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SIGHT REDUCTION - BY TABLES OR BY CELESTIAL NAVIGATION COMPUTER ?

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INTRODUCTION

The astro-navigator today, if he be not too conservative in his methods, is still seeking better ways of performing his calculation of the sight reduction problem to give him a position line. This paper presents three serious novelties and makes a detailed comparison of their attributes and benefits for the practicing navigator.

These methods are :

(a) The author's new Sight Reduction Tables K_{21} which, based on the entering arguments Latitude, Meridian Angle and Declination, give tabulated altitude and azimuth to an accuracy of 0.2′ and 0.2° respectively, for all celestial bodies and all Latitudes.

(b) Two new small navigational computers, the Galaxy 1 and the Intercepter, which are specially programmed for the solution of intercept and azimuth.

Procedures for using both the Rapid Inspection Tables and the computers are given in detail, to assist the navigator to make his choice. Comparisons are also made with the best known existing tables published by the U.S.A., Britain and the Hydrographic Office of the Yugoslav Navy.

PART I

TABLES K_{21} — COMPUTED RESULTS OF ALTITUDE AND AZIMUTH FOR ALL LATITUDES AND ALL CELESTIAL BODIES

Although we see everywhere increasing use of computers in all fields of human activity, including onboard ship, yet for sight reduction, Tables are still predominant, even in the ships of those countries most advanced in computer technology.

Existing Tables

The well known *altitude-azimuth* tables H.O. 214 (9 volumes each of some 260 pages) were published by the U.S. Hydrographic Office in 1937, identical versions being later issued by Britain (H.D. 486) and Spain. They were followed in 1951 by, among others, one of the simplest Modern Inspection Tables, H.O. 249 "Sight Reduction Tables for Air Navigation", which have been in standard use by the air forces of U.S.A., Britain (AP 3270) and Canada, as well as by many mariners, who have accepted their lesser accuracy, limited selection of stars and the need to replace one of the three volumes each 5-year epoch.

In 1970 the U.S. Naval Oceanographic Office published H.O. 229 "Sight Reduction Tables for Marine Navigation" (British H.D. 605/NP 401) in six volumes each covering 15° of Latitude. The intention in publication was to steer a middle course between H.O. 214 and H.O. 249 and to eliminate some inconveniences found in these earlier tables. Altitude is tabulated to decimal parts of a degree as in H.O. 214, but the correction to tabulated altitude is possible only for whole minutes of declination, so that an *assumed position* computation is made, as in H.O. 249; for *dead reckoning position* the intercept can be found graphically. Meanwhile the interpolation table for altitude correction is more complicated than the familiar type in H.O. 214 or H.O. 249, so that many mariners prefer these earlier Tables, in spite of their various imperfections.

Yugoslav Tables

My Tables K_1 "A Short Method of Computation of Altitude and Azimuth in Astronomical Navigation" [1], described by Bowditch as "Altitude method without use of navigation triangle" [2] are widely used, a fact evident from the three editions so far required (1958, 1963 and 1971). One single volume of 240 pages is sufficient for all latitudes and all celestial bodies. Compared to the 9-volume Tables H.O. 214 for working from an assumed position, only one book opening more, one subtraction more for azimuth and one more correction for altitude are required, *but* in K_1 the signs for altitude corrections are tabulated, the assumed position is rounded to a half-degree, and the need for azimuth interpolation is less.

In 1971 the first volume of K_{11} "Two-Star Fix without Use of Altitude Difference Method" [3] was published, followed by others in 1972, 1974 and 1975. Mariners have realised that these offer a completely new approach [4] [5] to fixing from celestial observations, giving directly Latitude and Longitude without intermediate computations and plotting. Tables K_{11} are unique among tabular methods because with the observed altitudes of two stars they provide the tabulated corrections to be applied to the assumed position in order to obtain the observed position. In the next printing of K_{11}, the number of star pairs on each page will be doubled by the introduction of two further pairs for each 10° of LHA Aries. This will meet the requirement of navigators for more selected star pairs for this direct method of fixing.

Tables K_{11} thus "constitute an elegant rendition of the double altitude technique" [6], and would have been published for the Sun/Moon combination, as suggested in my book [7], if finance had been available. It is a fact, however, that many navigators prefer to practice what they learned in their early training (before K_{11} existed) so that their use is not as extensive as it might be. And their concept is so radical that they are not really within the scope of this paper, which is concerned with solution of the traditional celestial triangle.

The new Tables K_{21}

As with other Modern Inspection Tables, K_{21} has been designed for extracting the altitude and azimuth in the simplest and shortest way using three entering arguments : Latitude, Meridian Angle and Declination. However the improvements over H.O. 249 are :

(1) Tables K_{21} are not limited to tabulated stars (like the 6 or 7 selected stars for each 15° interval of LHA Aries in H.O. 249, Vol. I) but enable observers in all latitudes to use all celestial bodies given in the Nautical Almanac. Consequently, it will not be necessary to publish yearly corrections for the effects of precession and nutation, or complete new editions of the volume.

(2) Tabulation of altitude and azimuth is made for the value of meridian angle (MA) from 0° to 180° on two pages (left and right), which is more practical for use than the three pages of H.O. 249.

(3) There are no separate rules for Northern and Southern latitudes for converting tabulated azimuth angle to azimuth, but one simple rule already familiar to mariners from the wide use of H.O. 214 and K_1 Tables. This is schematically shown at the top of each page of K_{21}.

(4) Although in the practice of navigation the interpolation of azimuth is generally not necessary, it may be helpful to see from the adjoining right hand column in K_{21} (tabulated for greater declination) whether the change of azimuth angle for an increase of 1° in declination is so large that interpolation cannot be avoided. For this purpose, and for possible subsequent interpolation, there is no need in K_{21} to turn over and compare the azimuth angle values from two different pages, because the last right-hand column on one page is repeated as the first left-hand column of the next. Further, there is no need to turn the book by 90° to read the tabulated values.

(5) Although in Tables K_{21} the digital tabulation of Altitude (Hc) and Altitude Correction Index (ID) is made only to a whole minute of arc, the special addition of the decimal point after Hc and ID enables the user to take these values from Tables K_{21} with greater accuracy than from H.O. 249, because if a decimal point is printed, this means add 0.5′ — in other words the tabulated figures for Hc and ID are rounded to 0.5′.

The first reason for inserting a decimal point instead of tabulating .5′ is that Tables K_{21} are computed and typed by IBM 1130, which has only 120 beats in one line. Thus there is no space without increasing the width of the Tables over the usual size used for marine navigation.

The second reason is to leave to users (according to their need to compute altitude with greater or lesser accuracy), whether, in writing down the data from K_{21}, to ignore the possible decimal point, or to include it (as .5′). With this system of decimal point the tabulated altitude can differ from the exact result (computed logarithmically) only by 0.2′.

(6) For the azimuth angle Z the same system of tabulation is applied, i.e. if after the whole number of degrees of Z a decimal point is printed, that means .5° because Z is expressed in *degrees*. In this way it is possible to extract the azimuth angle with higher accuracy than expressed by the printed digits, and the tabulated Z can differ by only 0.2° from the exact value. This also reduces the need for interpolation of azimuth angle, so that for practical purposes Z is simply copied down from the Tables.

(7) The Multiplication Table at the end of K_{21} is considerably larger than that in H.O. 249. The Index of correction ID at the left margin is tabulated to whole and half minutes of arc (as in the main tables), and at the top the declination is tabulated to whole minutes from 0′ to 59′ and decimal parts from 0.1′ to 0.9′. This tabulation enables the user to take out a more accurate value of the altitude correction for the minutes and tenths of declination ignored on the first entering. This is done without any additional procedure, compared to H.O. 249.

(8) The system of tabulating results of Hc, ID and Z in Tables K_{21} (items 5, 6 and 7 above) gives higher accuracy in computation of latitude and azimuth without increasing the number of tabulated figures and the format of the Tables, while at the same time the procedure is no longer than H.O. 249; it is left to the free decision of users in marine or air navigation whether to use this higher accuracy, or not.

(9) Tables K_{21} involve also three volumes, but there is no volume for selected stars as in H.O. 249. Each of the three volumes covers a belt of 30° of latitude, and for each degree of latitude the declination covers all celestial bodies used practically in navigation.

(10) For a possible need to compute the altitude for *dead reckoning position*, the *instructions for use of* K_{21} *explain the very simple graphical* procedure.

Presentation

The main characteristics of the tabulated data in K_{21} are illustrated in the excerpts given, which, at the same time, allow solution of the examples for computation of altitudes and azimuths.

Tables K_{21} will have three volumes : Volume I for latitudes from 0° to 29°, Volume II for latitudes 30°-59°, and Volume III for latitudes 60°-89°. Each Volume will have 570 pages, including auxiliary tables for altitude correction and instructions for use in the Serbo-Croat and English languages. The format of the Tables will be similar to H.O. 214 or K_1.

