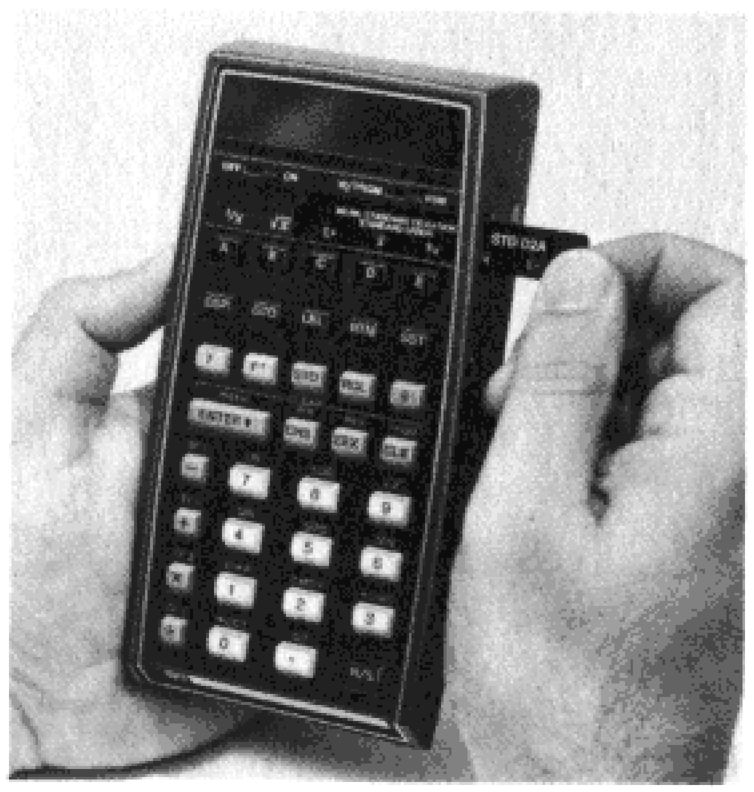
Turn the calculator ON. You should see 0.00

Gently insert the card (printed side up) in the right, lower slot as shown. When the card is part way in, the motor engages it and passes it out the left side of the calculator. Sometimes the motor engages but does not pull the card in. If this happens, push the card a little farther into the machine. Do not impede or force the card; let it move freely. (The display will flash if the card reads improperly. In this case, press R/S and reinsert the card.)



When the motor stops, remove the card from the left side of the calculator and insert it in the upper "window slot" on the right side of the calculator.

The program is now stored in the calculator. It remains stored until another program is entered or the calculator is turned off.



Appendix 2

FORMAT OF USER INSTRUCTIONS

The User Instruction Form is your guide to operating the programs in this pac.

The form is composed of five labeled columns. Reading from left to right, the first column, labeled STEP, gives the instruction step number.

The INSTRUCTIONS column gives instructions and comments concerning the operations to be performed. Items preceded by a dot (•) in the INSTRUCTIONS column may be performed in any convenient order. Absence of the dot indicates that the order of operations is important.

The INPUT-DATA/UNITS column specifies the input data, and the units of data if applicable. Data input keys consist of the numeric keys [0] to [9], [•] (decimal point), [EEX] (enter exponent), and [CHS] (change sign).

The KEYS column specifies the keys to be pressed. Where the [ENTER↑] key is used, it is indicated by [↑]. All other key designations are identical to those appearing on the HP-65. Ignore any blank spaces in the KEYS columns.

The OUTPUT-DATA/UNITS column specifies intermediate and final outputs and their units where applicable.

Angles are usually expressed as either degrees, minutes and tenths (DDMM.m) or as degrees and tenths (D.d). In certain cases, it is necessary to input angles as degrees, minutes and seconds (D.MS). There are keystroke procedures in Appendix 5 to facilitate conversion among these three forms of angular notation.

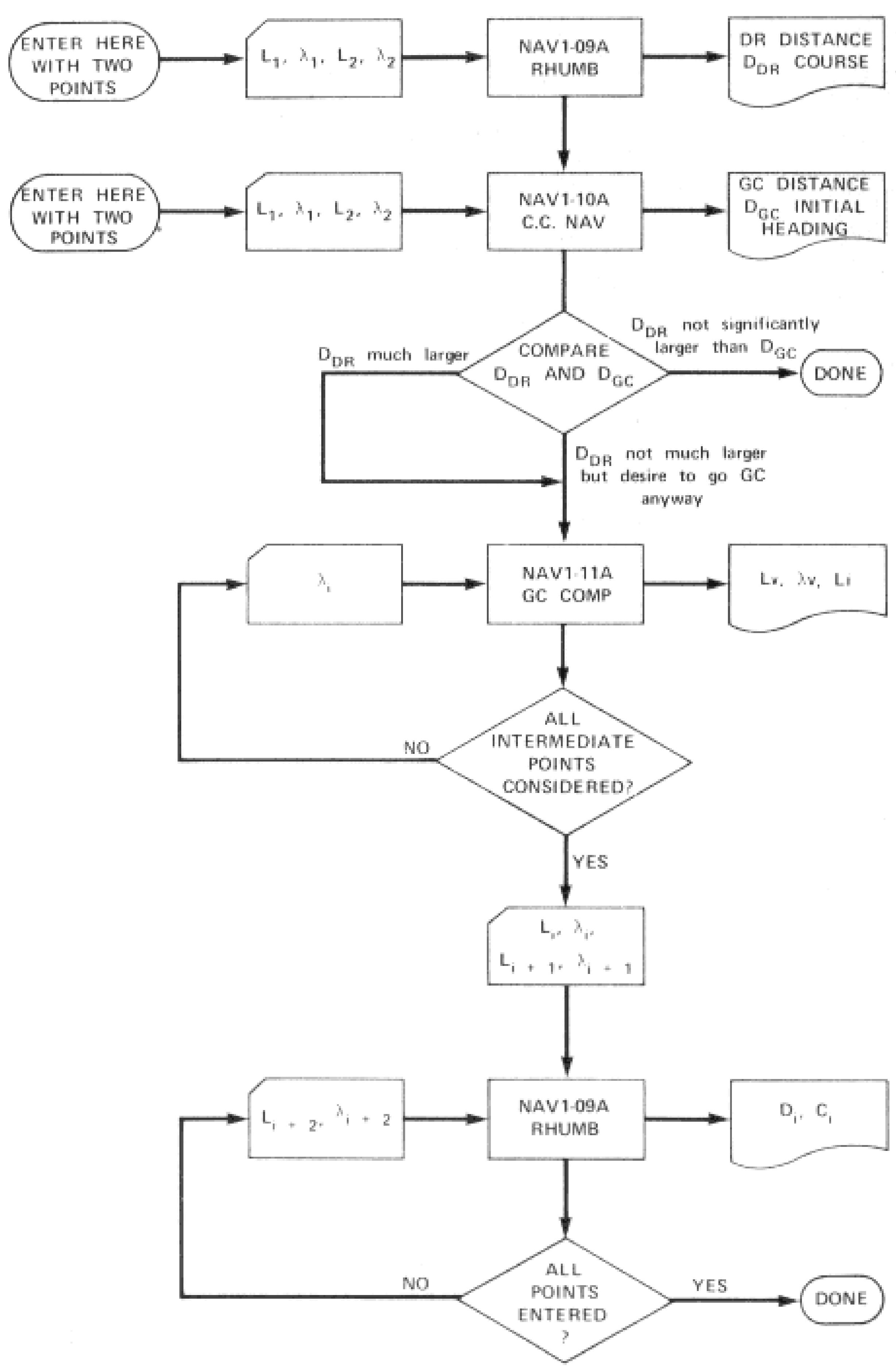
Some User Instruction Forms indicate that the value zero is output for any input. These programs are interchangeable solutions which solve for the missing variable in an equation when all others are specified. The zero is used by the program as a signal to calculate, thus, if a zero is not in the display when the calculation is attempted, no calculation will be done. All known values must be input before trying to calculate an unknown.

Appendix 3

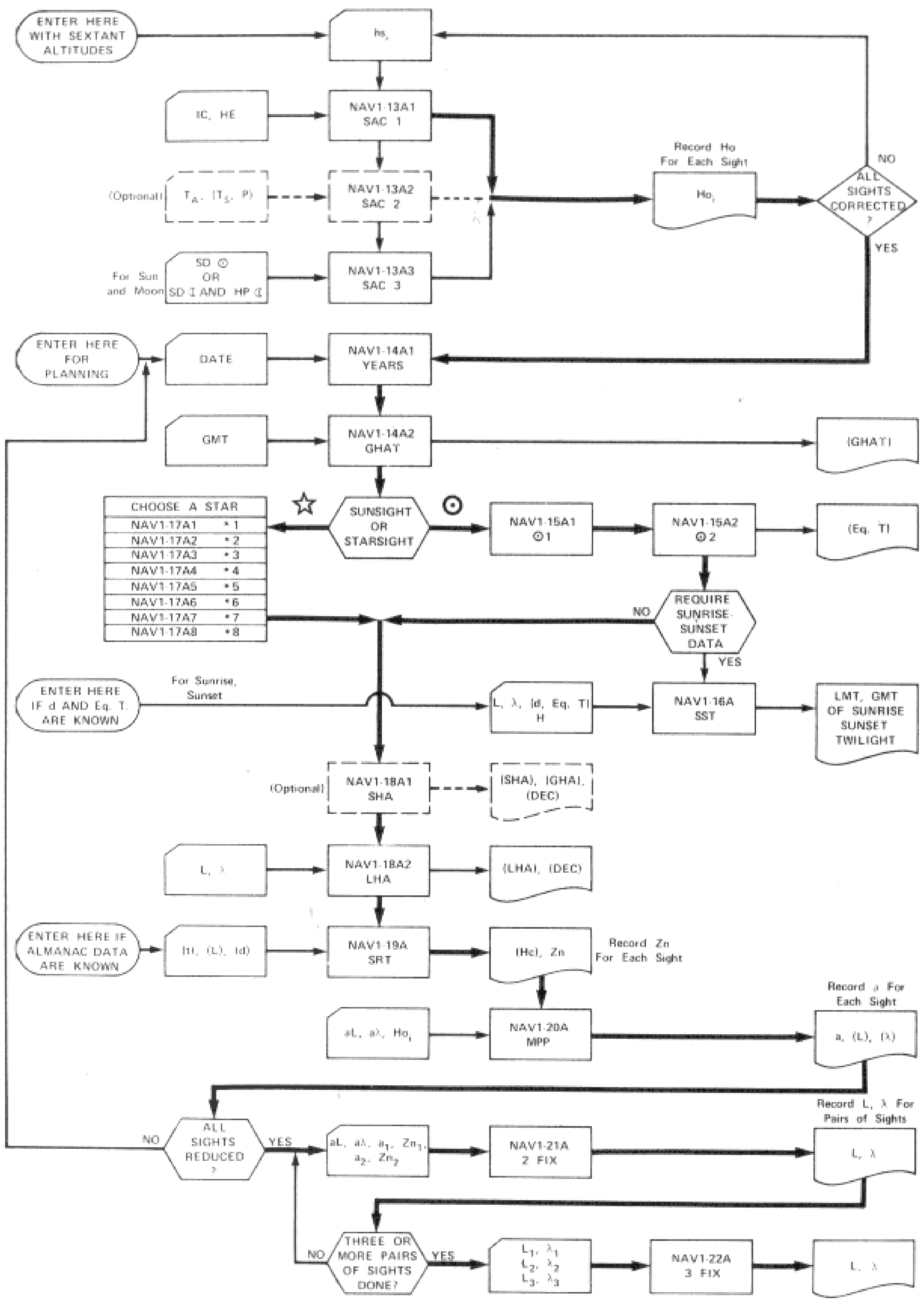
LINKED PROGRAMS, AND REGISTER USAGE

Most programs in the HP-65 Navigation Pac may be run alone, but certain sets of programs are designed so that they may follow each other in a particular order, passing data from program to program through the data registers. The accompanying flow charts show how the programs are intended to be linked for certain problems. The table showing register usage is useful for determining whether or not a variable may be passed to another program through the data registers.

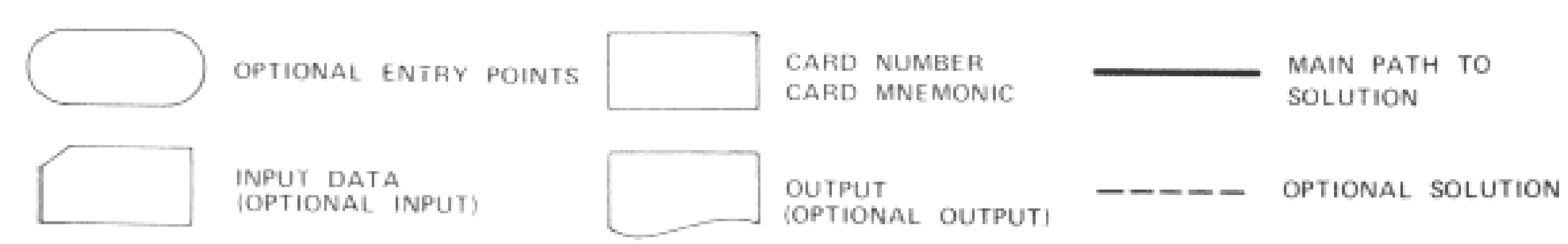
VOYAGE PLANNING



SIGHT PLANNING – REDUCTION



FLOW CHART SYMBOLS



		R1	R2	R3	R4	R5	R6	R7	R8	R9
01A	LENGTH	Used								Used
02A	STD	Speed	Time	Distance						Used
03A	ARC	t, sec								Used
04A	SLIP	RPM	Pitch	Slip	Speed					Used
05A	FUEL	F_1	F_2	S_1	S_2	D_1	D_2			Used
06A	D_{hor} +	IC	HE	H	ha		D	Used		Used
07A	D_{hor} −	IC	HE							Used
08A	DR	L	λ			S cos C	S sin C	Δt		Used
09A	RHUMB	L_2	L_1	λ_2	λ_1	$\ln\tan\left(45+\frac{L_2}{2}\right)$	$\ln\tan\left(45+\frac{L_1}{2}\right)$	$\lambda_1 - \lambda_2$	Used	Used
10A	GC NAV	L_2	L_1	λ_2	λ_1	$\lambda_2 - \lambda_1$	D/60	H_i		Used
11A	GC COMP	L_2	L_1	λ_2	λ_1			H_i	λ_i	Used
12A	COMP SAIL	L_2	L_1	λ_2	λ_1	tan L_{max}	sgn			Used
13A1	SAC 1	ha	Ho				HE	IC		Used
13A2	SAC 2	ha	Ho	T_{air}		P			T_{sea}	Used
13A3	SAC 3		Ho_{old}							Used
14A1	YEARS		Day	Month	Year	0, 1, 2, or 3	(M > 2)	n	($\overline{LY}$)	Y.y
14A2	GHA ♈	Time	Day	Month	Year		day #	n	($\overline{LY}$), GHA ♈	Y.y
15A1	☉ 1	Time	θ	SHA ☉	Eq.T.		day #	Y.y	GHA ♈	Used
15A2	☉ 2		θ	SHA ☉	Eq.T., ΔSHA = 0	DEC ☉	ΔSHA = 0			Y.y
16A	SST	H	L	λ		DEC ☉		Eq.T.		Used

