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TECHNICAL MEMORANDUM (NASA) 59

COMPUTING LORAN TIME DIFFERENCES WITH AN HP-25 HAND CALCULATOR

Accurate LORAN-C time differences can be calculated from known transmitter and receiver positions using the program described.

by

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I. INTRODUCTION

This technical memorandum presents a program for an HP-25 or HP-25C hand calculator that will calculate accurate LORAN-C time differences. The program is most useful when checking the accuracy of a LORAN-C receiver at a known latitude and longitude without the aid of an expensive computer. It can thus be used to compute time differences for known landmarks or waypoints to predict in advance the approximate readings during a navigation mission.

The Fischer spheroid is the earth model used in the program. This is the same system the U.S. Coast Guard and the U.S. Defense Mapping Agency [1] use to calculate transmitter baseline lengths and LORAN-C navigation charts and tables.

It is assumed that the program operator is familiar with the general operation and programming capabilities of the HP-25 calculator [2]

II. PROGRAM DESCRIPTION AND ACCURACY

The forty-three step program has a running time of approximately ten seconds and is relatively simple to operate. It operates in the decimal degree mode. Latitudes and longitudes must be stored as decimal degrees (dec.deg.). For each receiver position the program is run once to solve for T_m, Figure 1, and again to solve for T_{s1}. Formula I, Figure 1, will solve for T_1, the time delay for the first master-slave pair. Run the program again to solve for slave T_{s2} and again use formula I to solve for T_2, the time delay for the second master-slave pair, etc... Storage register seven (7) is left open to hold whatever number or time delay is desired.

The indicated formulas in Figure 1 are omitted in this program due to a lack of program memory. However, this has only a minor effect on accuracy. The comparison with the computer values, Table 1, shows that the hand calculator is usually within ± 5 µs. Although the program has not been tested over a large geographic area, it has always been within ± 10 µs of computer results compared so far.

III. COMPUTING TIME DIFFERENCES

By following the HP-25 program forms, Appendix A, time differences can be easily calculated. An example problem is shown on page 3 using Athens, Ohio coordinates in the supporting data, Table 1, and also using the U.S. East Coast Chain with the rate of 9930(SS7). The instruction steps in the example correspond to the instruction steps in Appendix A. Data for other LORAN chains is found in Appendix B [3].

IV. FUTURE PROGRAM CONSIDERATIONS

Similar programs for other makes of hand calculators, such as the TI-58, would be useful. Card reading calculators should hold the entire sequence of formulas, including those left out of this program. Card reading calculators should also be able to change time differences to latitude and longitude coordinates by using one of the methods described in Navigation[4]. It is possible that the HP-25 can perform one of these simple methods, but the accuracy and utility has yet to be determined.

V. SUMMARY

Although card reading calculators should give best results, the HP-25 LORAN Time Difference Program has proven itself to be reliable over the coordinates that it has been tested. Changing time differences into position on a low-cost hand calculator is a future area of pursuit.

VI. ACKNOWLEDGEMENTS

This effort was suggested by R. W. Burhans as part of the research on developing LORAN-C navigation methods for general aviation, supported by NASA LRC Grant NGR 36-009-017. Assistance in geodetic formulation, problem solving information, and programming suggestions were given by Joseph Fischer and James Nickum.

VII. REFERENCES

[1] "Method for Computing LORAN Hyperbolic Lattice", (Informal Report February 9, 1977), U.S. Defense Mapping Agency, Hydrographic Center, Washington, D.C.

[2] HP-25 Applications Program, Hewlett-Packard Company, 1975.

[3] "LORAN Chain Data", WGC Radionavigation Journal 1976, page 48-52, Wild Goose Association, Inc., 4 Townsend Road, Acton, MA 01720.

[4] Friedland B. and Hutton, M.F., "New Algorithms for Converting LORAN Time Differences to Position, Navigation, J. Inst. of Nav., Vol. 20, No. 2, Summer 1973.

HP-25 Program Form

Title Example Problem Page 1 of 1

Programmer Find LORAN Time Differences for Athens at rate 9930(SS7).