Meridian Angle MA as the entering argument is tabulated from 0° to 180° on two pages (left and right) for easier use, and the value of Declination DEC. in eight columns on these two pages, firstly for Latitudes of *same name* as Dec., and then for Lat. *contrary name* to Dec. Accordingly, to tabulate for each degree of latitude all values of declination of the celestial bodies commonly used in the practice of celestial navigation, 18 pages are necessary, i.e. nine pairs, each pair of pages having eight columns of declination. From 0° to 30°, declination is tabulated at intervals of 1°, then from 31°30′ to 89° there are 34 entries selected to cover all common celestial bodies used.

As the Tables are intended primarily for working from an assumed position, only the altitude correction index ID is tabulated for *minutes* of declination. It is recommended to enter the Tables with Declination equal to, or next smaller than, that taken from the Nautical Almanac, in order to use the sign of altitude correction printed before the index ID. With the ID value and the minutes of Declination the altitude correction is very easily taken from the separate auxiliary Multiplication Table, whose entering arguments (see excerpt from Table II) are : on the left the altitude correction index ID tabulated to whole and half minutes of arc, and at the top the minutes and decimal parts of Declination. Applying this correction, according to its sign, to the tabulated altitude gives the computed altitude.

Azimuth angle is taken from the Tables rounded to whole and half degrees; if higher accuracy is desired interpolation can be made by inspection of the value in the adjoining right hand column for the excess of minute of Declination. The Azimuth Angle Z is tabulated in values from 0° to 180° and should be converted to Azimuth AZ before plotting the position line, in accordance with the rule printed schematically at the top of each page. This same rule is also used in Tables H.O. 214 and K_1, i.e. the Azimuth is measured from the elevated pole of the observer through 180° *towards E* when the body is *rising*, and *towards W* when the body is *setting*.

Computed altitude from a Dead Reckoning position can be found by means of the altitude computed from assumed position with the additional graphic procedure as explained in figure 3.

In addition to abbreviations commonly used in celestial navigation calculations, certain other capital letter abbreviations were necessary because the IBM 1130 has no lower case or Greek letters.

Yugoslav :	*English :*	*Explanation :*
FI	LAT.	Latitude.
MS	MA	Meridian Angle.
DEK.	DEC.	Declination.
V	HC	Computed Altitude (Hc).
ID	ID	Index for altitude correction due to minutes of arc difference between the given and tabulated declination; difference between the accompanying tabulated altitude and that for the next 1° larger value of declination; entering argument in the Multiplication Table (Table II).
LAM.	LONG.	Longitude.
Z	Z	Azimuth Angle.
AZ	Zn	Azimuth (Az).

Example

Computation of a fix by simultaneous observations of two celestial bodies. Solution by Tables K_{21}

On 21st February 1950 the navigator of a ship in D.R. position Lat. 34°51.5′ N. Long. 38°06.4′ W, observed the Sun's lower limb with a marine sextant as follows : sextant altitude 30°40.5′, index correction + 0.9′, height of eye 6.5 metres, chronometer time $17^h 23^m 38.5^s$, chronometer error $3^m 02.3^s$ slow on GMT. 21^s later, i.e. at GMT $17^h 27^m 01.8^s$ the sextant altitude of the Moon's lower limb was taken (64°53.5′). Find the intercepts and azimuths, plot the position lines and determine the coordinates of the fix.

Preliminary work

First we apply altitude corrections to find observed altitudes and from the *Nautical Almanac* find the declinations and meridian angles for the assumed position. Then we enter Tables K_{21} to find the computed altitudes, azimuths and intercepts.

Sun :

IC	+ 0.9′	C	$17^h 23^m 38.5^s$	GHA	78° 13.9′
Corr	+ 14.7	CE slow	3 02.3	a Long.	38 13.9′
Dip	− 4.5	GMT	$17^h 26^m 40.8^s$	MA	40° W
Sum	+ 11.1′	Dec.	− 10° 34.7′	a Lat.	35° N
Hs	30° 40.5				
Ho	30° 51.6′				

Moon :

IC	+ 0.9′		$17^h 26^m 40.8^s$	GHA	29° 08.8′
Corr	+ 37.4		+ 21.0		+ 360
Dip	− 4.5	GMT	$17^h 27^m 01.8^s$	− a Long.	38 08.8
Sum	+ 33.8′	Dec.	− 11° 38.7′	MA	351°
Hs	64° 53.5′			MA	9° E
Ho	65° 27.3′			a Lat.	35° N

With the above data, i.e.

	Sun	Moon
Assumed Lat :	35° N	35° N
Dec.	−10° 34.7′	− 11° 38.7′
MA	40° W	9° E

enter K_{21} and find HC and AZ, using the extract given opposite.

EXCERPT FROM TABLES K 21 /left hand side/

35 FI LATITUDE	FI ISTOIMEN SA DEKLINACIJOM LAT. SAME NAME AS DECLINATION			AZ = N,S Z E,W LAT MA		FI 35 LAT.
MS / MA	DEK. 7 V/HC ID Z	DEC. 8 V/HC ID Z	9 V/HC ID	11 V/HC ID Z	12 V/HC ID Z	MS / MA
	° ′ °	° ′ °	° ′	° ′ °	° ′ °	
0	6200 +60 180	6300 +60 180	6400 +60....	6600 +60 180	6700 +60 180	0
1				6559 +60 178	6659 +60 177.	1
2				6556 60 175	6655. 59.175	2
3				6550. 59.173	6650. 59.172.	3
4				6543. 59.170.	6643 59.170	4
5				6534. 59 168	6633. 59 168	5
6				6523 +58.166	6622 +58.165	6
7				6510 58 163.	66 8. 58 163	7
8				6455 57.161	6553 57.160.	8
9	....	....	....	6438. 57 159	6535. 57 158.	9
10				6420 56.157	6516. 56 156	10
.						.
.						.
90				617 +34 81	651 +34 80	90

EXCERPT FROM TABLES K 21 /right hand side/

35 FI LATITUDE	FI ISTOIMEN SA DEKLINACIJOM LAT. SAME NAME AS DECLINATION			AZ = N,S Z E,W LAT MA		FI 35 LAT.
MS / MA	DEK. 7 V/HC ID Z	DEC. 8 V/HC ID Z	9 V/HC ID	11 V/HC ID Z	12 V/HC ID Z	MS / MA
	° ′ °	° ′ °	° ′	° ′ °	° ′ °	
91					6 2.+34 79.	91
92						92
93						93

35 FI LATITUDE	FI LAT. RAZNOIMEN CONTRARY NAME	SA DEKLINACIJOM TO DECLINATION		AZ = N,S Z E,W LAT MA		FI 35 LAT.
MS / MA	DEK. 7 V/HC ID Z	DEC. 8 V/HC ID	10 V/HC ID Z	11 V/HC ID Z	12 V/HC ID Z	MS / MA
	° ′ °	° ′	° ′ °	° ′ °	° ′ °	
0	4800 -60 180	4700 -60....	4500 -60 180	4400 -60 180	4300 -60 180	0
.						.
.						.
36			3334.-49 136	3245.-49 136.		36
37			33 0 48.135	3211. 49 136		37
38			3225 48 134	3137 48.135		38
39			3149. 48 133	31 1. 48 134		39
40	....	....	3113. 47.132	3026 47.133		40
41			3037 -47 131.	2950 -47 132		41
.						.
.						.
76	717 -36 104	641 -36....				76

TABL.II POPRAVAK RAČUNATE VISINE ZA MINUTE DEKLINACIJE
/CORRECTION TO TABULATED ALTITUDE FOR MINUTES OF DECLINATION/

ID	DEKLINACIJA / DECLINATION																		
	1'	2'	3'	4'	5'	6'	7'	8'	....	30'	.1'	.2'	.3'	.4'	.5'	.6'	.7'	.8'	.9'
1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1		0.5	.0	.0	.0	.0	.0	.0	.0	.0	.0
1.5	0.0				0.1					0.8					.0				
2	0.0				0.2					1.0					.0				
2.5	0.0				0.2					1.3					.0				
3	0.1				0.3					1.5					.0				
3.5	0.1				0.3					1.8					.0				
4	0.1				0.3					2.0					.0				
4.5	0.1				0.4					2.3					.0				
⋮																			
30.5	0.5	1.0	1.5	2.0	2.5	3.1	3.6	4.1	....	15.3	.1	.1	.2	.2	.3	.3	.4	.4	.5
31	0.5	1.0	1.6	2.1	2.6	3.1	3.6	4.1	....	15.5	.1	.1	.2	.2	.3	.3	.4	.4	.5
⋮																			
60	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	....	30.0	.1	.2	.3	.4	.5	.6	.7	.8	.9

TABL.II POPRAVAK RAČUNATE VISINE ZA MINUTE DEKLINACIJE
/CORRECTION TO TABULATED ALTITUDE FOR MINUTES OF DECLINATION/

ID	DEKLINACIJA / DECLINATION																
	31'	....	34'	....	38'	....	60'	.1'	.2'	.3'	.4'	.5'	.6'	.7'	.8'	.9'
31	16.0	....	17.6	....	19.6	....	31.0	.1	.1	.2	.2	.3	.3	.4	.4	.5
31.5	16.3		17.9		20.0		31.5					.3				
[47.5]	24.5	....	[26.9]	....	30.1	....	47.5	....				.4	.5	[.6]	....	
[57]	29.5	....	32.3	....	[36.1]	....	57.0	....				.5	.6	[.7]	....	
⋮																
60	31.0	....	34.0	....	38.0	....	60.0	.1	.2	.3	.4	.5	.6	.7	.8	.9

E x a m p l e s : Find computed altitude and azimuth for :

SUN: LAT. 35°N, DEC. -10°34.7' /Lat. contrary name to Dec./, MA 40°W.