		R1	R2	R3	R4	R5	R6	R7	R8	R9
17A1	★1			SHA(1900)	ΔSHA	DEC(1900)	ΔDEC		GHA ♈	Y.y
17A2	★2			SHA(1900)	ΔSHA	DEC(1900)	ΔDEC		GHA ♈	Y.y
17A3	★3			SHA(1900)	ΔSHA	DEC(1900)	ΔDEC		GHA ♈	Y.y
17A4	★4			SHA(1900)	ΔSHA	DEC(1900)	ΔDEC		GHA ♈	Y.y
17A5	★5			SHA(1900)	ΔSHA	DEC(1900)	ΔDEC		GHA ♈	Y.y
17A6	★6			SHA(1900)	ΔSHA	DEC(1900)	ΔDEC		GHA ♈	Y.y
17A7	★7			SHA(1900)	ΔSHA	DEC(1900)	ΔDEC		GHA ♈	Y.y
17A8	★8			SHA(1900)	ΔSHA	DEC(1900)	ΔDEC		GHA ♈	Y.y
18A1	SHA			SHA(1900)	ΔSHA	DEC(1900)	ΔDEC		GHA ♈	Y.y
18A2	LHA	LHA	L	SHA(1900), DEC	ΔSHA	DEC(1900)	ΔDEC	λ	GHA ♈	Y.y
19A	SRT	t	L	d	Hc	Zn				Used
20A	MPP		L		Hc	Zn	Ho	λ		Used
21A	2 FIX	aλ	aL	ΔL_1	$\Delta\lambda_1$	ΔL_2	$\Delta\lambda_2$	tan Zn_1, L	tan Zn_2, λ	Used
22A	3 FIX	L_1	λ_1	L_2	λ_2	L_3	λ_3			Used
23A	DIST	RB_1	RB_2	D_{run}	D_2	D_a	D_1			Used
24A	VECTOR	x_1	y_1	x_2	y_2					Used
25A	REL POS	90−C	S	90−B_1	RM_1	90−B_2	RM_2	Δt	em	Used
26A1	CPA		r_{CPA}	b_1, h_r	r_1, rm	b_2	r_2	t_1	t_2	Used
26A2	CA-SU	100C+S/1000	r_{CPA}, θ	h_r	rm	b_2, h	r_2, r_3, ϕ	t_1, em	t_2, $t_3 - t_2$, b_3	Used
26A3	CA-CC	100C+S/1000	θ	h_r	rm, $\beta + h_r$	h	ϕ	em	b_3	Used

Appendix 4

EQUATIONS, SYMBOLS, AND UNITS

The important navigational equations used in the HP-65 Navigation Pac are gathered here for quick reference along with a list of the symbols and units.

Equations For Sailing A Great Circle From (L_1, λ_1) to (L_2, λ_2)

The great-circle distance is

$$D = 60 \cos^{-1} \left[\sin L_1 \sin L_2 + \cos L_1 \cos L_2 \cos(\lambda_2 - \lambda_1)\right]$$

The initial great-circle heading is

$$H_i = \cos^{-1} \left[\frac{\sin L_2 - \sin L_1 \cos(D/60)}{\sin(D/60) \cos L_1}\right]$$

The intermediate points are (L_i, λ_i) where

$$L_i = \tan^{-1} \left[\frac{\tan L_2 \sin(\lambda_2 - \lambda_1) - \tan L_1 \sin(\lambda_i - \lambda_2)}{\sin(\lambda_2 - \lambda_1)}\right]$$

Vertices of the great circle are at (L_v, λ_v) and $(-L_v, \lambda_v + 180°)$ where

$$\lambda_v = \lambda_1 - \sin^{-1} \left[\frac{\cos H_i}{\sin(\cos^{-1}(\sin H_i \cos L_1))}\right]$$

The great circle crosses the equator at $(0, \lambda_v \pm 90°)$ making an angle with the equator of L_v.

The great circle is tangent to the small circle defined by $L = L_{max}$ at (L_{max}, λ_{v1}) where

$$\lambda_{v1} = \lambda_1 + \cos^{-1}\left(\frac{\tan L_1}{\tan L_{max}}\right) \operatorname{sgn}(\lambda_2 - \lambda_1) \operatorname{sgn}(L_{max})$$

Equations For Sailing A Rhumbline From (L_1, λ_1) to (L_2, λ_2)

The rhumbline course is

$$C = \frac{\pi(\lambda_1 - \lambda_2)}{180\left(\ln \tan\left(45 + \frac{L_2}{2}\right) - \ln \tan\left(45 + \frac{L_1}{2}\right)\right)}$$

The rhumbline distance is

$$D = \begin{cases} 60(\lambda_2 - \lambda_1)\cos L; & \cos C = 0 \\ 60 \dfrac{L_2 - L_1}{\cos C}; & \text{otherwise} \end{cases}$$

The position on the rhumbline at distance $S\Delta t$ from (L_1, λ_1) is (L_i, λ_i) where

$$L_i = L_1 + \frac{\Delta t\, S \cos C}{60}$$

$$\lambda_1 = \begin{cases} \lambda_1 + \dfrac{180 \tan C\left(\ln \tan\left(45 + \frac{L_1}{2}\right) - \ln \tan\left(45 + \frac{L_i}{2}\right)\right)}{\pi}; & C \neq 090° \text{ or } 270° \\ \lambda_i - \dfrac{\Delta t\, S \sin C}{60 \cos L_1}; & C = 090° \text{ or } 270° \end{cases}$$

Equations For Correcting Sextant Readings

The apparant altitude is

$$ha = hs + IC - D$$

where

$$D = 0'.97\sqrt{HE}$$

The corrected altitude is

$$Ho = ha - Rm$$

where

$$Rm = \begin{cases} 23'.6 - 8'.36 \ln(ha); & ha < 7° \\ 0'.97 \cot(ha) - 0'.0011 \cot^3(ha); & ha \geq 7° \end{cases}$$

Secondary corrections due to abnormal conditions are a modification to ha and a modification to Rm

$$ha = hs + IC - D + S$$

where

$$S = 0\overset{\prime}{.}11\,(T_{air} - T_{sea})$$

$$Ho = ha - Rm\,\frac{510}{460 + T_{air}}\;\frac{P}{29.83}$$

If a limb of the sun or moon is observed, Ho must be corrected further

$$Ho = \begin{cases} Ho_{old} \pm SD\ \odot \\ Ho_{old} \pm SD\ ☾ + HP\cos Ho_{old} \end{cases}$$

Equations For Computing Altitude and Azimuth

The altitude of a body is

$$Hc = \sin^{-1}\,[\sin d \sin L + \cos d \cos L \cos t]$$

The azimuth is

$$Zn = \begin{cases} Z; & \sin t < 0 \\ 360 - Z; & \sin t > 0 \end{cases}$$

where

$$Z = \cos^{-1}\left[\frac{\sin d - \sin L \sin Hc}{\cos Hc \cos L}\right]$$

Primary Symbols Used in This Work

$\vec{a}$	$m_a \angle\theta_a$ vector having magnitude m_a and angle θ_a
a	altitude intercept
C	course
d, DEC	declination
D	distance
eg	velocity of guide vessel
em	velocity of maneuvering vessel
Eq.T.	Equation of Time (mean time–apparent time)
F	quantity of fuel
G	position of guide vessel
GMT	Greenwich Mean Time
ha	apparent altitude
H_i	initial heading
Ho	corrected sextant altitude
hs	sextant altitude
H	height
HA	hour angle
HE	height-of-eye
HP	horizontal parallax
i	(subscript) initial or intermediate
L	latitude
LHA	Local hour angle
M	position of maneuvering vessel
RB	relative bearing
RPM	revolutions per minute
S	speed
SD	semi-diameter
SHA	sidereal hour angle
t	time
T	temperature
v	(subscript) vertex
Zn	Azimuth
Δ	[Greek capital delta] (prefix) change in (i.e. ΔSHA)
λ	[Greek lower case lambda] longitude

Units

Length measures

ft.	foot, feet
fth.	fathom
FF.II	feet and inches
m	metre
mi.	statute mile
naut.mi.	nautical mile (mi. if context is clear)
yd.	yard, yards

Time and angle measures

D.d	degrees and tenths
D.MS	degrees, minutes and seconds
DDMM.m	degrees, minutes and tenths
H.h	hours and tenths
H.MS	hours, minutes and seconds
M.m	minutes and tenths

Appendix 5

SIMPLE KEYSTROKE SEQUENCES

Collected here are a number of keystroke sequences to perform simple operations without the aid of a preprogrammed magnetic card.

To convert DDMM.m to D.MS

Data	Keystrokes
DDMM.m	[f] [→D.MS] [1] [0] [0] [÷]
	or
	[f] [→D.MS] [EEX] [2] [÷]

To convert D.MS to D.d

Data	Keystrokes
D.MS	[f^{-1}] [→D.MS]

To convert Hour Angle to Right Ascension

Data	Keystrokes
HA, D.d	[1] [5] [÷] [2] [4] [−] [CHS] [f] [→D.MS]

To convert H.MS to H.h

Data	Keystrokes
H.MS	[f^{-1}] [→D.MS]

To convert H.h to H.MS

Data	Keystrokes
H.h	[f] [→D.MS]

To compute Δt from t_1 and t_2

Data	Keystrokes
t_2, H.MS	[ENTER↑]
t_1, H.MS	[f^{-1}] [D.MS+]

Appendix 6

STAR ALMANAC CARDS

The data cards for the Star Almanac simply load position data into appropriate registers for use by the Almanac Positions program. Registers R3 through R6 are used for data and R8 and R9 are left undisturbed. A skeleton program is shown here along with a table of values for each star. Except for convenience, it is not necessary to write a program: the data may be loaded directly into the indicated registers if desired.

SKELETON PROGRAM

LBL A	LBL C	LBL E	
			SHA, D.MS
STO 3	STO 3	STO 3	
			ΔSHA, M.m
STO 4	STO 4	STO 4	
			DEC, D.MS
STO 5	STO 5	STO 5	
			ΔDEC, M.m
STO 6 RTN	STO 6 RTN	STO 6 RTN	

Star		R3 SHA(1900.0)	R4 ΔSHA	R5 DEC(1900.0)	R6 ΔDEC
Acamar	(θ Eri)	316°23′01″	-0′.57	-40°42′14″	0′.24
Achernar	(α Eri)	336°30′10″	-0′.56	-57°44′24″	0′.30
Acrux	(α Cru)	174°44′56″	-0′.84	-62°32′49″	-0′.33
Aldebaran	(α Tan)	292°29′15″	-0′.86	16°18′35″	0′.12
Alkaid	(η UMa)	154°05′56″	-0′.59	49°48′42″	-0′.30
Alphard	(α Hya)	219°20′02″	-0′.74	-8°13′26″	-0′.26
Alphecca	(α CrB)	127°23′32″	-0′.64	27°02′54″	-0′.20
Alpheratz	(α And)	359°12′05″	-0′.78	28°32′25″	0′.33
Altair	(α AqL)	63°31′23″	-0′.73	8°36′02″	0′.16
Antares	(α Sco)	114°10′55″	-0′.92	-26°12′55″	-0′.13
Arcturus	(α Boo)	147°13′17″	-0′.68	19°41′57″	-0′.31
Atria	(α TrA)	110°29′14″	-1′.59	-68°50′50″	-0′.11
Betelgeuse	(α Ori)	272°33′33″	-0′.81	7°23′27″	0′.01
Canopus	(α Car)	264°33′53″	-0′.33	-52°38′37″	-0′.03
Capella	(α Aur)	282°40′40″	-1′.11	45°53′56″	0′.06
Deneb	(α Cyg)	50°29′34″	-0′.51	44°55′34″	0′.21
Denebola	(β Leo)	184°00′22″	-0′.76	15°08′08″	-0′.34
Diphda	(β Cet)	350°21′18″	-0′.75	-18°32′11″	0′.33
Dubhe	(α UMa)	195°36′07″	-0′.92	62°17′13″	-0′.32
Enif	(ϵ Peg)	35°11′02″	-0′.74	9°24′37″	0′.28
Fomalhaut	(α PsA)	16°58′05″	-0′.83	-30°09′19″	0′.32
Hamal	(α Ari)	329°37′18″	-0′.85	22°59′37″	0′.28
Kochab	(β UMi)	137°15′34″	0′.04	74°34′06″	-0′.25
Menkent	(θ Cen)	149°47′59″	-0′.88	-35°53′04″	-0′.29
Mirfak	(α Per)	310°42′25″	-1′.07	49°30′39″	0′.21
Nunki	(θ Sgr)	77°43′59″	-0′.93	-26°25′41″	0′.08
Peacock	(α Pav)	55°33′56″	-1′.19	-57°03′20″	0′.19
Pollux	(β Gem)	245°12′07″	-0′.92	28°16′24″	-0′.15
Procyon	(α CMi)	246°28′41″	-0′.78	5°28′48″	-0′.15
Rasalhague	(α Oph)	97°25′48″	-0′.70	12°37′38″	-0′.04
Regulus	(α Leo)	209°14′18″	-0′.80	12°27′14″	-0′.29
Rigel	(β Ori)	282°34′01″	-0′.72	-8°19′01″	-0′.07
Rigil Kent.	(α Cen)	141°48′07″	-1′.02	-60°25′18″	-0′.25
Schedar	(α Cas)	351°17′42″	-0′.85	55°59′19″	0′.33
Sirius	(α CMa)	259°48′51″	-0′.66	-16°34′49″	-0′.08
Spica	(α Vir)	160°01′08″	-0′.79	-10°38′32″	-0′.31
Suhail	(λ Vel)	223°55′12″	-0′.55	-43°01′46″	-0′.24
Vega	(α Lyr)	81°36′51″	-0′.51	38°41′08″	0′.06

Appendix 7

COMPREHENSIVE EXAMPLES

A few examples are included here to demonstrate the power of the HP-65 Navigation Pac when its programs are run in the correct order. The forms used with these examples emphasize the fact that very little input data and answers need to be written down.