Solution by TABLES K 21

HC	ID	Z
31°13.5'	-47.5	N132°W
-27.5		inter.
HC=30°46.0'		AZ=N132.6°W

Solution by TABLES H.0.249

Hc	d	Z	Z inter.
31°13'	-47	-132°	-132.6°
- 27		+360	+360.0
Hc=30°46'		Zn=228°	227.4°

MOON: LAT. 35°N, DEC. +11°38.7' /Lat. same name as Dec./, MA 9°E.

Solution by TABLES K 21

HC	ID	Z
64°38.5'	+57	N159°E
+36.8		inter.
HC=65°15.3'		AZ=N158.3°E

Solution by TABLES H.0.249

Hc	d	Z	Z inter.
64°39'	+57	159°	158.4°
+37		Zn	
Hc=65°16'			

The same examples solved by another Yugoslav and foreign tables

SUN: LAT. 35°N, DEC. -10°34.7' /Lat. contrary name to Dec./, MA 40°W.

Solution by TABLES K 1

δ -10°34.7'
ω+F 154.3° M +47 34.3
M+δ 36°59.6'
C 58°13.7'
-F 21.4 Vr 30°17.6'
ω =N132.9°W kMδ +23.4
kC + 5.0
Vr=30°46.0'

Solution by TABL. H.O.214

Alt.	Δd	Az.
30°49.7'	79	132.6°
- 3.8		N W
Hc 30°45.9'		inter. N132.7°W

Solution by TABL. H.O.229

Hc	d	Z	Z int.
30°13.4'	-47.4	-132.2°	-132.7°
-23.2			
- 4.3		+360	+360
30°45.9'		Zn 227.8°	227.3°

MOON: LAT. 35°N, DEC. +11°38.7' / Lat. same name as Dec./, MA 9°E.

Solution by TABLES K 1

δ +11°38.7'
ω+F 174.8° M +54 39.9
M+δ 66°18.6'
C 82°38.3'
-F 16.3 Vr 64°55.3'
kMδ +17.7
ω =N158.5°E kC + 2.3
Vr=65°15.3'

Solution by TABL. H.O.214

Alt.	Δd	Az.
65°07.1'	95	158.6°
+ 8.3		N E
Hc 65°15.4'		inter. N158.5°E

Solution by TABL. H.O.229

Hc	d	Z	Z int.
64°38.5'	+57.1	159.0°	158.5°
+32.3		Zn	
+ 4.6			
65°15.4'			

COMPARISON OF COMPUTED ALTITUDES AND AZIMUTHS WITH DIFFERENT TABLES

from solutions of the above examples

TABLES and number of volumes	WITHOUT INTERPOLATION of Azimuth				WITH INTERPOLATION of Azimuth			
	SUN		MOON		SUN		MOON	
	Hc	AZ	Hc	AZ	Hc	AZ	Hc	AZ
TABLES K21 3 Volumes	30°46.0'	N132°W	65°15.3'	N159°E	30°46.0'	N132.6°W	65°15.3'	N158.3°E
TABL.HO 249 3 Volumes	30°46'	228°	65°16'	159°	30°46'	227.4°	65°16'	158.4°
TABLES K 1 1 Volume	30°46.0'	N132.9°W	65°15.3'	N158.5°E	30°46.0'	N132.7°W	65°15.3'	N158.4°E
TABL.HO 214 9 Volumes	30°45.9'	N132.6°W	65°15.4'	N158.6°E	30°45.9'	N132.7°W	65°15.4'	N158.5°E
TABL.HO 229 6 Volumes	30°45.9'	227.8°	65°15.4'	159.0°	30°45.9'	227.3°	65°15.4'	158.5°

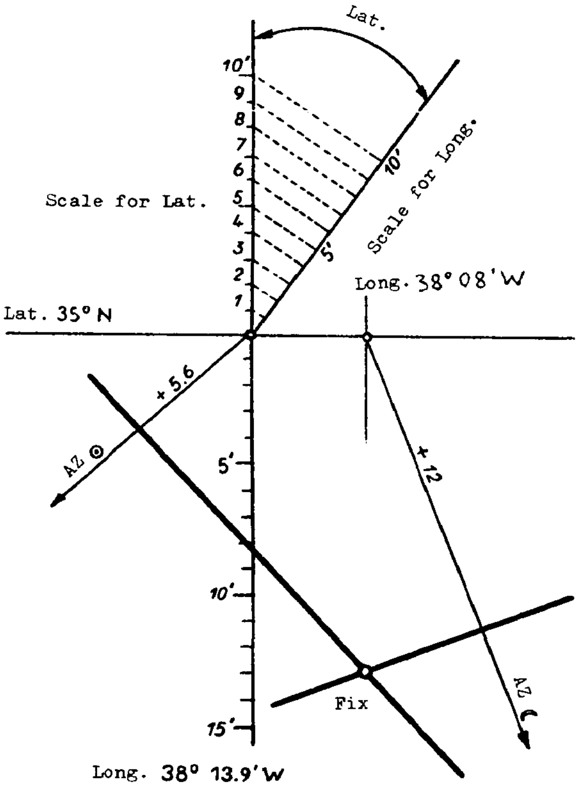
Plotting

Each position line is of course plotted from its own assumed position, as illustrated in figures 1 and 2. The intersection of these position lines gives the fix.

Plotting can be carried out in the following way :

(1) Graphic drawing on blank paper as shown in figure 1.

(2) Graphic drawing on a special plotting sheet, as shown in figure 2, which is a reduced photocopy of the original sheet.



a L 35° 00.0′ N	a λ 38° 13.9′ W
l 12.9 S	D Lo 5.1 E
Obs. Lat. 34° 47.1′ N	Obs. Long. 38° 8.8′ W

FIG. 1

For the above examples we have found computed altitudes and azimuths. Before plotting we have to find the intercepts.

Sun :	Moon :
Ho 30° 51.6′	Ho 65° 27.3′
− Hc 30 46.0	− Hc 65 15.3
Intercept + 5.6′ (Toward)	Intercept + 12.0′ (Toward)