Example: Three Star Fix

In the Tasman Sea on 30 Dec. 1974 the navigator observes three stars for his 0940 fix. His DR is L40°12'S, λ159°57'E, and the observations are made from 35 feet using a sextant requiring −1'.5 index correction. What is the fix? (L40°24'.8S, λ160°19'.9E)

	Rigil Kentaurus	Procyon	Alpheratz
GMT	$9^h 40^m 21^s$	$9^h 40^m 59^s$	$9^h 41^m 42^s$
h_s	11°25'.5	11°23'.2	10°28'.7

Solution:

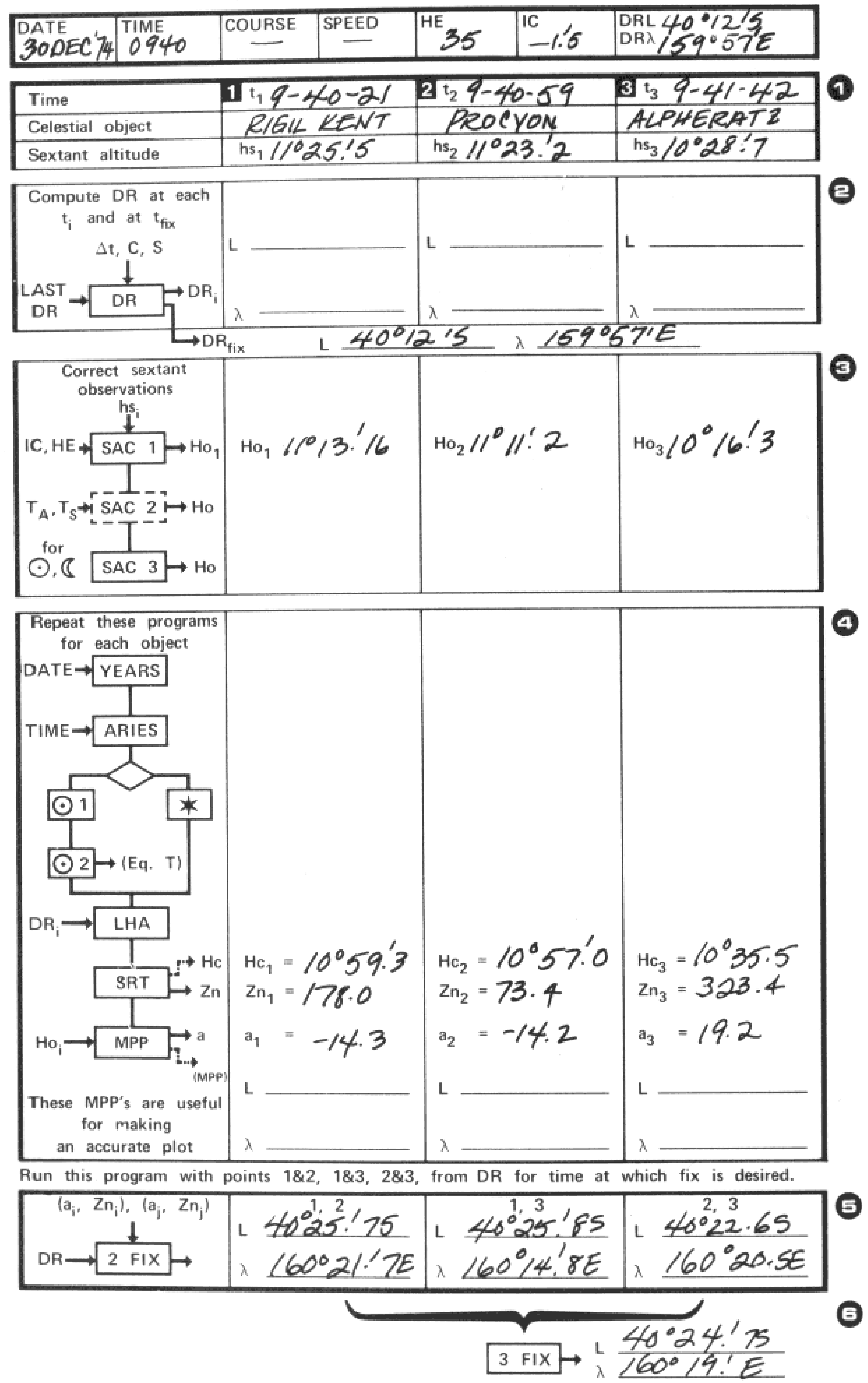
1. Record times and sextant altitudes
2. Use the 0940 DR for all sights
3. Compute and record corrected sextant altitude for each sight.
4. Run the almanac series for each sight. Record Zn from SRT and *a* from MPP.

4a. (optional) Record L and λ from MPP. These points are useful for making accurate plots.

5. Run 2 FIX for pairs of observations. The resulting points are useful when plotting, because they are the points at which LOP's intersect.
6. Run 3 FIX for three LOP intersections and record the fix.

Note:

If the observed celestial bodies were not well distributed in azimuth, it would be prudent to consider plotting an exterior fix instead of running 3 FIX.



SIGHT REDUCTION FORM

DATE	TIME	COURSE	SPEED	HE	IC	DRL / DRλ
30DEC'74	0940	—	—	35	−1'.5	DRL 40°12'.5 DRλ 159°57'E

1

	1	2	3
Time	t_1 9-40-21	t_2 9-40-59	t_3 9-41-42
Celestial object	RIGIL KENT	PROCYON	ALPHERATZ
Sextant altitude	hs_1 11°25'.5	hs_2 11°23'.2	hs_3 10°28'.7

2

Compute DR at each t_i and at t_{fix} (Δt, C, S; LAST DR → DR → DR_i, DR_{fix})

	L ____ λ ____	L ____ λ ____	L ____ λ ____

DR_{fix} L 40°12'.5 λ 159°57'E

3

Correct sextant observations hs_i (IC, HE → SAC 1 → Ho_i; T_A, T_S → SAC 2 → Ho; for ⊙, ☾ SAC 3 → Ho)

Ho_1 11°13'.16	Ho_2 11°11'.2	Ho_3 10°16'.3

4

Repeat these programs for each object (DATE → YEARS; TIME → ARIES; ⊙1, ✶; ⊙2 → (Eq. T); DR_i → LHA; SRT → Hc, Zn; Ho_i → MPP → a, (MPP)). These MPP's are useful for making an accurate plot

Hc_1 = 10°59'.3	Hc_2 = 10°57'.0	Hc_3 = 10°35.5
Zn_1 = 178.0	Zn_2 = 73.4	Zn_3 = 323.4
a_1 = −14.3	a_2 = −14.2	a_3 = 19.2
L ____	L ____	L ____
λ ____	λ ____	λ ____

Run this program with points 1&2, 1&3, 2&3, from DR for time at which fix is desired.

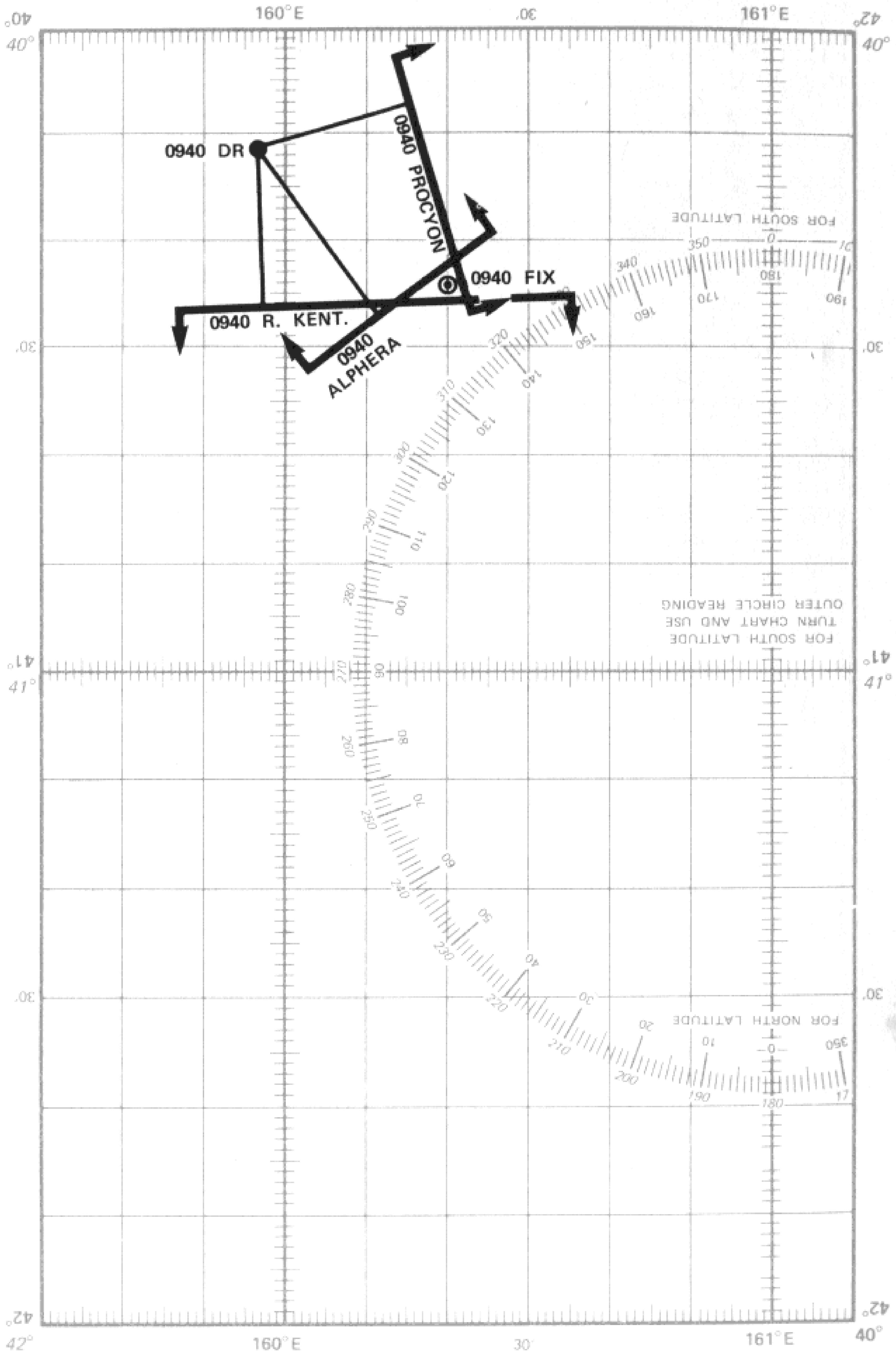
5

(a_i, Zn_i), (a_j, Zn_j); DR → 2 FIX

1, 2	1, 3	2, 3
L 40°25'.75	L 40°25'.85	L 40°22.65
λ 160°21'.7E	λ 160°14'.8E	λ 160°20.5E

6

3 FIX → L 40°24'.75 λ 160°19'.E



Example: Three Star Fix Accounting For Movement Of Ship

On 1 Jan. 1975, enroute San Francisco for San Bernardino Strait, Philippine Islands, the 1520 DR is L40°02′N, λ132°15′W. From 30 feet with a sextant requiring a 1′.5 index correction the navigator observes three stars for a fix.

Our course is 288°, speed 20 knots. What is the fix obtained by adjusting the LOP's resulting from the three sights to 1520? (L40°09′.5N, λ132°21′.4W)

	Pollux	Spica	Vega
GMT	$15^h 19^m 45^s$	$15^h 20^m 15^s$	$15^h 21^m 25^s$
h_s	23°18′.1	38°49′.5	30°18′.3

Solution:

1. Record times and sextant altitudes on form.
2. Compute and record DR corresponding to the times of the observations.
3. Compute and record corrected sextant altitude for each sight.
4. Run the almanac series for each sight using the appropriate DR when running LHA. Record Zn from SRT and *a* from MPP.

4a. (optional) Record L and λ from MPP. These points are useful for making accurate plots

5. Run 2 FIX for pairs of observations using the DR corresponding to the desired time of the fix. These resultant points are useful when plotting, because they are the points at which LOP's intersect.
6. Run 3 FIX for three LOP intersections and record the fix.

Required:

1. The initial great-circle course.
2. The great-circle distance.
3. The latitude and longitude of points on the great circle at longitude 15°E and at each 5° of longitude thereafter to longitude 70°W.
4. Rhumbline courses and distances between each of the points calculated in 3.

SIGHT REDUCTION FORM

DATE	TIME	COURSE	SPEED	HE	IC	DRL / DRλ
1 JAN 1975	1520	288	20	30	+1.5	DRL 40°02'N DRλ 132° 15'W

❶	1	2	3
Time	t_1 15-19-45	t_2 15-20-15	t_3 15-21-35
Celestial object	POLLUX	SPICA	VEGA
Sextant altitude	hs_1 23°18.'1	hs_2 38°49.'5	hs_3 30°18.'3

❷			
Compute DR at each t_i and at t_{fix} Δt, C, S → DR LAST DR → DR → DR_i → DR_{fix}	L 40°01'58" λ 132°14'54"	L 40°02'02" λ 132°15'06"	L 40°02'09" λ 132°15'35"

DR_{fix} L 40° 02' λ 132°15'