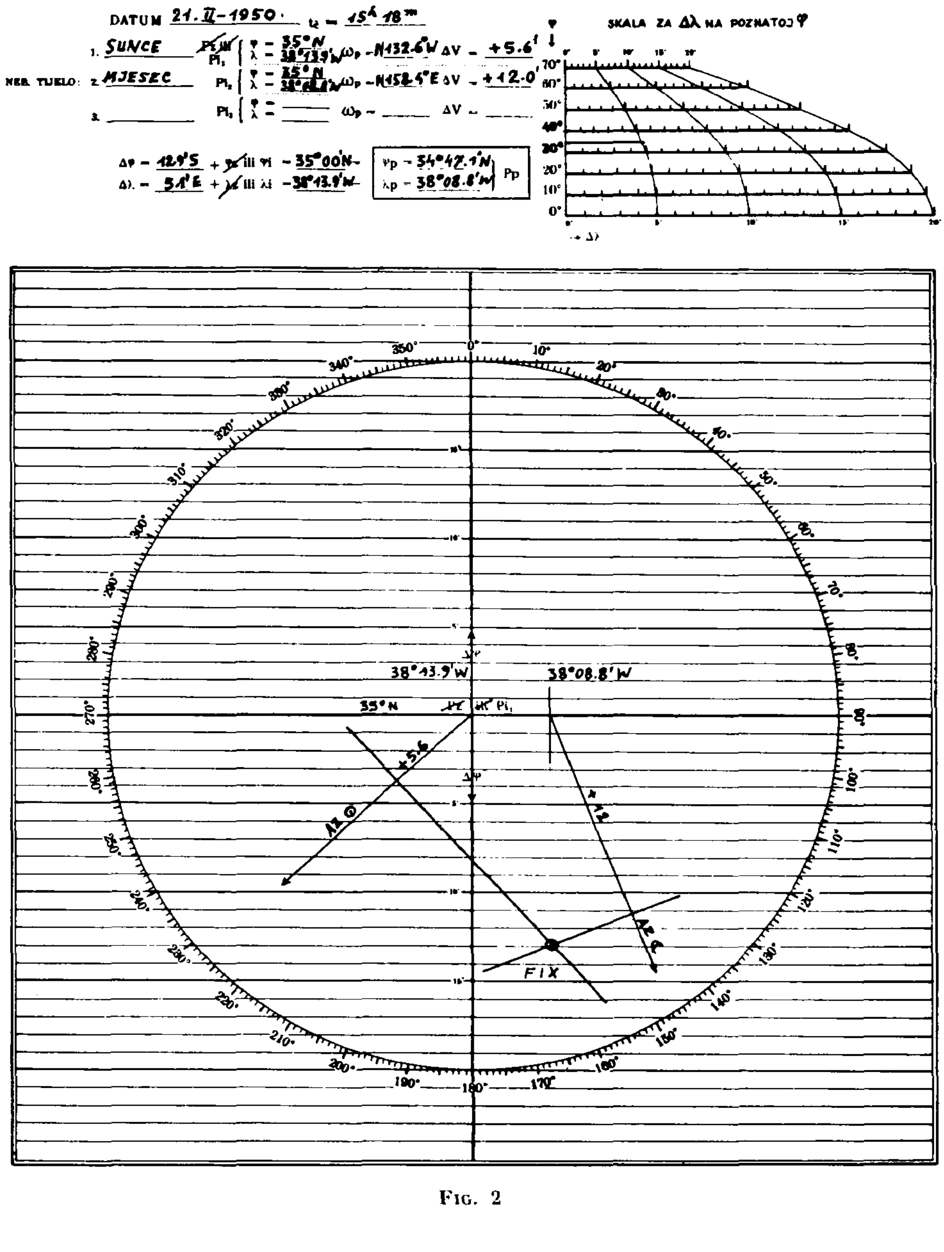


FIG. 2

Computations from D.R. Position

Tables K_{21} are conceived, as are H.O. 249 and H.O. 229, for computation from an assumed position, i.e. for whole degrees of Latitude and Meridian Angle. If it is required to find the altitude from the *Dead Reckoning position* this can be done graphically after computation of the altitude and azimuth from the assumed position. The additional plotting of the Dead Reckoning position and azimuth is done on the same drawing made for the assumed position (see figure 3). The distance along the plotted azimuth line from the D.R. position to the position line represents the Intercept (a) for the D.R. position.

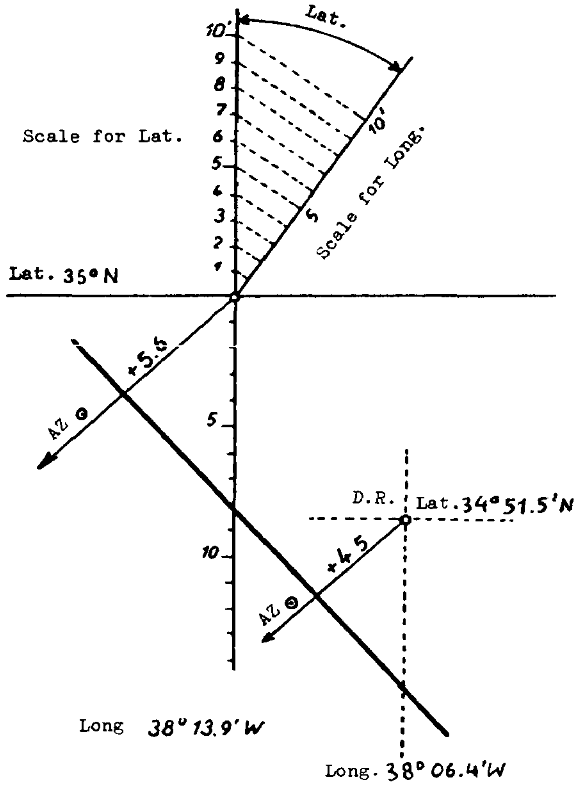


FIG. 3

From the known relation Ho − Hc = a we obtain Hc = Ho − a. Consequently :

	Ho 30°	51.6′
−	a	4.5
	Hc 30°	47.1′

CRITICAL REVIEW

The above analysis of the procedure for computation of altitude and azimuth by Tables K_{21}, and of the advantages demonstrated over H.O. 249, shows that K_{21} have fulfilled the goal laid down at the beginning of the paper. Their advantages for marine navigation make them second to none among Modern Inspection Tables for sight reduction.

Furthermore it is pointed out that in K_{21} the altitude and azimuth are tabulated with an accuracy of 0.2′ for Hc and 0.2° for Z, and that three Volumes cover all latitudes and all celestial bodies used in the practice of navigation. Finally, the procedure for computing the altitude and azimuth is so simple and fast that it can enter into competition with the newest small celestial navigation computers programmed for sight reduction, as discussed in Part II.

PART II

CELESTIAL NAVIGATION COMPUTERS IN COMPETITION WITH MODERN INSPECTION TABLES FOR SIGHT REDUCTION

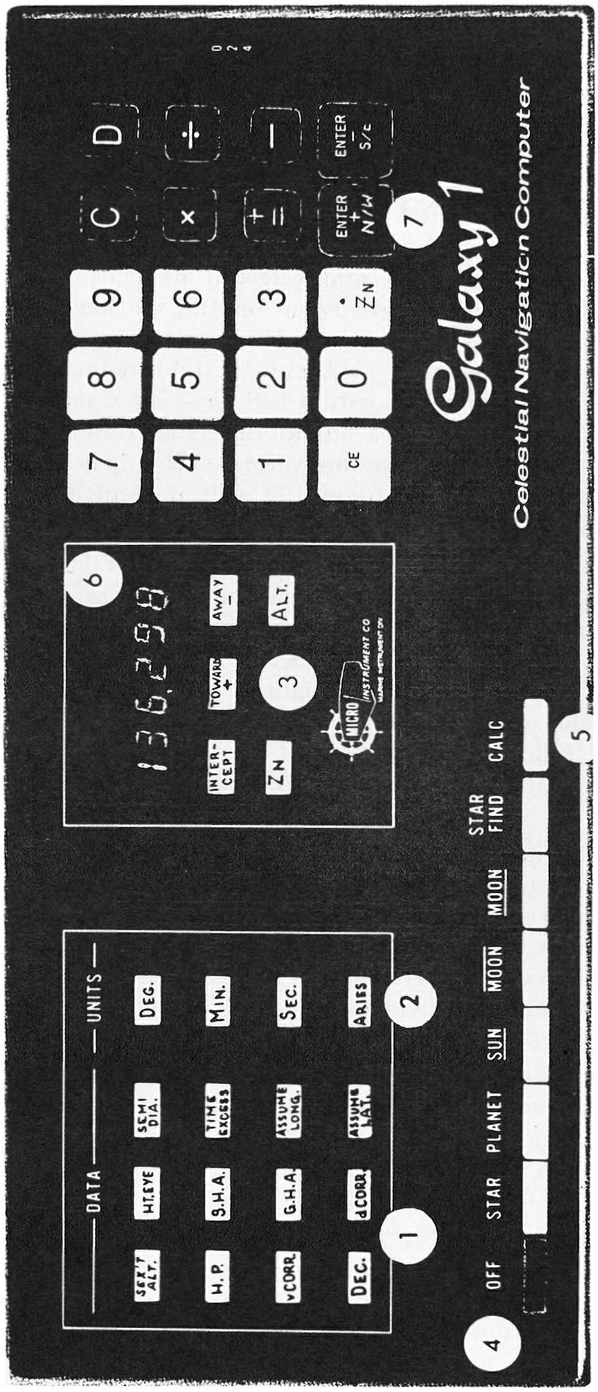
Recently pocket electronic calculators and celestial navigation computers programmed for sight reduction have come on the market. Prospectuses on these astro-navigation computers include attractive claims such as : "A fully programmed computer"; "Accurate sight reduction in two minutes or less"; "Accurate instrument with a full one-year warranty"; etc. These draw the attention of navigators but at the same time impose a need to make a closer investigation of these innovations. This is best done by a comparison between procedures for computing altitude and azimuth by small size computers and by Modern Inspection Tables, and by answering the question : which is more practical for use on board ship ?

It is necessary first to analyse in detail the procedure for computation of altitude (intercept) and azimuth using celestial navigation programmed computers. I have chosen the American GALAXY 1 and the Canadian INTERCEPTER, giving for each of them a photograph, technical data and the detailed description of the procedure for solution of the example given in their prospectus. Then follows the solution of the same example by Tables K_{21}, one of the simplest and shortest tabular solutions, as shown in Part I of this paper.

From the analysis of the procedures, the reader can assess which is better for shipboard use now and in the future — until the characteristics of either Modern Inspection Tables or celestial navigation computers are considerably changed. I give my personal opinion on this important topical question, while striving to remain impartial in this assessment and to use only facts which can be checked by the reader.

This paper does not analyse the computation of altitude (intercept) and azimuth by such electronic pocket calculators as Texas Instruments SR-50, because the procedure with these non-programmable calculators is longer, and therefore they are not strong rivals to Modern Inspection Tables. For instance, for computation of intercept and azimuth with the SR-50 28 entries were necessary [8].

The programmable pocket calculator Hewlett-Packard HP-65, if used only with the programmed card Nav. Pac 1-19A for computation of altitude and azimuth, needs 9 steps with 38 button pressings, but its price is about one hundred times more than Tables K_{21}, and those who own the HP-65 are still not liberated from the need to have sight reduction tables in reserve. However, the HP-65 also has programs for the computation of fix coordinates from the computed intercepts and azimuths and the coordinates of the Most Probable Position. The program for Sun and



1 **Data Display** gives you step by step sight reduction instructions.

2 **Unit's Display** specifies the units to use, such as DEG, MIN, SEC.

3 **Readout Units** indicates the units for the digital display, such as altitude or azimuth.

4 **Function Switch** selects each celestial body program star find or calculator modes.

5 **Calculator Function** enables use of Galaxy 1 for most bridge or chart house mathematical calculations.

6 **Digital Display** six electronic LED digits, indicates data entered and final solutions.

7 **20-Button Keyboard** for numeric data entry of all programmed functions or other calculations.

Fig. 4

Moon observations has 17 magnetic cards for insertion into and removal from the calculator; proceeding according to special instructions and a long scheme it is necessary to press a key — digit or symbol — about 180 times. Thus the solution of the fix by this pocket-size programmable calculator is long and risks the possibility of errors. Meanwhile, the specialised celestial navigation computers Galaxy 1 and Intercepter run through a self-check program, i.e. data can only be entered when the appropriate Lamp is On, showing which quantity should be keyed and which result is displayed.

1. — THE CELESTIAL NAVIGATION COMPUTER "GALAXY 1"

This small specialised astro-navigation computer is produced by the firm Micro Instrument Company, Marine Instrument Division, PO Box 1565, Escondido, Cal. 92025, USA; size 134 × 315 × 143 mm, weight 3.65 kg, power 12 to 24 V DC or 115-230 V AC, consumption 12 watts, operating temperature 0°-50 °C (see figure 4). The prospectus says that it is fully programmed and is an accurate instrument with a full one year warranty, computing a sight reduction in two minutes or less. It also features computations of great circle distance and bearing, and star identification. The suggested price is 1295.00 U.S. dollars (June 1976).

Example

On November 30, 1973 the ship's assumed position is Lat. 30° N, Long. 137° W. At $02^h36^m30^s$ Greenwich Mean Time the navigator observes the star Markab at the sextant altitude 70°35.5′, index correction is zero, height of eye 12 feet above the water line. Find the intercept and azimuth.

Preliminary work

Enter the Nautical Almanac with the date and GMT of observation for the sidereal hour angle (SHA) and declination (DEC) of Markab, and GHA Aries. The assumed position (ASSUME LAT. and ASSUME LONG.), as well as the sextant altitude (SEX'T ALT.) and the height of eye above the sea (HT. EYE) are already known, so that the computer is entered with the following data :

G.H.A. ARIES (2^h)	99°47.5′	ASSUME LAT.	30° N
TIME EXCESS	36^m30^s	ASSUME LONG.	137° W
S.H.A.	14°7.8′	SEX'T ALT.	70°35.5′
DEC.	15°4.1′ N	HT. EYE	12 feet

Computer procedure

(1) Switch on power supply and push the button STAR; immediately the sextant altitude indicator SEX'T ALT. lights up as well as degrees indicator DEG.

(2) Enter 70 followed by a plus (+).
Note : After the number has been keyed into the computer an ENTER key must be pushed before the computer will proceed to the next step. Of the ENTER keys, the "plus" (+) key performs the same function as the "ENTER N/W" key; either of these keys are used to enter data which consists of positive numbers or signless numbers of direction in the Northerly or Westerly direction. The "negative" (−) key performs the same function as the "ENTER S/E" key; either of these keys are used to enter data consisting of negative numbers or signless numbers of direction in the Southerly or Easterly directions.

The + key transfers the data into the computer. The SEX'T ALT. indicator light remains on, the DEG light goes off and the minute light MIN comes on.

(3) Enter 35.5 followed by a +, whereupon the SEX'T ALT. light goes out and the HT. EYE light comes on.

(4) Key 12 followed by a +. The computer then skips to sidereal hour angle S.H.A. and also lights the DEG indicator.

(5) Key 14 followed by a +. The S.H.A. indicator light remains on, the DEG light goes off and the MIN comes on, requesting minutes of sidereal hour angle.

(6) Enter 7.8 followed by a +. The computer then lights the TIME EXCESS indicator and also the MIN.

(7) Enter 36 followed by a +, whereupon the computer steps to TIME EXCESS in SEC.

(8) Enter 30 followed by a +. The computer then skips to G.H.A. and ARIES, and also lights the DEG indicator.

(9) Enter 99 followed by a +. The DEG light goes off and the MIN indicator comes on, requesting minutes of G.H.A.γ.

(10) Enter 47.5 followed by a + and Galaxy 1 moves on to light ASSUME LONG and DEG.

(11) Enter 137 followed by the W button and the instrument lights ASSUME LONG. and MIN.

(12) Enter 0.0 followed by W. Galaxy 1 moves on again, this time to declination DEC. and DEG indicators.

(13) Enter 15 followed by N. The unit moves on to ask for DEC. in MIN.

(14) Enter 4.1 followed by N. Galaxy 1 moves on to assumed latitude ASSUME LAT. in DEG.

(15) Enter 30 followed by N, whereupon the computer asks for ASSUME LAT. in MIN.

(16) Enter 0.0 followed by N, whereupon the Galaxy 1 will compute intercept. It then displays 11.6 minutes (11.6 nautical miles) also lighting up the INTERCEPT and TOWARD indicators.

(17) The navigator then presses the Z_N button followed by a + key, at which time the Galaxy 1 computes azimuth. In this particular case, Z_N and 136.3 degrees are displayed.

With the Intercept and Azimuth the navigator then plots the position line.

2. — THE CELESTIAL NAVIGATION COMPUTER "INTERCEPTER"

This also is a small-size astro-navigation computer. It is produced by the firm Digital Systems Marine, 1010 St. Catherine Street West, Suite 1102, Montreal, Quebec H3B 1E6; size 270 × 180 × 165 mm, weight 2.7 kg, power 10-24 V DC or 115 V 60 Hz/230 V 50 Hz AC, consumption 24 watts (see figure 5). Accuracy of the results displayed is to 0.1′, internal accuracy much greater. This computer is designed primarily for sight reduction (computing the intercept and azimuth) but can also solve other celestial and great circle calculations (identifying an unknown star, checking the compass, great circle sailing). The price is $ 1250 Canadian, FOB Montreal (May 1976).

Example

On 12th November 1958 in D.R. position Lat. 40°4.0′ S, Long. 100°0.0′ W, the sextant altitude of the star Canopus was 39°26.5′. Index error 2.0′ off the arc. Height of eye 37 ft. The time by chronometer correct for G.M.T. was $14^h37^m28^s$. Find the Azimuth and Intercept.

Preliminary work

From the Nautical Almanac take out the Greenwich hour angle and declination of Canopus, and convert the sextant altitude into true altitude.

GHA Aries (14^h)	261° 11.5′	Sextant altitude	39° 26.5′
Increment (37^m 28^s)	9 23.5	Index error	+ 2.0
GHA Aries	270° 35.0′		39° 28.5′
SHA	264 14.0	Combined star corr.	− 7.1
GHA Canopus	534° 49.0′	True altitude	39° 21.4′
Declination Canopus	52° 40.3′ S		

All the parameters are now ready for entry into the computer as follows :

GHA	Enter	534°49.0′
LONG.	Enter	100°00.0′ W
LAT.	Enter	40°04.0′ S
DEC.	Enter	52°40.3′ S
TRUE ALT.	Enter	39°21.4′

Computer procedure

(1) Switch on by simply pressing the button POWER, when the power indicator lamp will light.