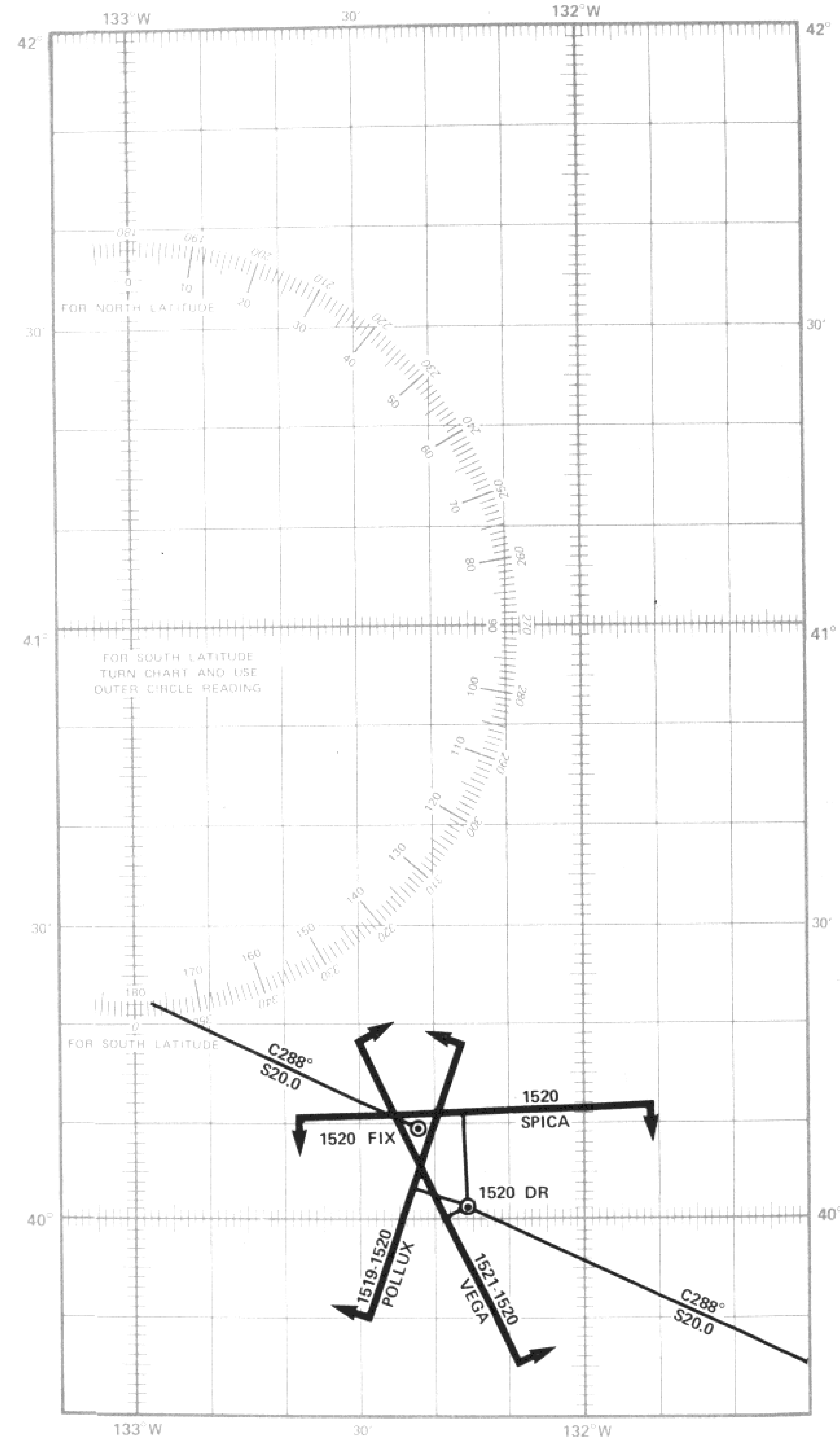
❸			
Correct sextant observations hs_i IC, HE → SAC 1 → Ho_1 T_A, T_S → SAC 2 → Ho for ☉, ☾ SAC 3 → Ho	Ho_1 23°12.'0	Ho_2 38°44.'5	Ho_3 30°12.8

❹			
Repeat these programs for each object DATE → YEARS TIME → ARIES ☉1 / ✶ ☉2 → (Eq. T) DR_i → LHA SRT → Hc, Zn Ho_i → MPP → a, (MPP) These MPP's are useful for making an accurate plot	Hc_1 = Zn_1 = 288.1 a_1 = 6.4 L λ	Hc_2 = Zn_2 = 176.8 a_2 = 8.5 L λ	Hc_3 = Zn_3 = 62.8 a_3 = 1.6 L λ

Run this program with points 1&2, 1&3, 2&3, from DR for time at which fix is desired.

❺	1, 2	1, 3	2, 3
(a_i, Zn_i), (a_j, Zn_j) DR → 2 FIX →	L 40°10.'3 λ 132°20.'3	L 40°08.'0 λ 132°21.'2	L 40°10.'2 λ 132°22.'7

❻ 3 FIX → L 40°09.'5 λ 132°21.'4



Example: Course Planning

A ship is to steam from Valparaiso, Chile, to Wellington, New Zealand. The captain wishes to use composite sailing from L32°58ʹ.0S to λ71°41ʹ.2W off Punta Angeles Light, to L42°00ʹ.0S, λ175°00ʹ.0E, near Cape Palliser, limiting the maximum latitude to 50°S.

Required:

1. The longitude at which the limiting parallel is reached.
2. The longitude at which the limiting parallel should be left.
3. The initial great circle course.
4. The total distance.
5. The latitude and longitude of points along the great circles at convenient intervals of longitude.

Solution:

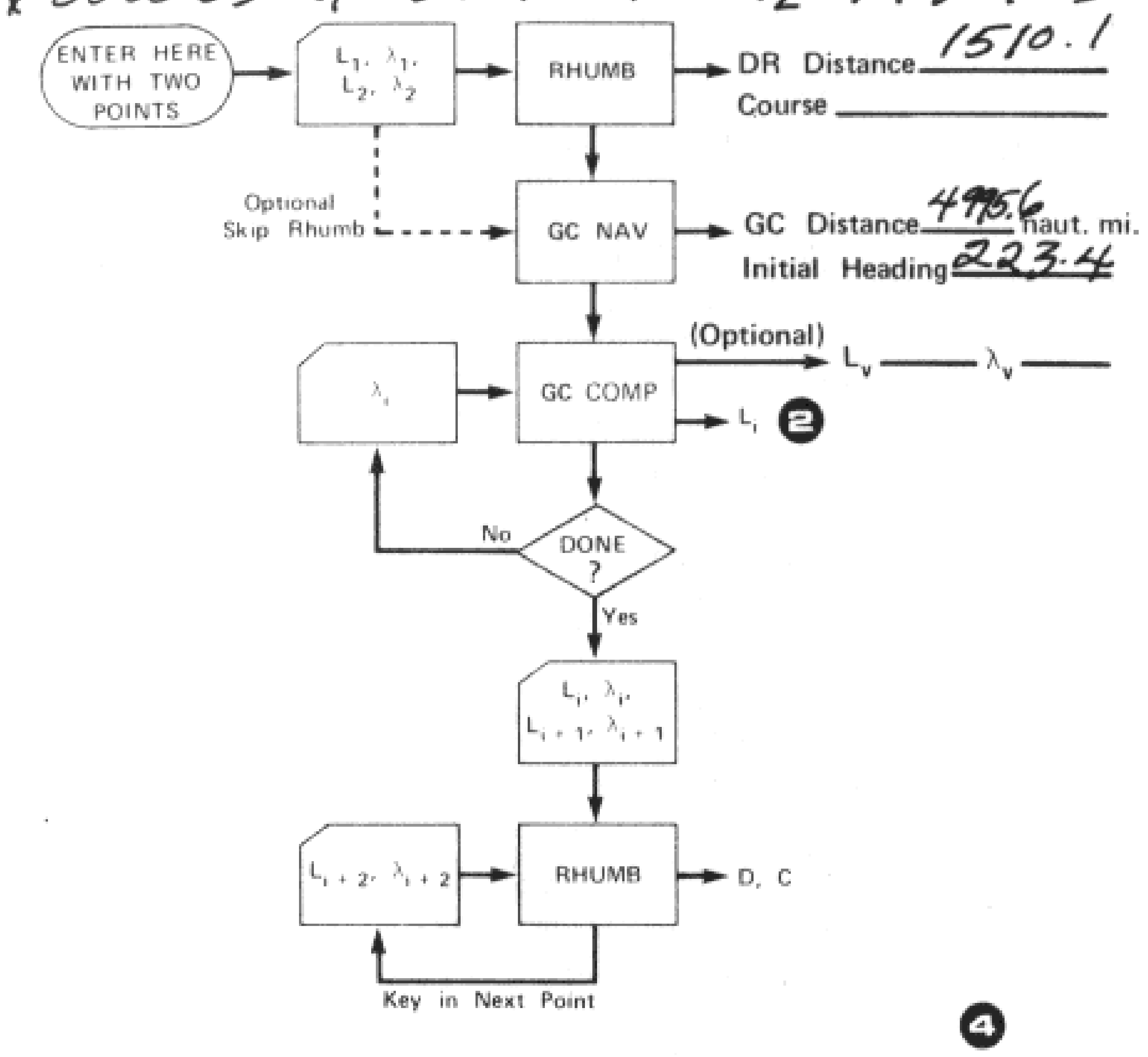
1. Run COMPSAIL to determine points of tangency with limiting parallel.
2. Run GC COMP from departure to first point of tangency.
3. Run GC COMP from second point of tangency to destination.
4. Run RHUMB from point to point.
5. Add up all distances.
   (This course is plotted on the chart on p. 37.)

COURSE PLANNING SHEET

DEPARTURE	VALPARAISO	L_1 32 58 S	λ_1 71 41.2 W
DESTINATION	WELLINGTON	L_2 42 00 S	λ_2 175 00 E

LMAX 50 00.0 S λ_1 128 42.9 λ_{V_2} 148 04.3

❶



❷ ❹

❸

	L_i	λ_i		D_{RHUMB}	C_{RHUMB}
1	-32 58.0	71 41.2	1-2	212.1	230.9
2	-35 11.7	75 00	2-3	578	234.8
3	-40 44.5	85 00	3-4	501.8	241.4
4	-44 45.0	95 00	4-5	447.2	248.4
5	-47 29.7	105 00	5-6	411.4	255.8
6	-49 10.9	115 00	6-7	391.8	263.3
7	-49 56.4	125 00	7-8	143.4	268.6
8	-50 00	128 42.9	8-9	746.5	270.0
9	-50 00	148 04.3	9-10	269.9	275.8
10	-49 32.5	165 00	10-11	404.3	282.3
11	-48 06.4	165 00	11-12	435.6	289.7
12	-45 39.3	175 00	12-13	485.1	296.9
13	-42 00	175 00	13-14		
14			14-15		
15			15-16		
16			16-17		
17			17-18		
18			18-19		
19			19-20		
20			20-21		
21			21-22		
22			22-23		
23			23-24		
24			24-25		
25			25-26		
26					

❺ $\Sigma D = 5027.1$

Appendix 6

BIBLIOGRAPHY

The following references were used extensively in the preparation of the HP-65 Navigation Pac. Some of the formulas and methods used were developed during the production of the pac and are not published in any known reference.

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PROGRAM LISTINGS

LENGTH CONVERSIONS

KEYS	CODE
x	71
STO 1	33 01
0	00
RTN	24
LBL	23
A	11
1	01
g x⇄y	35 07
0	00
g x≠y	35 21
g R↓	35 08
GTO	22
0	00
GTO	22
1	01
LBL	23
B	12
•	83
3	03
0	00
4	04
8	08
g x⇄y	35 07
0	00
g x≠y	35 21
g R↓	35 08
GTO	22
0	00
GTO	22
1	01
LBL	23
C	13
1	01
•	83
8	08

KEYS	CODE
2	02
8	08
8	08
g x⇄y	35 07
0	00
g x≠y	35 21
g R↓	35 08
GTO	22
0	00
GTO	22
1	01
LBL	23
D	14
1	01
8	08
5	05
2	02
g x⇄y	35 07
0	00
g x≠y	35 21
g R↓	35 08
GTO	22
0	00
GTO	22
1	01
LBL	23
E	15
1	01
6	06
0	00
9	09
•	83
3	03
4	04
4	04

KEYS	CODE
g x⇄y	35 07
0	00
g x≠y	35 21
g R↓	35 08
GTO	22
0	00
LBL	23
1	01
g R↑	35 09
STO	33
÷	81
1	01
RCL 1	34 01
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1 Used	R_4	R_7
R_2	R_5	R_8
R_3	R_6	R_9 Used

SPEED, TIME, AND DISTANCE

KEYS	CODE
LBL	23
A	11
DSP	21
•	83
2	02
STO 1	33 01
0	00
g x≠y	35 21
0	00
RTN	24
RCL 3	34 03
RCL 2	34 02
÷	81
STO 1	33 01
RTN	24
LBL	23
B	12
f^{-1}	32
→D.MS	03
C	13
DSP	21
•	83
4	04
f	31
→D.MS	03
RTN	24
LBL	23
C	13
DSP	21
•	83
2	02
STO 2	33 02
0	00
g x≠y	35 21
0	00

KEYS	CODE
RTN	24
RCL 3	34 03
RCL 1	34 01
÷	81
STO 2	33 02
RTN	24
LBL	23
D	14
DSP	21
•	83
2	02
STO 3	33 03
0	00
g x≠y	35 21
0	00
RTN	24
RCL 1	34 01
RCL 2	34 02
x	71
STO 3	33 03
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

KEYS	CODE
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
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g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1 Speed	R_4	R_7
R_2 Time	R_5	R_8
R_3 Distance	R_6	R_9

TIME-ARC CONVERSION

KEYS	CODE
g R↓	35 08
x	71
STO 1	33 01
0	00
DSP	21
·	83
0	00
RTN	24
LBL	23
A	11
f	31
→D.MS	03
EEX	43
2	02
÷	81
f^{-1}	32
→D.MS	03
2	02
4	04
0	00
g x⇄y	35 07
0	00
g x≠y	35 21
GTO	22
0	00
RCL 1	34 01
2	02
4	04
0	00
÷	81
f	31
→D.MS	03
EEX	43
2	02
x	71

KEYS	CODE
f^{-1}	32
→D.MS	03
DSP	21
·	83
1	01
RTN	24
LBL	23
B	12
3	03
6	06
0	00
0	00
g x⇄y	35 07
0	00
g x≠y	35 21
GTO	22
0	00
GTO	22
1	01
LBL	23
C	13
6	06
0	00
g x⇄y	35 07
0	00
g x≠y	35 21
GTO	22
0	00
GTO	22
1	01
LBL	23
D	14
1	01
g x⇄y	35 07
0	00

KEYS	CODE
g x≠y	35 21
GTO	22
0	00
LBL	23
1	01
+	61
CLX	44
RCL 1	34 01
g x⇄y	35 07
÷	81
DSP	21
·	83
2	02
RTN	24
LBL	23
E	15
f^{-1}	32
→D.MS	03
B	12
f	31
→D.MS	03
DSP	21
·	83
4	04
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1 t, sec	R_4	R_7
R_2	R_5	R_8
R_3	R_6	R_9 Used

PROPELLER SLIP

KEYS	CODE
STO 1	33 01
0	00
g x≠y	35 21
g NOP	35 01
RTN	24
RCL 4	34 04
RCL 2	34 02
÷	81
1	01
RCL 3	34 03
–	51
÷	81
LBL	23
E	15
6	06
0	00
7	07
6	06
x	71
6	06
0	00
÷	81
RTN	24
LBL	23
B	12
f	31
INT	83
g LST X	35 00
f^{-1}	32
INT	83
·	83
1	01
2	02
÷	81
+	61

KEYS	CODE
STO 2	33 02
0	00
g x≠y	35 21
g NOP	35 01
RTN	24
RCL 4	34 04
RCL 1	34 01
÷	81
1	01
RCL 3	34 03
–	51
÷	81
E	15
f	31
INT	83
g LST X	35 00
f^{-1}	32
INT	83
·	83
1	01
2	02
x	71
÷	61
RTN	24
LBL	23
C	13
EEX	43
2	02
÷	81
STO 3	33 03
0	00
g x≠y	35 21
g NOP	35 01
RTN	24
1	01

KEYS	CODE
RCL 4	34 04
RCL 1	34 01
÷	81
RCL 2	34 02
÷	81
E	15
–	51
EEX	43
2	02
x	71
RTN	24
LBL	23
D	14
STO 4	33 04
0	00
g x≠y	35 21
g NOP	35 01
RTN	24
RCL 1	34 01
RCL 2	34 02
x	71
1	01
E	15
÷	81
1	01
RCL 3	34 03
–	51
x	71
RTN	24
g NOP	35 01

R_1 RPM	R_4 Speed	R_7
R_2 Pitch	R_5	R_8
R_3 Slip	R_6	R_9

FUEL CONSUMPTION

KEYS	CODE
RCL 2	34 02
STO 1	33 01
g R↓	35 08
STO 2	33 02
0	00
g x≠y	35 21
g NOP	35 01
RTN	24
RCL 6	34 06
RCL 5	34 05
÷	81
RCL 4	34 04
RCL 3	34 03
÷	81
f^{-1}	32
$\sqrt{x}$	09
x	71
RCL 1	34 01
x	71
RTN	24
LBL	23
B	12
RCL 4	34 04
STO 3	33 03
g R↓	35 08
STO 4	33 04
0	00
g x≠y	35 21
g NOP	35 01
RTN	24
RCL 2	34 02
RCL 1	34 01
÷	81
RCL 5	34 05
RCL 6	34 06

KEYS	CODE
÷	81
x	71
f	31
$\sqrt{x}$	09
RCL 3	34 03
x	71
RTN	24
LBL	23
C	13
RCL 6	34 06
STO 5	33 05
g R↓	35 08
STO 6	33 06
0	00
g x≠y	35 21
g NOP	35 01
RTN	24
RCL 2	34 02
RCL 1	34 01
÷	81
RCL 3	34 03
RCL 4	34 04
÷	81
f^{-1}	32
$\sqrt{x}$	09
x	71
RCL 5	34 05
x	71
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

KEYS	CODE
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	F_1	R_4	s_1	R_7	
R_2	F_2	R_5	D_1	R_8	
R_3	s_1	R_6	D_2	R_9	

DISTANCE TO OR BEYOND HORIZON

KEYS	CODE
LBL	23
A	11
STO 1	33 01
RTN	24
LBL	23
B	12
STO 2	33 02
RTN	24
LBL	23
C	13
STO 3	33 03
RTN	24
LBL	23
D	14
f	31
→D.MS	03
EEX	43
2	02
÷	81
f^{-1}	32
→D.MS	03
RCL 1	34 01
RCL 2	34 02
f	31
$\sqrt{x}$	09
•	83
9	09
7	07
x	71
−	51
6	06
0	00
÷	81
+	61
STO 4	33 04

KEYS	CODE
f	31
TAN	06
2	02
•	83
4	04
6	06
EEX	43
CHS	42
4	04
÷	81
STO 7	33 07
↑	41
x	71
RCL 3	34 03
RCL 2	34 02
−	51
•	83
7	07
4	04
7	07
3	03
6	06
÷	81
+	61
f	31
$\sqrt{x}$	09
RCL 7	34 07
−	51
STO 6	33 06
RTN	24
LBL	23
E	15
RCL 2	34 02
f	31
$\sqrt{x}$	09

KEYS	CODE
1	01
•	83
1	01
4	04
4	04
x	71
RTN	24
RCL 2	34 02
f	31
$\sqrt{x}$	09
RCL 3	34 03
f	31
$\sqrt{x}$	09
+	61
1	01
•	83
1	01
4	04
4	04
x	71
R/S	84
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	IC	R_4	ha	R_7	Used
R_2	HE	R_5		R_8	
R_3	H	R_6	D	R_9	Used

DISTANCE BY HORIZON ANGLE AND DISTANCE SHORT OF HORIZON

KEYS	CODE
LBL	23
A	11
STO 1	33 01
RTN	24
LBL	23
B	12
STO 2	33 02
RTN	24
LBL	23
C	13
f	31
→D.MS	03
EEX	43
2	02
÷	81
f^{-1}	32
→D.MS	03
RCL 1	34 01
RCL 2	34 02
f	31
$\sqrt{x}$	09
•	83
9	09
7	07
x	71
+	61
6	06
0	00
÷	81
+	61
f	31
TAN	06
RCL 2	34 02
g x⇄y	35 07
÷	81

KEYS	CODE
GTO	22
1	01
LBL	23
D	14
f	31
→D.MS	03
EEX	43
2	02
÷	81
f^{-1}	32
→D.MS	03
RCL 1	34 01
6	06
0	00
÷	81
+	61
f	31
TAN	06
÷	81
LBL	23
1	01
R/S	84
6	06
0	00
7	07
6	06
÷	81
RTN	24
LBL	23
E	15
f	31
→D.MS	03
EEX	43
2	02
÷	81

KEYS	CODE
f^{-1}	32
→D.MS	03
RCL 1	34 01
6	06
0	00
÷	81
+	61
f	31
TAN	06
x	71
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1 IC	R_4	R_7
R_2 HE	R_5	R_8
R_3	R_6	R_9 Used

DEAD RECKONING

KEYS	CODE
f^{-1}	32
→D.MS	03
STO 2	33 02
g x⇄y	35 07
f^{-1}	32
→D.MS	03
STO 1	33 01
RTN	24
LBL	23
B	12
f^{-1}	32
R→P	01
STO 5	33 05
g R↓	35 08
STO 6	33 06
g R↓	35 08
f^{-1}	32
→D.MS	03
STO 7	33 07
RTN	24
LBL	23
C	13
DSP	21
•	83
4	04
RCL 5	34 05
RCL 7	34 07
x	71
6	06
0	00
÷	81
RCL 1	34 01
+	61
STO 1	33 01
g LST X	35 00

KEYS	CODE
E	15
RCL 1	34 01
E	15
÷	81
1	01
g x=y	35 23
GTO	22
1	01
g R↓	35 08
f	31
LN	07
RCL 6	34 06
x	71
RCL 5	34 05
÷	81
1	01
8	08
0	00
x	71
g	35
π	02
LBL	23
2	02
÷	81
RCL 2	34 02
+	61
1	01
f^{-1}	32
R→P	01
f	31
R→P	01
g x⇄y	35 07
STO 2	33 02
RCL 1	34 01
f	31

KEYS	CODE
→D.MS	03
R/S	84
RCL 2	34 02
f	31
→D.MS	03
RTN	24
LBL	23
1	01
RCL 6	34 06
RCL 7	34 07
x	71
RCL 1	34 01
f	31
COS	05
6	06
0	00
x	71
CHS	42
GTO	22
2	02
LBL	23
E	15
9	09
0	00
+	61
2	02
÷	81
f	31
TAN	06
RTN	24

R_1 L	R_4	R_7 Δt
R_2 λ	R_5 S cos C	R_8
R_3	R_6 S sin C	R_9 Used

RHUMBLINE NAVIGATION

KEYS	CODE
f^{-1}	32
→D.MS	03
RCL 1	34 01
STO 2	33 02
g x⇄y	35 07
STO 1	33 01
2	02
÷	81
4	04
5	05
+	61
f	31
TAN	06
f	31
LN	07
RCL 5	34 05
STO 6	33 06
g x⇄y	35 07
STO 5	33 05
RCL 1	34 01
RTN	24
LBL	23
B	12
f^{-1}	32
→D.MS	03
RCL 3	34 03
STO 4	33 04
g x⇄y	35 07
STO 3	33 03
RTN	24
LBL	23
D	14
RCL 4	34 04
RCL 3	34 03
–	51

KEYS	CODE
STO 7	33 07
2	02
÷	81
f	31
SIN	04
f^{-1}	32
SIN	04
9	09
0	00
÷	81
g	35
π	02
x	71
RCL 5	34 05
RCL 6	34 06
–	51
f	31
R→P	01
g R↓	35 08
STO 8	33 08
RCL 7	34 07
f	31
SIN	04
f^{-1}	32
SIN	04
0	00
g x>y	35 24
3	03
6	06
0	00
RCL 8	34 08
g	35
ABS	06
–	51
g	35

KEYS	CODE
ABS	06
RTN	24
LBL	23
C	13
D	14
RCL 7	34 07
RCL 1	34 01
f	31
COS	05
x	71
↑	41
RCL 1	34 01
RCL 2	34 02
–	51
RCL 8	34 08
f	31
COS	05
0	00
g x≠y	35 21
g R↓	35 08
÷	81
g x=y	35 23
g R↑	35 09
g NOP	35 01
6	06
0	00
x	71
g	35
ABS	06
RTN	24

R_1	L_2	R_4	λ_1	R_7	$\lambda_1 - \lambda_2$
R_2	L_1	R_5	$\ln \tan (45 + L_2/2)$	R_8	Used
R_3	λ_2	R_6	$\ln \tan (45 + L_1/2)$	R_9	Used

GREAT CIRCLE NAVIGATION

KEYS	CODE
E	15
RCL 1	34 01
STO 2	33 02
g x⇄y	35 07
STO 1	33 01
RTN	24
LBL	23
B	12
E	15
RCL 3	34 03
STO 4	33 04
g x⇄y	35 07
STO 3	33 03
RTN	24
LBL	23
C	13
RCL 1	34 01
f	31
SIN	04
RCL 2	34 02
f	31
SIN	04
x	71
RCL 1	34 01
f	31
COS	05
RCL 2	34 02
f	31
COS	05
x	71
RCL 3	34 03
RCL 4	34 04
–	51
STO 5	33 05
f	31

KEYS	CODE
COS	05
x	71
+	61
f^{-1}	32
COS	05
STO 6	33 06
6	06
0	00
x	71
RTN	24
LBL	23
D	14
RCL 1	34 01
f	31
SIN	04
RCL 2	34 02
f	31
SIN	04
RCL 6	34 06
f	31
COS	05
x	71
–	51
RCL 6	34 06
f	31
SIN	04
÷	81
RCL 2	34 02
f	31
COS	05
÷	81
f^{-1}	32
COS	05
RCL 5	34 05
f	31

KEYS	CODE
SIN	04
0	00
g x>y	35 24
GTO	22
1	01
3	03
6	06
0	00
g R↑	35 09
–	51
STO 7	33 07
RTN	24
LBL	23
1	01
x	71
+	61
STO 7	33 07
RTN	24
LBL	23
E	15
f	31
→D.MS	03
EEX	43
2	02
÷	81
f^{-1}	32
→D.MS	03
RTN	24
g NOP	35 01
g NOP	35 01

R_1	L_2	R_4	λ_1	R_7	Hi
R_2	L_1	R_5	$\lambda_2 - \lambda_1$	R_8	
R_3	λ_2	R_6	D/60	R_9	Used

GREAT CIRCLE COMPUTATIONS

KEYS	CODE
E	15
RCL 1	34 01
STO 2	33 02
g x⇄y	35 07
STO 1	33 01
RTN	24
LBL	23
B	12
E	15
RCL 3	34 03
STO 4	33 04
g x⇄y	35 07
STO 3	33 03
RTN	24
LBL	23
E	15
f	31
→D.MS	03
EEX	43
2	02
÷	81
f^{-1}	32
→D.MS	03
RTN	24
LBL	23
C	13
E	15
STO 8	33 08
RCL 4	34 04
–	51
f	31
SIN	04
RCL 1	34 01
f	31
TAN	06

KEYS	CODE
x	71
RCL 8	34 08
RCL 3	34 03
–	51
f	31
SIN	04
RCL 2	34 02
f	31
TAN	06
x	71
–	51
RCL 3	34 03
RCL 4	34 04
–	51
f	31
SIN	04
÷	81
f^{-1}	32
TAN	06
LBL	23
1	01
f	31
→D.MS	03
EEX	43
2	02
x	71
f^{-1}	32
→D.MS	03
DSP	21
•	83
1	01
RTN	24
LBL	23
D	14
RCL 7	34 07

KEYS	CODE
1	01
f^{-1}	32
R→P	01
g x⇄y	35 07
RCL 2	34 02
f	31
COS	05
x	71
f^{-1}	32
COS	05
f	31
SIN	04
÷	81
f^{-1}	32
SIN	04
RCL 4	34 04
–	51
CHS	42
1	01
f^{-1}	32
R→P	01
f	31
R→P	01
g x⇄y	35 07
GTO	22
1	01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	L_2	R_4	λ_1	R_7	Hi
R_2	L_1	R_5		R_8	λ_i
R_3	λ_2	R_6		R_9	Used

COMPOSITE SAILING

KEYS	CODE
E	15
RCL 1	34 01
STO 2	33 02
g x⇄y	35 07
STO 1	33 01
RTN	24
LBL	23
B	12
E	15
RCL 3	34 03
STO 4	33 04
g x⇄y	35 07
STO 3	33 03
RTN	24
LBL	23
C	13
E	15
STO 5	33 05
RTN	24
LBL	23
D	14
RCL 4	34 04
RCL 2	34 02
f	31
TAN	06
RCL 5	34 05
f	31
TAN	06
÷	81
f^{-1}	32
COS	05
RCL 3	34 03
RCL 4	34 04
–	51
RCL 5	34 05

KEYS	CODE
x	71
↑	41
g	35
ABS	06
÷	81
x	71
+	61
LBL	23
2	02
DSP	21
•	83
1	01
1	01
f^{-1}	32
R→P	01
f	31
R→P	01
g x⇄y	35 07
f	31
→D.MS	03
EEX	43
2	02
x	71
f^{-1}	32
→ D.MS	03
RTN	24
RCL 3	34 03
RCL 1	34 01
f	31
TAN	06
RCL 5	34 05
f	31
TAN	06
÷	81
f^{-1}	32

KEYS	CODE
COS	05
RCL 4	34 04
RCL 3	34 03
–	51
RCL 5	34 05
x	71
↑	41
g	35
ABS	06
÷	81
x	71
+	61
GTO	22
2	02
LBL	23
E	15
f	31
→D.MS	03
EEX	43
2	02
÷	81
f^{-1}	32
→D.MS	03
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	L_2	R_4	λ_1	R_7	
R_2	L_1	R_5	L_{max}	R_8	
R_3	λ_2	R_6		R_9	Used

SEXTANT ALTITUDE CORRECTIONS

KEYS	CODE
STO 7	33 07
RTN	24
LBL	23
B	12
STO 6	33 06
RTN	24
LBL	23
C	13
2	02
CHS	42
E	15
RCL 7	34 07
RCL 6	34 06
f	31
$\sqrt{x}$	09
•	83
9	09
7	07
x	71
–	51
6	06
0	00
÷	81
+	61
f	31
SIN	04
f^{-1}	32
SIN	04
STO 1	33 01
•	83
9	09
7	07
g x⇄y	35 07
7	07
g x>y	35 24