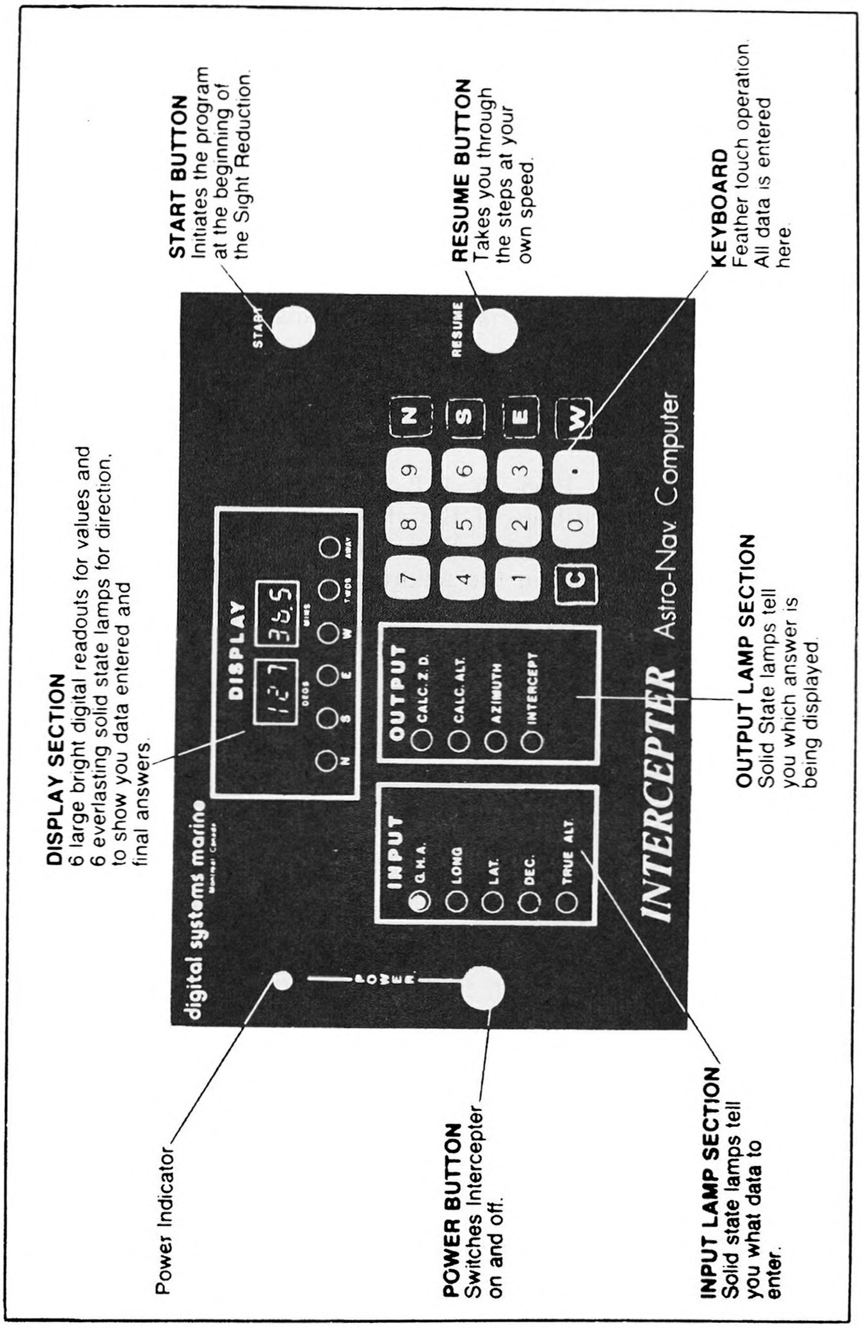

DISPLAY SECTION
6 large bright digital readouts for values and 6 everlasting solid state lamps for direction, to show you data entered and final answers.
START BUTTON
Initiates the program at the beginning of the Sight Reduction.
RESUME BUTTON
Takes you through the steps at your own speed.
KEYBOARD
Feather touch operation. All data is entered here.
OUTPUT LAMP SECTION
Solid State lamps tell you which answer is being displayed.
INPUT LAMP SECTION
Solid state lamps tell you what data to enter.
POWER BUTTON
Switches Intercepter on and off.
Power Indicator
digital systems marine
DISPLAY
DEGS
MINS
N
S
E
W
TWDS
AWAY
START
RESUME
POWER
INPUT
G.H.A.
LONG
LAT.
DEC.
TRUE ALT.
OUTPUT
CALC. Z.D.
CALC. ALT.
AZIMUTH
INTERCEPT
INTERCEPTER
Astro-Nav. Computer

FIG. 5

(2) Press the START button, which causes the computer to run through its self-check program and display the first of two check numbers 999°999′.

(3) Press the RESUME button, and the second number 000°000′ will be displayed. If either of these numbers is incorrect, the computer is faulty and the navigator should not proceed, but carry out the calculations by tabular method.
All operations on Intercepter start in this manner.

(4) Assuming the check numbers are correct, the RESUME button is pressed, when the computer will enter the navigation program and light the INPUT lamp marked G.H.A., indicating to the navigator that he should enter that quantity.

(5) Enter 534 49.0, observing the correct method as given below under Data Entry Format.

Data Entry Format

The data entered into Intercepter via the Keyboard is always an angle and must have the correct format to be accepted. Data can only be entered when one of the INPUT lamps is ON. At other times the Keyboard is disconnected.

While the angle is being entered, the display will remain blank until the last key has been pressed, when it will display the value that has been entered. If the display does not illuminate, then the navigator knows that he has done something incorrectly. If this occurs or he realises he has made an error in the middle, pressing the C (clear) key will clear all data entered. If the display illuminates, but it is seen that the value is incorrect, pressing the C key will clear everything, ready for a new entry.

The following errors prevent the display from illuminating :

— Entry of more than six digits (key bounce can cause this);
— Decimal point omitted } (GHA and True Alt. only);
— Last digit omitted }
— Direction i.e. NSEW omitted (Lat., Long. and Dec. only).

Leading zeroes do not have to be entered, but trailing zeroes do. If the tens of minutes is a zero, it must always be entered, except when there are no degrees preceding it. In this case, it becomes a leading zero.

Examples are shown below :

Lat.	56°31.0′ N	:	5631.0 N
Long.	134°7.2′ W	:	13407.2 W
True Alt.	38°0.0′	:	3800.0
GHA	8.5′	:	8.5
Lat.	0.0′	:	No action

Parameter limits : Lat., Dec., Alt. : 0° to 89°59.9′.
Long. : 180° W to 179°59.9′ E.
GHA : 0° to 719°59.8′.
Z.D : 0° to 180°.

(6) When satisfied that the value displayed is correct, press the RESUME button whereupon the lamps GHA and DISPLAY go out and the INPUT lamp LONG. comes on, requesting for this quantity to be keyed.

(7) Enter for Longitude 10000.0 W, check the DISPLAY, and if correct press the RESUME button, whereupon the computer asks for the next quantity by lighting the corresponding INPUT lamp. In this way the program should be continued for the following quantity.

(8) Enter for LAT. 4004.0 S, check the DISPLAY and press RESUME button.

(9) Enter for DEC. 5240.3 S, check the DISPLAY and press the RESUME button. The computer will calculate the Zenith Distance, DISPLAY 50°42.0′ and light the OUTPUT lamp CALC. Z.D.

(10) Press the RESUME button, whereupon the computer will calculate Altitude, DISPLAY 39°17.9′ and light the OUTPUT lamp CALC. ALT.

(11) Press the RESUME button, whereupon the computer will calculate Azimuth, DISPLAY 229°8.1′ and light the OUTPUT lamp AZIMUTH.

(12) Press the RESUME button, which causes the INPUT lamp TRUE ALT. to light, requesting to enter True Altitude.

(13) Enter for TRUE ALT. 3921.4, check the DISPLAY, and if correct press the RESUME button, whereupon the computer will calculate the Intercept, light the OUTPUT lamps INTERCEPT and TWDS (towards) and display 3.4′.

(14) After the Intercept value has been displayed, pressing the RESUME button will cause the computer to return to step 9 in the program where the Zenith Distance was displayed, and to proceed from there. Hence, the navigator can review all the quantities just displayed without having to re-enter the data except for True Altitude.

For sight reduction the only quantities normally of interest are Azimuth and Intercept, which the navigator should note for plotting the position line (see figure 6).

3. — COMPUTATION OF THE INTERCEPT AND AZIMUTH BY TABLES K_{21}

Below is given the solution of the same example solved above by the Intercepter.

The preliminary work is similar to that shown above for Intercepter except for the use of position coordinates, because these Modern Inspection Tables are conceived to use the assumed Latitude rounded to the nearest whole degree and an assumed Longitude chosen to differ from the D.R. Longitude by not more than 30′ but which, when algebraically added to GHA gives LHA in whole degrees. By such an assumed (chosen) position, interpolation of Altitude and Azimuth due to minutes of Lat. and Meridian Angle are eliminated. This procedure from an assumed position is well known to every navigator and is applied with many short method tables (WEEMS, GINGRICH, KOTLARIĆ K_1, etc.) and modern inspection tables (H.O.

214, H.O. 249, H.O. 229, etc.). The position line obtained is the same as that obtained from the D.R. position, but should be plotted from the assumed position. See figure 6, which shows the position line plotted from the D.R. position using the intercept and azimuth computed by the Intercepter, and also the plotting from the assumed position using data computed by Tables K_{21}.

Example : as for Intercepter on page 141.

Preliminary work

Using the Nautical Almanac find the Meridian Angle and declination of Canopus, choose the assumed latitude and longitude, and convert the sextant altitude to the true (observed) altitude by the auxiliary correction table in K_{21} or in the American/British Nautical Almanac.

GHA Aries (14^h)	261° 11.5′	Hs	39° 26.5′
Corr. (37^m 28^s)	9 23.5	IC +	2.0
GHA Aries	270° 35.0′		39° 28.5′
SHA	264 14.0	corr. −	7.1
GHA Canopus	534° 49.0′	Ho	39° 21.4′
LONG.	− 99 49.0 W		
MA	435° 00.0′	LAT.	40° S
	− 360	DEC.	52° 40.3′ S
MA Canopus	75° W		

Tabular procedure

(1) With LAT. and MA found in the preliminary work, open the Tables and under the heading LAT. SAME NAME AS DECLINATION (or LAT. CONTRARY NAME TO DECLINATION, in accordance with the example to be solved) enter the DEC. column using the equal or the next smaller whole or half degrees of tabulated Declination and take out : Computed Altitude HC, Altitude Correction Index ID with its sign, and Azimuth Angle Z.

Note : If after the HC and ID a decimal point is printed, that means 0.5′, and a decimal point following Z means 0.5°, because Z is measured in degrees (see Excerpt from Tables K_{21}). The extracted values are : HC 39°06.0′, ID + 17.5, Z 49.5°.

(2) To correct the extracted Altitude for the excess of minutes and tenths of Declination ignored on the first entering in the main tables, open the Tables inside the back cover pages and from the MULTIPLICATION TABLE (Table II) with ID (at the left margin) and DECLINATION (at the top) take out the altitude correction. This correction should be added to, or subtracted from, HC (depending on whether the sign of ID is positive or negative) to obtain accurate HC.

The extracted correction is + 3.0′ (see Excerpt from Table II and below that the solution of the example).