KEYS	CODE
GTO	22
1	01
g R↓	35 08
f	31
TAN	06
÷	81
•	83
0	00
0	00
1	01
1	01
g LST X	35 00
3	03
g	35
y^x	05
÷	81
–	51
LBL	23
2	02
6	06
0	00
÷	81
RCL 1	34 01
–	51
CHS	42
STO 2	33 02
2	02
E	15
RTN	24
LBL	23
1	01
g R↓	35 08
f	31
LN	07
8	08

KEYS	CODE
•	83
3	03
6	06
CHS	42
x	71
2	02
3	03
•	83
6	06
+	61
GTO	22
2	02
LBL	23
E	15
DSP	21
•	83
1	01
f^{-1}	32
LOG	08
g x⇄y	35 07
f	31
→D.MS	03
x	71
f^{-1}	32
→D.MS	03
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1 ha	R_4	R_7 IC
R_2 Ho	R_5	R_8
R_3	R_6 HE	R_9 Used

SECONDARY SEXTANT ALTITUDE CORRECTIONS

KEYS	CODE
STO 8	33 08
g R↓	35 08
STO 3	33 03
RTN	24
LBL	23
B	12
STO 5	33 05
RTN	24
LBL	23
C	13
RCL 1	34 01
•	83
0	00
0	00
1	01
8	08
RCL 3	34 03
RCL 8	34 08
–	51
x	71
+	61
•	83
9	09
7	07
g x⇄y	35 07
STO 2	33 02
7	07
g x>y	35 24
GTO	22
1	01
g R↓	35 08
f	31
TAN	06
÷	81
•	83

KEYS	CODE
0	00
0	00
1	01
1	01
g LST X	35 00
3	03
g	35
y^x	05
÷	81
–	51
LBL	23
2	02
•	83
2	02
8	08
5	05
RCL 5	34 05
x	71
4	04
6	06
0	00
RCL 3	34 03
+	61
÷	81
x	71
RCL 2	34 02
–	51
CHS	42
STO 2	33 02
2	02
E	15
RTN	24
LBL	23
1	01
f	31

KEYS	CODE
LN	07
8	08
•	83
3	03
6	06
CHS	42
x	71
2	02
3	03
•	83
6	06
+	61
GTO	22
2	02
LBL	23
E	15
f^{-1}	32
LOG	08
g x⇄y	35 07
f	31
→D.MS	03
x	71
f^{-1}	32
→D.MS	03
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1 ha	R_4	R_7
R_2	R_5 P	R_8 T_{sea}
R_3 T_{air}	R_6	R_9 Used

SEXTANT CORRECTIONS FOR SUN AND MOON

KEYS	CODE	KEYS	CODE	KEYS	CODE
0	00	÷	81	g NOP	35 01
g x=y	35 23	–	51	g NOP	35 01
1	01	GTO	22	g NOP	35 01
6	06	1	01	g NOP	35 01
+	61	LBL	23	g NOP	35 01
RCL 2	34 02	C	13	g NOP	35 01
g x⇄y	35 07	RCL 2	34 02	g NOP	35 01
6	06	f	31	g NOP	35 01
0	00	COS	05	g NOP	35 01
÷	81	x	71	g NOP	35 01
+	61	+	61	g NOP	35 01
LBL	23	6	06	g NOP	35 01
1	01	0	00	g NOP	35 01
f	31	÷	81	g NOP	35 01
→D.MS	03	RCL 2	34 02	g NOP	35 01
EEX	43	+	61	g NOP	35 01
2	02	GTO	22	g NOP	35 01
x	71	1	01	g NOP	35 01
f^{-1}	32	LBL	23	g NOP	35 01
→D.MS	03	D	14	g NOP	35 01
DSP	21	RCL 2	34 02	g NOP	35 01
•	83	f	31	g NOP	35 01
1	01	COS	05	g NOP	35 01
RTN	24	x	71	g NOP	35 01
LBL	23	–	51	g NOP	35 01
B	12	6	06	g NOP	35 01
0	00	0	00	g NOP	35 01
g x=y	35 23	÷	81	g NOP	35 01
1	01	RCL 2	34 02	g NOP	35 01
6	06	g x⇄y	35 07	g NOP	35 01
+	61	–	51		
RCL 2	34 02	GTO	22		
g x⇄y	35 07	1	01		
6	06	g NOP	35 01		
0	00	g NOP	35 01		

R_1	R_4	R_7
R_2 $H_{o\,old}$	R_5	R_8
R_3	R_6	R_9 Used

YEARS FROM 1900.0

KEYS	CODE	KEYS	CODE	KEYS	CODE
STO 2	33 02	4	04	+	61
RTN	24	÷	81	RCL 5	34 05
LBL	23	f	31	3	03
B	12	INT	83	6	06
STO 3	33 03	STO 8	33 08	5	05
RTN	24	2	02	x	71
LBL	23	RCL 3	34 03	+	61
C	13	g x>y	35 24	RCL 8	34 08
STO 4	33 04	1	01	+	61
RTN	24	STO 6	33 06	1	01
LBL	23	2	02	4	04
E	15	•	83	6	06
0	00	3	03	1	01
STO 6	33 06	RCL 3	34 03	÷	81
RCL 4	34 04	•	83	RCL 7	34 07
1	01	4	04	+	61
9	09	x	71	4	04
0	00	+	61	x	71
0	00	f	31	STO	33
–	51	INT	83	9	09
4	04	CHS	42	RTN	24
÷	81	1	01	g NOP	35 01
f	31	+	61	g NOP	35 01
INT	83	RCL 8	34 08	g NOP	35 01
STO 7	33 07	–	51	g NOP	35 01
g LST X	35 00	RCL 6	34 06	g NOP	35 01
f^{-1}	32	x	71	g NOP	35 01
INT	83	RCL 2	34 02	g NOP	35 01
4	04	+	61	g NOP	35 01
x	71	RCL 3	34 03	g NOP	35 01
STO 5	33 05	1	01		
g	35	–	51		
ABS	06	3	03		
3	03	1	01		
+	61	x	71		

R_1	R_4 Year	R_7 n
R_2 Day	R_5 0, 1, 2, or 3	R_8 $(\overline{LY})$
R_3 Month	R_6 (M > 2)	R_9 Y.y

GREENWICH HOUR ANGLE OF ARIES

KEYS	CODE
LBL	23
A	11
f^{-1}	32
→D.MS	03
STO 1	33 01
RTN	24
LBL	23
B	12
RCL	34
9	09
7	07
4	04
—	51
3	03
6	06
5	05
·	83
2	02
5	05
x	71
1	01
·	83
5	05
—	51
RCL 1	34 01
2	02
4	04
÷	81
+	61
STO 6	33 06
RCL	34
9	09
4	04
÷	81
f^{-1}	32

KEYS	CODE
INT	83
4	04
x	71
3	03
6	06
0	00
·	83
0	00
0	00
6	06
2	02
7	07
x	71
RCL 7	34 07
·	83
0	00
3	03
0	00
7	07
5	05
7	07
x	71
+	61
9	09
8	08
·	83
2	02
2	02
0	00
4	04
+	61
RCL 1	34 01
1	01
5	05
·	83

KEYS	CODE
0	00
4	04
1	01
0	00
6	06
9	09
x	71
+	61
3	03
6	06
0	00
÷	81
f^{-1}	32
INT	83
3	03
6	06
0	00
x	71
STO 8	33 08
f	31
→D.MS	03
EEX	43
2	02
x	71
f^{-1}	32
→D.MS	03
DSP	21
·	83
1	01
RTN	24

R_1	Time	R_4	Year	R_7	n
R_2	Day	R_5		R_8	$(\overline{LY})$, GHA♈
R_3	Month	R_6	day #	R_9	Y.y

1974–1975 SUN ALMANAC (CARD 1)

KEYS	CODE
RCL	34
9	09
STO 7	33 07
RCL 6	34 06
·	83
9	09
8	08
5	05
6	06
x	71
STO 2	33 02
3	03
·	83
4	04
1	01
—	51
f	31
SIN	04
1	01
8	08
4	04
2	02
x	71
2	02
RCL 2	34 02
x	71
2	02
0	00
·	83
3	03
8	08
+	61
f	31
SIN	04
2	02

KEYS	CODE
4	04
8	08
2	02
x	71
+	61
3	03
RCL 2	34 02
x	71
1	01
7	07
+	61
f	31
SIN	04
7	07
9	09
x	71
+	61
4	04
RCL 2	34 02
x	71
4	04
0	00
+	61
f	31
SIN	04
5	05
5	05
x	71
+	61
5	05
RCL 2	34 02
x	71
4	04
1	01
+	61

KEYS	CODE
f	31
SIN	04
3	03
x	71
+	61
EEX	43
3	03
÷	81
CHS	42
STO 4	33 04
·	83
5	05
RCL 1	34 01
2	02
4	04
÷	81
+	61
3	03
6	06
0	00
x	71
+	61
RCL 8	34 08
—	51
f	31
→D.MS	03
STO 3	33 03
R/S	84
g NOP	35 01
g NOP	35 01

R_1	Time	R_4	Eq.T	R_7	Y.y
R_2	θ	R_5		R_8	GHA ♈
R_3	Month SHA ☉	R_6	day #	R_9	

1974–1975 SUN ALMANAC (CARD 2)

KEYS	CODE
0	00
STO 6	33 06
RCL 2	34 02
1	01
0	00
•	83
2	02
7	07
4	04
+	61
f	31
COS	05
2	02
3	03
2	02
6	06
7	07
x	71
RCL 2	34 02
2	02
x	71
7	07
•	83
4	04
+	61
f	31
COS	05
3	03
8	08
1	01
x	71
+	61
RCL 2	34 02
3	03
x	71

KEYS	CODE
2	02
9	09
•	83
7	07
+	61
f	31
COS	05
1	01
7	07
1	01
x	71
+	61
RCL 2	34 02
4	04
x	71
2	02
6	06
+	61
f	31
COS	05
8	08
x	71
+	61
RCL 2	34 02
5	05
x	71
4	04
5	05
+	61
f	31
COS	05
3	03
x	71
+	61
3	03

KEYS	CODE
7	07
9	09
–	51
EEX	43
3	03
÷	81
CHS	42
f	31
→D.MS	03
STO 5	33 05
RCL 7	34 07
STO	33
9	09
RCL 4	34 04
0	00
STO 4	33 04
+	61
1	01
5	05
÷	81
STO 7	33 07
f	31
→D.MS	03
DSP	21
•	83
4	04
R/S	84
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	R_4 ΔSHA = 0	R_7 Eq.T.
R_2 θ	R_5 DEC ☉	R_8
R_3 SHA ☉	R_6 ΔDEC = 0	R_9 Y.y

SUNRISE, SUNSET, TWILIGHT

KEYS	CODE
E	15
STO 3	33 03
g $x \rightleftarrows y$	35 07
E	15
STO 2	33 02
RTN	24
LBL	23
B	12
f^{-1}	32
→D.MS	03
STO 7	33 07
g $x \rightleftarrows y$	35 07
E	15
STO 5	33 05
RTN	24
LBL	23
C	13
f	31
→D.MS	03
EEX	43
2	02
÷	81
f^{-1}	32
→D.MS	03
STO 1	33 01
f	31
SIN	04
RCL 2	34 02
f	31
SIN	04
RCL 5	34 05
f	31
SIN	04
x	71
–	51

KEYS	CODE
RCL 2	34 02
f	31
COS	05
÷	81
RCL 5	34 05
f	31
COS	05
÷	81
f^{-1}	32
COS	05
1	01
5	05
÷	81
1	01
2	02
–	51
RCL 7	34 07
+	61
CHS	42
f	31
→D.MS	03
RTN	24
LBL	23
1	01
RCL 3	34 03
1	01
5	05
÷	81
f	31
→D.MS	03
f	31
D.MS+	02
R/S	84
LBL	23
D	14

KEYS	CODE
C	13
f^{-1}	32
→D.MS	03
2	02
4	04
RCL 7	34 07
2	02
x	71
–	51
–	51
CHS	42
f	31
→D.MS	03
RTN	24
GTO	22
1	01
LBL	23
E	15
f	31
→D.MS	03
EEX	43
2	02
÷	81
f^{-1}	32
→D.MS	03
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1 H	R_4	R_7 Eq.T.
R_2 L	R_5 DEC ☉	R_8
R_3 λ	R_6	R_9

LONG TERM STAR ALMANAC (CARD 1)

KEYS	CODE
3	03
3	03
6	06
·	83
3	03
0	00
1	01
STO 3	33 03
·	83
5	05
6	06
CHS	42
STO 4	33 04
5	05
7	07
·	83
4	04
4	04
2	02
4	04
CHS	42
STO 5	33 05
·	83
3	03
STO 6	33 06
RTN	24
LBL	23
C	13
1	01
7	07
4	04
·	83
4	04
4	04
5	05

KEYS	CODE
6	06
STO 3	33 03
·	83
8	08
4	04
CHS	42
STO 4	33 04
6	06
2	02
·	83
3	03
2	02
4	04
9	09
CHS	42
STO 5	33 05
·	83
3	03
3	03
CHS	42
STO 6	33 06
RTN	24
LBL	23
E	15
2	02
9	09
2	02
·	83
2	02
7	07
1	01
5	05
STO 3	33 03
·	83
8	08

KEYS	CODE
6	06
CHS	42
STO 4	33 04
1	01
6	06
·	83
1	01
8	08
3	03
5	05
STO 5	33 05
·	83
1	01
2	02
STO 6	33 06
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	R_4 ΔSHA	R_7
R_2	R_5 DEC	R_8
R_3 SHA	R_6 ΔDEC	R_9

LONG TERM STAR ALMANAC (CARD 2)

KEYS	CODE
3	03
5	05
9	09
·	83
1	01
2	02
0	00
5	05
STO 3	33 03
·	83
7	07
8	08
CHS	42
STO 4	33 04
2	02
8	08
·	83
3	03
2	02
2	02
5	05
STO 5	33 05
·	83
3	03
3	03
STO 6	33 06
RTN	24
LBL	23
C	13
6	06
3	03
·	83
3	03
1	01
2	02

KEYS	CODE
3	03
STO 3	33 03
·	83
7	07
3	03
CHS	42
STO 4	33 04
8	08
·	83
3	03
6	06
0	00
2	02
STO 5	33 05
·	83
1	01
6	06
STO 6	33 06
RTN	24
LBL	23
E	15
1	01
1	01
4	04
·	83
1	01
0	00
5	05
5	05
STO 3	33 03
·	83
9	09
2	02
CHS	42
STO 4	33 04