EXCERPT FROM TABLES K 21

40 FI LATITUDE	FI ISTOIMEN SA DEKLINACIJOM LAT. SAME NAME AS DECLINATION			[AZ] = N,S [Z] E,W LAT MA			FI 40 LAT.
MS / MA	DEK.	DEC.		52° 30'			MS / MA
	V/HC ID Z	V/HC ID Z	V/HC ID Z	V/HC ID Z	V/HC ID Z		
	° ' °	° ' °	° ' °	° ' °	° ' °		
0				7730 +60 00			0
:							:
[75]	....	....	....	[3906 +17. 49.]			75
:							:
90				3039.+27 45			90

TABL.II POPRAVAK RAČUNATE VISINE ZA MINUTE DEKLINACIJE
/CORRECTION TO TABULATED ALTITUDE FOR MINUTES OF DECLINATION/

ID	DEKLINACIJA / DECLINATION																		
	1′	2′	3′	4′	5′	6′		10	....	30′	.1′	.2′	.3′	.4′	.5′	.6′	.7′	.8′	.9′
1	0.0	0.1	0.1	0.1	0.1	0.1		0.2	....	0.5	.0	.0	.0	.0	.0	.0	.0	.0	.0
1.5	0.0				0.1					0.8					.0				
2	0.0				0.2					1.0					.0				
2.5	0.0				0.2					1.3					.0				
:																			
[17.5]	....	....	....	....	...	....		[2.9]	....	.....	...	...	[.1]						

	HC	ID	AZ		
	39° 06.0'	+17.5	S 49.5° W	Ho	39° 21.4'
	+ 3.0			-Hc	-39 9.0
HC	39° 9.0'			a	+ 12.4'

(3) Convert the extracted Azimuth Angle Z to Azimuth AZ in accordance with the rule shown schematically at the top of each page, i.e. by adding before Z the abbreviation N or S as Latitude, and after Z the abbreviation E or W as Meridian Angle. That means the Azimuth is measured from the elevated pole of the observer from 0° through 180° to the E when the body is rising and to the W when the body is setting. Accordingly we obtain AZ S 49.5° W.

The Azimuth obtained is correct for the values with which the Tables are entered and, for plotting the position line, generally needs no correction.

If extreme accuracy is desired, or when the change of Z for increase of 1° of Declination is large because the observed body is near the zenith, Z may be interpolated by inspection for the neglected minutes of Declination by comparing the tabulated Z for the adjoining right hand column of tabulated Declination. For this eventuality a glance at the adjoining right hand value of Z may be of use.

(4) The computed Altitude HC is subtracted from the true (observed) altitude Ho to obtain the Intercept (*a*), *plus* for Toward, or *minus* for Away. Accordingly we obtain 39°21.4′−39°09.0′=+12.4′ (Toward).

PLOTTING THE POSITION LINES

With data computed by the Intercepter ($a + 3.4'$ (Toward), AZ 229.1°) the position line is plotted from the D.R. position.

With data computed by Tables K_{21} ($a + 12.4'$, AZ S 49.5° W) the position line is plotted from the assumed position.

From figure 6 it is seen that the same position line is given by both Intercepter and Tables K_{21}. However, the procedure for computation of

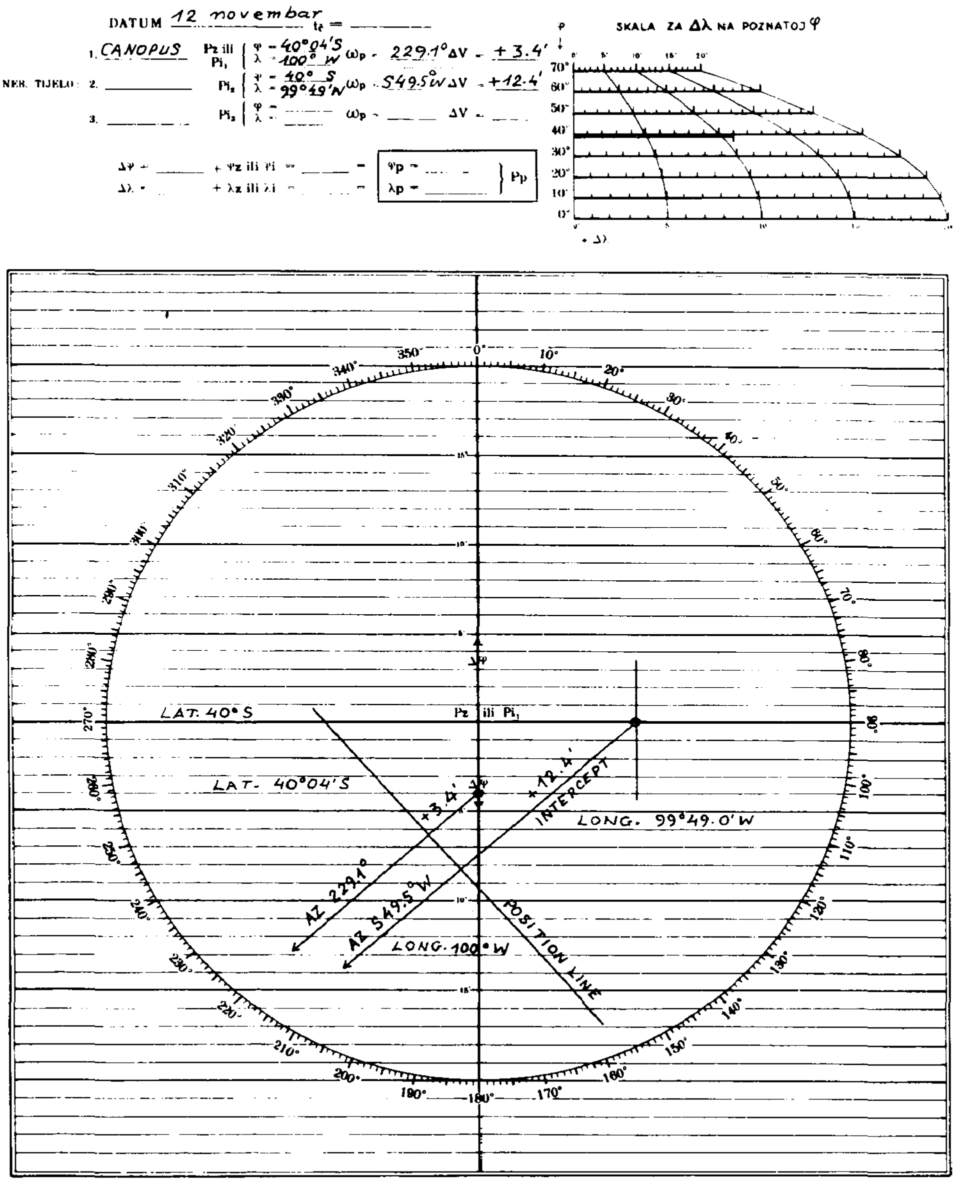


FIG. 6

the data was different. To make an assessment of these procedures it is necessary to analyze and compare them.

CHECKING OF SOLUTION

(1) The **Intercepter** using parameters D.R. Lat 40°04′ S, D.R. Long. 100°00′ W, GHA Canopus 534°49.0′ (i.e. Meridian Angle 74°49′ W) and Dec. 52°40.3′ S, computed and displayed CALC.ALT. 39°17.9′ and AZ 229.1°.

The same parameters were used for checking the computation of the altitude and azimuth, and the following results are obtained :

— *By Tables H.O. 214* : Hc 39° 18.0′, Az S 49.3° W.

— *By Kotlarić's Tables K_t* : Hc 39° 18.0′, Az S 49.4° W.

Note : The logarithmic solution of the basic formula for altitude also gave Hc 39° 18.0′. Considering that the Intercepter in step 9 displayed Zenith Distance 50° 42.0′, then the Calculated Altitude displayed in step 10 as 39°17.9′ is evidently erroneous; the computer should have given exactly the complement of the Zenith Distance, i.e. 39°18.0′.

(2) **Tables K_{21}** using the assumed Lat. 40° S, Meridian Angle 75° W, assumed Long. 99°49′ W, Declination 52°40.3′ S gave HC 39°09.0′ and AZ S 49.5° W.

For the purpose of checking, the same parameters were used for computation of altitude and azimuth, and the following results are obtained :

— *By Tables H.O. 214* : Hc 39°09.0′, Az S 49.3° W.

— *By Kotlarić's Tables K_t* : Hc 39°09.1′, Az S 49.3° W.

Note : The checking showed that the results obtained by Tables K_{21} are correct. This has been also shown in figure 6 where both solutions (Intercepter and Tables K_{21}) gave the same position line.

(3) The **Galaxy 1** was also checked for the example given in the original prospectus. Since Galaxy 1 solves some operations usually carried out with the Nautical Almanac or Nautical Tables (like correction to GHA Aries for minutes and seconds of GMT, and corrections applied to sextant altitude to obtain the true altitude) it is first necessary to find the Meridian Angle MA and the True (Observed) Altitude Ho, and with these parameters and the already known latitude and declination to compute the Intercept and Azimuth for checking the Galaxy 1 results (Intercept 11.6′ Toward, and AZ 136.3°).