KEYS	CODE
2	02
6	06
·	83
1	01
2	02
5	05
5	05
CHS	42
STO 5	33 05
·	83
1	01
3	03
CHS	42
STO 6	33 06
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	R_4 ΔSHA	R_7
R_2	R_5 DEC	R_8
R_3 SHA	R_6 ΔDEC	R_9

LONG TERM STAR ALMANAC (CARD 3)

KEYS	CODE	KEYS	CODE	KEYS	CODE
1	01	3	03	CHS	42
4	04	3	03	STO 4	33 04
7	07	3	03	5	05
•	83	STO 3	33 03	2	02
1	01	•	83	•	83
3	03	8	08	3	03
1	01	1	01	8	08
7	07	CHS	42	3	03
STO 3	33 03	STO 4	33 04	7	07
•	83	7	07	CHS	42
6	06	•	83	STO 5	33 05
8	08	2	02	•	83
CHS	42	3	03	0	00
STO 4	33 04	2	02	3	03
1	01	7	07	CHS	42
9	09	STO 5	33 05	STO 6	33 06
•	83	•	83	RTN	24
4	04	0	00	g NOP	35 01
1	01	1	01	g NOP	35 01
5	05	STO 6	33 06	g NOP	35 01
7	07	RTN	24	g NOP	35 01
STO 5	33 05	LBL	23	g NOP	35 01
•	83	E	15	g NOP	35 01
3	03	2	02	g NOP	35 01
1	01	6	06	g NOP	35 01
CHS	42	4	04	g NOP	35 01
STO 6	33 06	•	83	g NOP	35 01
RTN	24	3	03	g NOP	35 01
LBL	23	3	03	g NOP	35 01
C	13	5	05	g NOP	35 01
2	02	3	03		
7	07	STO 3	33 03		
2	02	•	83		
•	83	3	03		
3	03	3	03		

R_1	R_4 ΔSHA	R_7
R_2	R_5 DEC	R_8
R_3 SHA	R_6 ΔDEC	R_9

LONG TERM STAR ALMANAC (CARD 4)

KEYS	CODE	KEYS	CODE	KEYS	CODE
2	02	3	03	CHS	42
8	08	4	04	STO 4	33 04
2	02	STO 3	33 03	1	01
•	83	•	83	5	05
4	04	5	05	•	83
0	00	1	01	0	00
4	04	CHS	42	8	08
0	00	STO 4	33 04	0	00
STO 3	33 03	4	04	8	08
1	01	4	04	STO 5	33 05
•	83	•	83	•	83
1	01	5	05	3	03
1	01	5	05	4	04
CHS	42	3	03	CHS	42
STO 4	33 04	4	04	STO 6	33 06
4	04	STO 5	33 05	RTN	24
5	05	•	83	g NOP	35 01
•	83	2	02	g NOP	35 01
5	05	1	01	g NOP	35 01
3	03	STO 6	33 06	g NOP	35 01
5	05	RTN	24	g NOP	35 01
6	06	LBL	23	g NOP	35 01
STO 5	33 05	E	15	g NOP	35 01
•	83	1	01	g NOP	35 01
0	00	8	08	g NOP	35 01
6	06	4	04	g NOP	35 01
STO 6	33 06	•	83	g NOP	35 01
RTN	24	0	00	g NOP	35 01
LBL	23	0	00	g NOP	35 01
C	13	2	02	g NOP	35 01
5	05	2	02		
0	00	STO 3	33 03		
•	83	•	83		
2	02	7	07		
9	09	6	06		

R_1	R_4 ΔSHA	R_7
R_2	R_5 DEC	R_8
R_3 SHA	R_6 ΔDEC	R_9

LONG TERM STAR ALMANAC (CARD 5)

KEYS	CODE
1	01
9	09
5	05
·	83
3	03
6	06
0	00
7	07
STO 3	33 03
·	83
9	09
2	02
CHS	42
STO 4	33 04
6	06
2	02
·	83
1	01
7	07
1	01
3	03
STO 5	33 05
·	83
3	03
2	02
CHS	42
STO 6	33 06
RTN	24
LBL	23
C	13
1	01
6	06
·	83
5	05
8	08

KEYS	CODE
0	00
5	05
STO 3	33 03
·	83
8	08
3	03
CHS	42
STO 4	33 04
3	03
0	00
·	83
0	00
9	09
1	01
9	09
CHS	42
STO 5	33 05
·	83
3	03
2	02
STO 6	33 06
RTN	24
LBL	23
E	15
5	05
5	05
·	83
3	03
3	03
5	05
6	06
STO 3	33 03
1	01
·	83
1	01

KEYS	CODE
9	09
CHS	42
STO 4	33 04
5	05
7	07
·	83
0	00
3	03
2	02
CHS	42
STO 5	33 05
·	83
1	01
9	09
STO 6	33 06
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	R_4 ΔSHA	R_7
R_2	R_5 DEC	R_8
R_3 SHA	R_6 ΔDEC	R_9

LONG TERM STAR ALMANAC (CARD 6)

KEYS	CODE
2	02
4	04
5	05
·	83
1	01
2	02
0	00
7	07
STO 3	33 03
·	83
9	09
2	02
CHS	42
STO 4	33 04
2	02
8	08
·	83
1	01
6	06
2	02
4	04
STO 5	33 05
·	83
1	01
5	05
CHS	42
STO 6	33 06
RTN	24
LBL	23
C	13
2	02
4	04
6	06
·	83
2	02

KEYS	CODE
8	08
4	04
1	01
STO 3	33 03
·	83
7	07
8	08
CHS	42
STO 4	33 04
5	05
·	83
2	02
8	08
4	04
8	08
STO 5	33 05
·	83
1	01
5	05
CHS	42
STO 6	33 06
RTN	24
LBL	23
E	15
2	02
0	00
9	09
·	83
1	01
4	04
1	01
8	08
STO 3	33 03
·	83
8	08

KEYS	CODE
CHS	42
STO 4	33 04
1	01
2	02
·	83
2	02
7	07
1	01
4	04
STO 5	33 05
·	83
2	02
9	09
CHS	42
STO 6	33 06
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	R_4 ΔSHA	R_7
R_2	R_5 DEC	R_8
R_3 SHA	R_6 ΔDEC	R_9

LONG TERM STAR ALMANAC (CARD 7)

KEYS	CODE	KEYS	CODE	KEYS	CODE
2	02	0	00	·	83
8	08	7	07	8	08
2	02	STO 3	33 03	5	05
·	83	1	01	CHS	42
3	03	·	83	STO 4	33 04
4	04	0	00	5	05
0	00	2	02	5	05
1	01	CHS	42	·	83
STO 3	33 03	STO 4	33 04	5	05
·	83	6	06	9	09
7	07	0	00	1	01
2	02	·	83	9	09
CHS	42	2	02	STO 5	33 05
STO 4	33 04	5	05	·	83
8	08	1	01	3	03
·	83	8	08	3	03
1	01	CHS	42	STO 6	33 06
9	09	STO 5	33 05	RTN	24
0	00	·	83	g NOP	35 01
1	01	2	02	g NOP	35 01
CHS	42	5	05	g NOP	35 01
STO 5	33 05	CHS	42	g NOP	35 01
·	83	STO 6	33 06	g NOP	35 01
0	00	RTN	24	g NOP	35 01
7	07	LBL	23	g NOP	35 01
STO 6	33 06	E	15	g NOP	35 01
RTN	24	3	03	g NOP	35 01
LBL	23	5	05	g NOP	35 01
C	13	1	01	g NOP	35 01
1	01	·	83	g NOP	35 01
4	04	1	01		
1	01	7	07		
·	83	4	04		
4	04	2	02		
8	08	STO 3	33 03		

R_1	R_4 ΔSHA	R_7
R_2	R_5 DEC	R_8
R_3 SHA	R_6 ΔDEC	R_9

LONG TERM STAR ALMANAC (CARD 8)

KEYS	CODE	KEYS	CODE	KEYS	CODE
2	02	0	00	·	83
5	05	1	01	5	05
9	09	0	00	1	01
·	83	8	08	CHS	42
4	04	STO 3	33 03	STO 4	33 04
8	08	·	83	3	03
5	05	7	07	8	08
1	01	9	09	·	83
STO 3	33 03	CHS	42	4	04
·	83	STO 4	33 04	1	01
6	06	1	01	0	00
6	06	0	00	8	08
CHS	42	·	83	STO 5	33 05
STO 4	33 04	3	03	·	83
1	01	8	08	0	00
6	06	3	03	6	06
·	83	2	02	STO 6	33 06
3	03	CHS	42	RTN	24
4	04	STO 5	33 05	g NOP	35 01
4	04	·	83	g NOP	35 01
9	09	3	03	g NOP	35 01
CHS	42	1	01	g NOP	35 01
STO 5	33 05	CHS	42	g NOP	35 01
·	83	STO 6	33 06	g NOP	35 01
0	00	RTN	24	g NOP	35 01
8	08	LBL	23	g NOP	35 01
CHS	42	E	15	g NOP	35 01
STO 6	33 06	8	08	g NOP	35 01
RTN	24	1	01	g NOP	35 01
LBL	23	·	83	g NOP	35 01
C	13	3	03		
1	01	6	06		
6	06	5	05		
0	00	1	01		
·	83	STO 3	33 03		

R_1	R_4 ΔSHA	R_7
R_2	R_5 DEC	R_8
R_3 SHA	R_6 ΔDEC	R_9

POSITION OF SUN AND STARS

KEYS	CODE
LBL	23
A	11
RCL 3	34 03
RCL 4	34 04
E	15
RTN	24
LBL	23
B	12
A	11
f	31
→D.MS	03
EEX	43
2	02
÷	81
RCL 8	34 08
f	31
→D.MS	03
GTO	22
1	01
LBL	23
C	13
RCL 5	34 05
RCL 6	34 06
E	15
R/S	84
f	31
→D.MS	03
DSP	21
•	83
4	04
EEX	43
2	02
÷	81
RTN	24
LBL	23

KEYS	CODE
D	14
f	31
→D.MS	03
EEX	43
2	02
÷	81
f^{-1}	32
→D.MS	03
3	03
6	06
0	00
–	51
CHS	42
1	01
5	05
÷	81
f	31
→D.MS	03
DSP	21
•	83
4	04
RTN	24
LBL	23
E	15
6	06
0	00
÷	81
RCL	34
9	09
x	71
f	31
→D.MS	03
LBL	23
1	01
f	31

KEYS	CODE
D.MS+	02
f^{-1}	32
→D.MS	03
3	03
6	06
0	00
÷	81
f^{-1}	32
INT	83
3	03
6	06
0	00
x	71
f	31
→D.MS	03
EEX	43
2	02
x	71
f^{-1}	32
→D.MS	03
DSP	21
•	83
1	01
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1		R_4	ΔSHA	R_7	
R_2		R_5	DEC	R_8	GHA ♈
R_3	SHA	R_6	ΔDEC	R_9	Y.y

RELATIVE POSITION OF SUN AND STARS

KEYS	CODE
f	31
→D.MS	03
EEX	43
2	02
÷	81
f^{-1}	32
→D.MS	03
STO 7	33 07
RTN	24
LBL	23
A	11
f	31
→D.MS	03
EEX	43
2	02
÷	81
f^{-1}	32
→D.MS	03
STO 2	33 02
RTN	24
LBL	23
C	13
RCL 3	34 03
RCL 4	34 04
6	06
0	00
÷	81
RCL	34
9	09
x	71
g x⇄y	35 07
f^{-1}	32
→D.MS	03
+	61
RCL 8	34 08

KEYS	CODE
+	61
RCL 7	34 07
–	51
E	15
RCL	34
9	09
STO 1	33 01
g x⇄y	35 07
1	01
f^{-1}	32
R→P	01
f	31
R→P	01
g x⇄y	35 07
RCL 1	34 01
STO	33
9	09
g x⇄y	35 07
STO 1	33 01
GTO	22
1	01
LBL	23
D	14
RCL 5	34 05
RCL 6	34 06
6	06
0	00
÷	81
RCL	34
9	09
x	71
g x⇄y	35 07
f^{-1}	32
→D.MS	03
+	61

KEYS	CODE
E	15
STO 3	33 03
LBL	23
1	01
f	31
→D.MS	03
EEX	43
2	02
x	71
f^{-1}	32
→D.MS	03
RTN	24
LBL	23
E	15
3	03
6	06
0	00
÷	81
f^{-1}	32
INT	83
3	03
6	06
0	00
x	71
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	LHA	R_4	ΔSHA	R_7	λ
R_2	L	R_5	DEC(1900.0)	R_8	GHA ♈
R_3	SHA(1900.0),DEC	R_6	ΔDEC	R_9	Y.y

SIGHT REDUCTION TABLE

KEYS	CODE
E	15
STO 1	33 01
RTN	24
LBL	23
B	12
E	15
STO 2	33 02
RTN	24
LBL	23
C	13
E	15
STO 3	33 03
RTN	24
LBL	23
E	15
f	31
→D.MS	03
EEX	43
2	02
÷	81
f^{-1}	32
→D.MS	03
RTN	24
LBL	23
D	14
DSP	21
·	83
1	01
RCL 2	34 02
f	31
SIN	04
RCL 3	34 03
f	31
SIN	04
x	71

KEYS	CODE
RCL 2	34 02
f	31
COS	05
RCL 3	34 03
f	31
COS	05
x	71
RCL 1	34 01
f	31
COS	05
x	71
+	61
f^{-1}	32
SIN	04
STO 4	33 04
f	31
→D.MS	03
EEX	43
2	02
x	71
f^{-1}	32
→D.MS	03
RTN	24
LBL	23
D	14
RCL 3	34 03
f	31
SIN	04
RCL 2	34 02
f	31
SIN	04
RCL 4	34 04
f	31
SIN	04
x	71

KEYS	CODE
–	51
RCL 4	34 04
f	31
COS	05
÷	81
RCL 2	34 02
f	31
COS	05
÷	81
f^{-1}	32
COS	05
RCL 1	34 01
f	31
SIN	04
0	00
g x>y	35 24
x	71
GTO	22
3	03
6	06
0	00
g R↑	35 09
–	51
0	00
LBL	23
3	03
+	61
STO 5	33 05
RTN	24
R/S	84

R_1 t	R_4 Hc	R_7
R_2 L	R_5 Zn	R_8
R_3 d	R_6	R_9 Used

MOST PROBABLE POSITION

KEYS	CODE
E	15
STO 7	33 07
g x⇄y	35 07
E	15
STO 2	33 02
RTN	24
LBL	23
B	12
STO 5	33 05
g x⇄y	35 07
E	15
STO 4	33 04
RTN	24
LBL	23
C	13
E	15
STO 6	33 06
RCL 4	34 04
g x⇄y	35 07
–	51
GTO	22
1	01
LBL	23
D	14
RCL 2	34 02
RCL 6	34 06
RCL 4	34 04
–	51
RCL 5	34 05
g x⇄y	35 07
f^{-1}	32
R→P	01
g x⇄y	35 07
g R↓	35 08
+	61