GHA Aries for 2^h is 99° 47.5′, correction for 36^m30^s is 9°09.0′, so the GHA Aries for the given GMT is 108°56.5′, and after adding the SHA Markab and Longitude the MA Markab is 13°55.7′ E. Combined correction — 3.7′ added algebraically to the sextant altitude gives Ho 70°31.8′.

Using the parameters : Lat. 30° N, MA 13°55.7′ E and Dec. 15°4.1′ N, the following results were obtained :

— *By Tables H.O. 214* : Hc 70°19.8′, Az 136.4°, Intercept 12.0′ (Toward).

— *By logarithmic solution of the basic formulae* : Hc 70°19.6′, Az 136.3° and Intercept + 12.2′ (Toward).

Consequently, tabular checking shows a small difference in the Intercept of about half a nautical mile in comparison with the result obtained by Galaxy 1. I do not own this relatively expensive mini-computer to solve personally the example given in the prospectus, and up to completion of this paper I have not received from the manufacturer the explanation for the above small difference.

— *By Tables K_{21}* : For the Galaxy 1 example an assumed position is used of Lat. 30° N and Long. 137°4.3′ W, and MA 14° E. With these parameters and Dec. 15°04.1′ N, the computed results are : HC 70°17.2′, AZ N 136.5° E, and Intercept + 14.6′.

Checking these results from the same assumed position by Tables H.O. 214 gives : Hc 70°17.2′, Az N 136.3° E and Intercept 14.6′ (Toward), which shows that the results obtained by Tables K_{21} are correct; the small difference in Azimuth is negligible for the practice of navigation. Further, graphic checking by plotting the K_{21} Intercept (+ 14.6′) from the assumed position, and the H.O. 214 Intercept (+ 12.0′) from the D.R. position, gave the same position line.

THE METHODS COMPARED

From the procedures described and examples solved for these two celestial navigation computers on the one hand, and Tables K_{21} on the other hand, navigators can themselves assess which is faster, simpler and more practical for use in practice.

Against the computer technique of the Galaxy 1 and Intercepter, I have pitted my newly conceived Tables K_{21} as the outstanding representative of the shortest and simplest procedures of tabular solution for sight reduction with sufficient accuracy for marine navigation. In fact, Tables K_{21} can also be used in air navigation, where high-speed aircraft can sacrifice some accuracy in favour of rapidity and simplicity. For this purpose suitable auxiliary tables (Correction for the motion of the observer, Correction for refraction and Coriolis correction) will be inserted.

Accordingly, comparing such efficient representatives of tabular and computer technique for the solution of intercept and azimuth one can draw certain conclusions valid at least for the near future, until either the Tables or the celestial navigation computers are further improved. Every reader will have his own ideas, with his own work in mind, but I consider that for sight reduction (computation of the intercept and azimuth) these celestial navigation computers have not shown outstanding advantages over Modern Inspection Tables for the following reasons :

(1) From the analysis of the procedures for computation of Altitude (Intercept) and Azimuth by these two celestial navigation computers it can be realised that the procedure by these mini-computers is neither shorter nor simpler than the procedure by Tables K_{21}. This is evident because when the Tables are opened for the first time we immediately see the results of computed Altitude and Azimuth if the actual Declination is equal to the tabulated one. In this case from the first entering in the Tables

we obtain the results that on the Intercepter are displayed only after 11 entries, always observing the special rules for keying entering values, which for working with Tables are not necessary. Meanwhile, if the actual Declination *differs* from the tabulated one, then with the Altitude Correction Index ID tabulated with its sign and the excess of minutes and tenths of Declination we enter the Multiplication table at the back cover and take out the exact value of altitude correction without any mental interpolation; this single correction added (according to the sign of ID) to the altitude extracted from the first opening of the book gives the correct value of Hc. Then Hc subtracted from Ho gives the Intercept with its sign, and with this the task is solved.

(2) The Galaxy 1 solves the Intercept and Azimuth from an assumed position but can also work from the D.R. position. The Intercepter solved the sight reduction from the D.R. position, and Tables K_{21} from the assumed position. However, from figure 6 it is seen that the position line computed and plotted from the assumed position is the same as that computed from the D.R. position; consequently, in practice the facility of the Galaxy 1 and Intercepter to work from the D.R. position is not of great importance.

(3) The lighting up of indicators (lamps) in these computers, to indicate either the next parameter to be entered or which result is being displayed, also does not represent a significant benefit over the Tables because the scheme for work with Tables K_{21} is shorter (the first entering gives HC and AZ, and the second the altitude correction for minutes of declination), so that a scheme showing the next step in the Tables is not necessary. Nevertheless, there will be a work-form booklet printed to accompany Tables K_{21}, whereon the extracted values from the Nautical Almanac and the Tables are recorded; such a printed work-form not only shows the *next* step, but also allows a review of all that has been done.

(4) The notice printed in the prospectuses of these mini-computers, showing that the sight reduction is solved ready for plotting in two minutes or less, is attractive; but using the K_{21} the computation of altitude and azimuth can also be solved in less than two minutes, and to substract Hc from Ho is certainly not a long or complicated operation.

(5) The second commendation "An accurate instrument with a full one year warranty" also printed in the prospectuses of these mini-computers has, in comparison with Tables K_{21}, the contrary effect. Such a commendation means that the instrument may have a need for repair by a highly qualified expert, usually authorised by the producer, which further means not only increasing expenses after the purchase and warranty period, but also inconvenience to the navigator because a possible defect would interrupt work with the instrument he has got used to, and compel him to start with a tabular method for which he had already lost the habit, which risks the possibility of errors.

(6) It should be also kept in mind that all navigators in the world are already familiar with tabular work in general, and that navigators are often conservative, which means they do not accept new methods (manuals or accessories) unless these have important and obvious advantages, which I think have not been demonstrated by these two celestial navigation computers.

To illustrate this, my paper "Two-star fix without use of altitude difference method" [4] gives an extract from Tables K_{11} for Lat. 12° N, LHA Aries 200°-220° and the pair of stars Antares - Vega. All the results determining the observer's position within the given interval of LHA Aries (i.e. the contents of one half page of Tables K_{11}) were printed by computer IBM 1130 on the basis of this single command written in ciphers :

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This was possible because the IBM 1130, with its punched card reader and printer, has the process of work really fully programmed. When future mini-computers can work under these conditions — i.e. keying the known parameters and pressing the button to give not just Intercept and Azimuth (because these results can be solved in a fast, simple and very cheap way by the familiar tabular methods, e.g. Tables K_{21}), but from two observations to give the coordinates (Lat. and Long.) of the observed position (as is now possible for the two selected stars by my Tables K_{11}) *without* plotting position lines and without a special procedure for determining the coordinates of their intersection — *then* such celestial navigation computers would convince even conservative navigators. Such a programmed mini-computer would be more practical than Modern Inspection Tables like K_{21}, and faster and more complete than Tables K_{11} for *direct* solution of the fix.

(7) Once celestial navigation computers have reached such capabilities and realised the goals set forth above in item 6, still the following facts should be noted :

— The Tables represent a cheap manual, personal to the navigator, suitable to be carried with him from ship to ship, and with which he becomes familiar; this contributes to greater reliability and eliminates personal errors.

— The Tables are much cheaper; the price is incomparably lower than that of a celestial navigation computer — the money necessary to equip one ship with such a mini-computer would provide a fleet of 130 ships with three volumes of Tables K_{21} each !

— Tables need no repairs. A defect on the computer can be expected sometime, and the producer gives only a one-year warranty. For this eventuality the navigator must have in reserve some sight reduction tables, and in order to avoid difficulties with computation it is advisable for the tables to be easy for use.

Therefore the ship should be also provided with Modern Inspection Tables for sight reduction, even if equipped with a celestial navigation computer.

(8) The prospectuses of the celestial navigation computers claim that they can be used for solution of star identification and great circle sailing calculations. It should be pointed out that the identification of stars, and the compilation of an advance list of stars for observation at a given time, can be more easily and more completely done by my New Star Finder [9], because with one opening of the manual and by placing the template of the visible hemisphere with the zenith at the given latitude, it reveals not only the name of the unknown observed star but also gives the presentation of the whole visible celestial sky, with dotted lines for connec-

ting constellations and solid lines indicating alignments, for easier orientation in the sky. Star identification can be also solved by Tables K_{21}, but the New Star Finder is much better. Regarding great circle sailing calculations, in the practice of navigation they are not often required, but they can also be solved by Tables, as already shown in H.O.214 and my Tables K_1, and this will also be explained in K_{21}. However, Pilot Charts, well known to the mariner, give great circle sailing routes for all oceans for different types of ship, seasons and meteorological conditions, and this reduces the need for this calculation. It should be noted that the symbols and abbreviations on the keys of these computers are specially arranged and marked for sight reduction, therefore when the other calculations are performed a special written scheme has to be applied to change the meaning of these markings.

CONCLUSION

It is considered there is little to be gained for a navigator by the investment in a Galaxy 1 or Intercepter when excellent Tables are available at a fraction of the cost. However, as I said in a previous paper [5], let us leave navigators the major responsibility of deciding which of the accessories available — tables or electronic gadgets — they will use for their onboard calculations.

Finally I would like to mention that foreign agencies interested in publishing Tables K_{21} may contact the author.

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