KEYS	CODE
LBL	23
1	01
f	31
→D.MS	03
EEX	43
2	02
x	71
f^{-1}	32
→D.MS	03
DSP	21
·	83
1	01
RTN	24
RCL 7	34 07
RCL 6	34 06
RCL 4	34 04
–	51
RCL 5	34 05
g x⇄y	35 07
f^{-1}	32
R→P	01
g R↓	35 08
RCL 2	34 02
f	31
COS	05
÷	81
–	51
1	01
f^{-1}	32
R→P	01
f	31
R→P	01
g x⇄y	35 07
GTO	22
1	01

KEYS	CODE
LBL	23
E	15
f	31
→D.MS	03
EEX	43
2	02
÷	81
f^{-1}	32
→D.MS	03
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	R_4 Hc	R_7 λ
R_2 L	R_5 Zn	R_8
R_3	R_6 Ho	R_9 Used

FIX BY TWO OBSERVATIONS

KEYS	CODE
2	02
E	15
STO 1	33 01
g R↓	35 08
2	02
E	15
STO 2	33 02
RTN	24
LBL	23
B	12
g x⇄y	35 07
f^{-1}	32
R→P	01
STO 3	33 03
g x⇄y	35 07
STO 4	33 04
RTN	24
LBL	23
C	13
g x⇄y	35 07
f^{-1}	32
R→P	01
STO 5	33 05
g x⇄y	35 07
STO 6	33 06
RTN	24
LBL	23
D	14
RCL 4	34 04
RCL 3	34 03
÷	81
STO 7	33 07
RCL 6	34 06
RCL 5	34 05
÷	81

KEYS	CODE
STO 8	33 08
RCL 5	34 05
RCL 3	34 03
–	51
RCL 4	34 04
RCL 7	34 07
x	71
–	51
RCL 6	34 06
RCL 8	34 08
x	71
+	61
RCL 8	34 08
RCL 7	34 07
–	51
÷	81
↑	41
↑	41
RCL 4	34 04
–	51
RCL 7	34 07
x	71
RCL 3	34 03
–	51
2	02
E	15
RCL 2	34 02
+	61
STO 7	33 07
g R↓	35 08
RCL 2	34 02
f	31
COS	05
÷	81
2	02

KEYS	CODE
E	15
RCL 1	34 01
+	61
1	01
f^{-1}	32
R→P	01
f	31
R→P	01
g x⇄y	35 07
STO 8	33 08
RCL 7	34 07
2	02
CHS	42
LBL	23
E	15
CHS	42
f^{-1}	32
LOG	08
g x⇄y	35 07
f	31
→D.MS	03
x	71
f^{-1}	32
→D.MS	03
RTN	24
RCL 8	34 08
2	02
CHS	42
E	15
RTN	24

R_1	$a\lambda$	R_4	$\Delta\lambda_1$	R_7	tan Zn_1, L
R_2	aL	R_5	ΔL_2	R_8	tan Zn_2, λ
R_3	ΔL_1	R_6	$\Delta\lambda_2$	R_9	Used

FIX BY THREE OBSERVATIONS

KEYS	CODE
E	15
STO 2	33 02
g R↓	35 08
E	15
STO 1	33 01
RTN	24
LBL	23
B	12
E	15
STO 4	33 04
g R↓	35 08
E	15
STO 3	33 03
RTN	24
LBL	23
C	13
E	15
STO 6	33 06
g R↓	35 08
E	15
STO 5	33 05
RTN	24
LBL	23
D	14
RCL 1	34 01
RCL 3	34 03
RCL 5	34 05
+	61
+	61
3	03
÷	81
LBL	23
1	01
f	31
→D.MS	03

KEYS	CODE
EEX	43
2	02
x	71
f^{-1}	32
→D.MS	03
RTN	24
RCL 2	34 02
RCL 4	34 04
RCL 6	34 06
+	61
+	61
3	03
÷	81
1	01
f^{-1}	32
→D.MS	03
f	31
→D.MS	03
g R↓	35 08
GTO	22
1	01
LBL	23
E	15
f	31
→D.MS	03
EEX	43
2	02
÷	81
f^{-1}	32
→D.MS	03
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

KEYS	CODE
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	L_1	R_4	λ_2	R_7	
R_2	λ_1	R_5	L_3	R_8	
R_3	L_2	R_6	λ_3	R_9	Used

DISTANCE OFF AN OBJECT BY TWO BEARINGS

KEYS	CODE
LBL	23
A	11
STO 2	33 02
g x⇄y	35 07
STO 1	33 01
RTN	24
LBL	23
B	12
STO 3	33 03
RTN	24
LBL	23
C	13
6	06
0	00
÷	81
x	71
STO 3	33 03
RTN	24
LBL	23
D	14
RCL 2	34 02
RCL 1	34 01
–	51
f	31
SIN	04
g	35
$1/x$	04
RCL 1	34 01
f	31
SIN	04
x	71
RCL 3	34 03
x	71
STO 4	33 04
RCL 2	34 02

KEYS	CODE
f	31
SIN	04
x	71
g	35
ABS	06
STO 5	33 05
RCL 1	34 01
f	31
SIN	04
÷	81
g	35
ABS	06
STO 6	33 06
RCL 5	34 05
RTN	24
LBL	23
E	15
D	14
RCL 6	34 06
R/S	84
RCL 4	34 04
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

KEYS	CODE
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	RB_1	R_4	D_2	R_7	
R_2	RB_2	R_5	D_{abeam}	R_8	
R_3	D_{run}	R_6	D_1	R_9	

VECTOR ADDITION

KEYS	CODE
LBL	23
A	11
f^{-1}	32
R→P	01
STO 1	33 01
g R↓	35 08
STO 2	33 02
CLX	44
RTN	24
LBL	23
B	12
f^{-1}	32
R→P	01
STO 3	33 03
g R↓	35 08
STO 4	33 04
CLX	44
RTN	24
LBL	23
C	13
RCL 2	34 02
RCL 4	34 04
+	61
RCL 1	34 01
RCL 3	34 03
+	61
f	31
R→P	01
RTN	24
LBL	23
1	01
g x⇄y	35 07
0	00
g x>y	35 24
3	03

KEYS	CODE
6	06
0	00
+	61
+	61
R/S	84
g x⇄y	35 07
R/S	84
GTO	22
1	01
LBL	23
D	14
RCL 2	34 02
RCL 4	34 04
–	51
RCL 1	34 01
RCL 3	34 03
–	51
f	31
R→P	01
RTN	24
GTO	22
1	01
LBL	23
E	15
RCL 4	34 04
RCL 2	34 02
–	51
RCL 3	34 03
RCL 1	34 01
–	51
f	31
R→P	01
RTN	24
GTO	22
1	01

KEYS	CODE
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1	$r_1 \cos b_1$	R_4	$r_2 \sin b_2$	R_7	
R_2	$r_1 \sin b_1$	R_5		R_8	
R_3	$r_2 \cos b_2$	R_6		R_9	

VELOCITY TO CHANGE RELATIVE POSITION

KEYS	CODE
STO 2	33 02
g x⇄y	35 07
9	09
0	00
–	51
CHS	42
STO 1	33 01
RTN	24
LBL	23
B	12
STO 4	33 04
g x⇄y	35 07
9	09
0	00
–	51
CHS	42
STO 3	33 03
CLX	44
RTN	24
RCL 1	34 01
9	09
0	00
–	51
STO	33
+	61
3	03
R/S	84
LBL	23
C	13
STO 6	33 06
g x⇄y	35 07
9	09
0	00
–	51
CHS	42
STO 5	33 05
CLX	44
RTN	24
RCL 1	34 01
9	09
0	00
–	51
STO	33
+	61
5	05
R/S	84
LBL	23
D	14
f^{-1}	32
→D.MS	03
STO 7	33 07
RTN	24
LBL	23
E	15
RCL 5	34 05
RCL 6	34 06
f^{-1}	32
R→P	01
g x⇄y	35 07
RCL 3	34 03
RCL 4	34 04
f^{-1}	32
R→P	01
g R↓	35 08
–	51
g R↓	35 08
–	51
CHS	42
g R↑	35 09
g x⇄y	35 07
f	31
R→P	01
RCL 7	34 07
÷	81
f^{-1}	32
R→P	01
g x⇄y	35 07
RCL 1	34 01
RCL 2	34 02
f^{-1}	32
R→P	01
g R↓	35 08
+	61
g R↓	35 08
+	61
g R↑	35 09
g x⇄y	35 07
f	31
R→P	01
STO 8	33 08
g R↓	35 08
9	09
0	00
–	51
CHS	42
STO	33
9	09
R/S	84
RCL 8	34 08
RTN	24

R_1 90−C	R_4 RM_1	R_7 Δt
R_2 S	R_5 $90-b_2$	R_8
R_3 $90-b_1$	R_6 RM_2	R_9

CLOSEST POINT OF APPROACH

KEYS	CODE
RCL 8	34 08
STO 7	33 07
g x⇄y	35 07
f^{-1}	32
→D.MS	03
STO 8	33 08
RTN	24
LBL	23
B	12
RCL 6	34 06
STO 4	33 04
g R↓	35 08
STO 6	33 06
g R↓	35 08
RCL 5	34 05
STO 3	33 03
g R↓	35 08
STO 5	33 05
RTN	24
LBL	23
C	13
RCL 3	34 03
RCL 4	34 04
f^{-1}	32
R→P	01
g x⇄y	35 07
RCL 5	34 05
RCL 6	34 06
f^{-1}	32
R→P	01
g R↑	35 09
–	51
g R↓	35 08
–	51
g R↑	35 09
g x⇄y	35 07
÷	81
f^{-1}	32
TAN	06
↑	41
↑	41
RCL 5	34 05
–	51
f	31
COS	05
RCL 6	34 06
x	71
E	15
g x⇄y	35 07
STO 2	33 02
RTN	24
LBL	23
D	14
RCL 5	34 05
RCL 6	34 06
f^{-1}	32
R→P	01
g x⇄y	35 07
RCL 3	34 03
RCL 4	34 04
CHS	42
f^{-1}	32
R→P	01
g R↓	35 08
+	61
g R↓	35 08
+	61
g R↑	35 09
g x⇄y	35 07
f	31
R→P	01
RCL 8	34 08
RCL 7	34 07
–	51
÷	81
2	02
0	00
2	02
5	05
÷	81
E	15
STO 3	33 03
g x⇄y	35 07
STO 4	33 04
RTN	24
LBL	23
E	15
f^{-1}	32
R→P	01
f	31
R→P	01
g x⇄y	35 07
0	00
g x>y	35 24
3	03
6	06
0	00
+	61
+	61
RTN	24

R_1	R_4 r_1, $\lvert\overrightarrow{rm}\rvert$	R_7 t_1
R_2 CPA range	R_5 b_2	R_8 t_2
R_3 b_1, $\angle\overrightarrow{rm}$	R_6 r_2	R_9 Used

COLLISION AVOIDANCE – SET UP

KEYS	CODE
EEX	43
3	03
÷	81
g x⇄y	35 07
EEX	43
2	02
x	71
f	31
INT	83
+	61
STO 1	33 01
RTN	24
LBL	23
B	12
f^{-1}	32
→D.MS	03
RCL 8	34 08
–	51
STO 8	33 08
RCL 3	34 03
RCL 4	34 04
RCL 8	34 08
x	71
2	02
0	00
2	02
5	05
x	71
RCL 5	34 05
RCL 6	34 06
E	15
g x⇄y	35 07
STO 8	33 08
g x⇄y	35 07
STO 6	33 06

KEYS	CODE
RTN	24
LBL	23
C	13
RCL 6	34 06
÷	81
f^{-1}	32
SIN	04
STO 6	33 06
RCL 1	34 01
f	31
INT	83
EEX	43
2	02
÷	81
RCL 1	34 01
f^{-1}	32
INT	83
EEX	43
3	03
x	71
RCL 3	34 03
RCL 4	34 04
E	15
STO 7	33 07
g x⇄y	35 07
STO 5	33 05
RCL 8	34 08
1	01
8	08
0	00
+	61
RCL 3	34 03
–	51
STO 2	33 02
RCL 5	34 05

KEYS	CODE
RCL 7	34 07
RTN	24
LBL	23
E	15
f^{-1}	32
R→P	01
g R↓	35 08
g R↓	35 08
f^{-1}	32
R→P	01
g x⇄y	35 07
g R↑	35 09
+	61
g R↓	35 08
+	61
g R↑	35 09
g x⇄y	35 07
f	31
R→P	01
RTN	24
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01
g NOP	35 01

R_1 100C+S/1000	R_4 rm, $\beta + h_r$	R_7 t_1, em
R_2 r_{CPA}, θ	R_5 b_2, h	R_8 t_2, $t_3 - t_2$, b_3
R_3 h_r	R_6 r_2, r_3, θ	R_9 Used

COLLISION AVOIDANCE – COURSE CHANGES

KEYS	CODE
E	15
+	61
GTO	22
1	01
LBL	23
B	12
E	15
–	51
GTO	22
1	01
LBL	23
C	13
E	15
g R↓	35 08
LBL	23
1	01
DSP	21
•	83
3	03
STO 4	33 04
–	51
f	31
SIN	04
RCL 7	34 07
x	71
RCL 1	34 01
f^{-1}	32
INT	83
÷	81
EEX	43
3	03
÷	81
f^{-1}	32
SIN	04
RCL 4	34 04

KEYS	CODE
–	51
1	01
8	08
0	00
–	51
CHS	42
1	01
f^{-1}	32
R→P	01
f	31
R→P	01
g x⇄y	35 07
0	00
g x>y	35 24
3	03
6	06
0	00
+	61
+	61
EEX	43
CHS	42
3	03
g x⇄y	35 07
•	83
5	05
+	61
f	31
INT	83
x	71
g LST X	35 00
↑	41
RCL 1	34 01
f	31
INT	83
EEX	43

KEYS	CODE
2	02
÷	81
–	51
f	31
SIN	04
f^{-1}	32
SIN	04
0	00
g x>y	35 24
GTO	22
2	02
+	61
+	61
RTN	24
LBL	23
2	02
+	61
CHS	42
+	61
CHS	42
RTN	24
LBL	23
E	15
RCL 5	34 05
RCL 3	34 03
RCL 2	34 02
+	61
RCL 6	34 06
RTN	24
g NOP	35 01

R_1 100C + S/1000	R_4 rm, $h_r + \beta$	R_7 em
R_2 θ	R_5 h	R_8 b_3
R_3 h_r	R_6 ϕ	R_9 Used