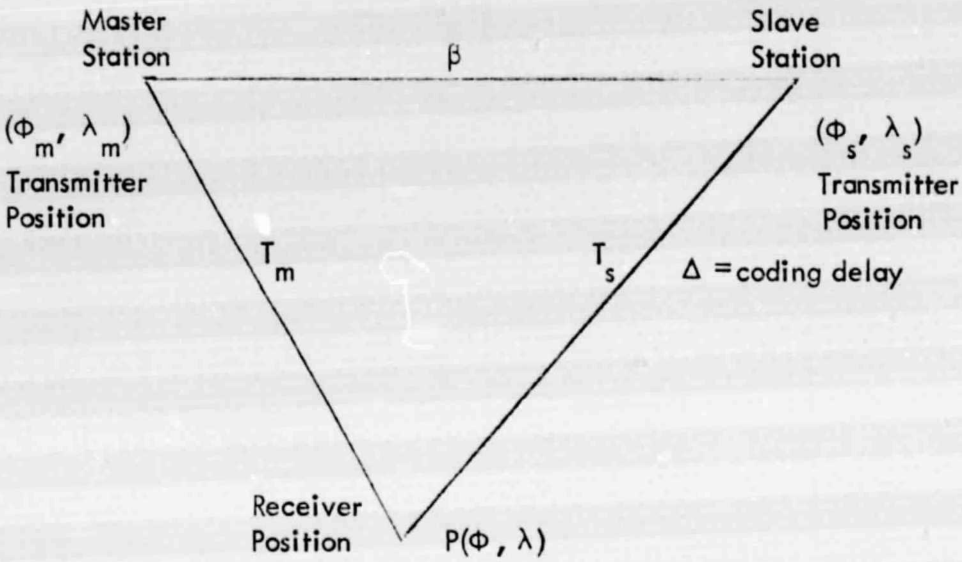
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS				OUTPUT DATA/UNITS
1	Key in program						
2	A	21282.339	STO	5			
	C	0.99664767	STO	6			
3	Latitude, ϕ_R	39.1930	g	→H	STO	3	39.3250
	Longitude, λ_R	82.0615	g	→H	STO	4	82.1042
4	Latitude, ϕ_T	34.034604	g	→H	STO	1	34.0628
	Longitude, λ_T	77.544676	g	→H	STO	2	77.9130
5	Compute T_m		f	PRGM	R/S		2317.8
6	Store T_m	2317.8	STO	0			
7	Latitude, ϕ_T	27.015849	g	→H	STO	1	27.0329
	Longitude, λ_T	80.065352	g	→H	STO	2	80.0931
8	Return to top of memory		f	PRGM			
9	Compute T_s		R/S				4602.0
10	Compute T_s - T_m	4602.0	R/S				2283.4
11	Compute T	11000	+				13283.4
		2695.57	+				15979.0
12	Compute another						
	secondary, go to step 7						
7	Latitude, ϕ_T	46.463218	g	→H	STO	1	46.7756
	Longitude, λ_T	53.102816	g	→H	STO	2	53.1745
8	Return to top of memory		f	PRGM			
9	Compute T_s		R/S				8281.3
10	Compute T_s - T_m	8281.3	R/S				5963.5
11	Compute T	28000	+				33963.5
		8389.55	+				42353.1
12	Compute another:						
	secondary, go to step 7;						
	chain, go to step 4;						
	receiver position, go						
	to step 3; etc...						

The LORAN reading or time difference (T) is defined by the formula below and portrayed by Figure 1.

* Indicated formulas are omitted.
(Minor geodetic corrections)

$A = 21282.33935$ μsec. (Equatorial radius)
$B = 21210.99393$ μsec. (Polar radius)
$C = B/A = 0.99664767$

Formula (I) $T = \beta + \Delta + T_s - T_m$



$\beta_T = \tan^{-1} [C \tan(\Phi_T)]$

$\beta_R = \tan^{-1} [C \tan \Phi_R]$

$X = \cos^{-1} [\sin(\beta_R)\sin(\beta_T) + \cos(\beta_R)\cos(\beta_T)\cos(\lambda_R - \lambda_T)]$

* $P_o = (A-B)[X - \sin(X)]/(4.0)[1.0 + \cos(X)]$

* $A_o = [\sin(\beta_R) + \sin(\beta_T)]^2$

* $Q = (A-B)[X + \sin(X)]/(4.0)[1.0 - \cos(X)]$

* $B_o = [\sin(\beta_R) - \sin(\beta_T)]^2$

$d = AX - A_o P - B_o Q \cong AX$

$d = T_m$ if $(\Phi_T, \lambda_T) = (\Phi_m, \lambda_m)$, Master

$D = T_s$ if $(\Phi_T, \lambda_T) = (\Phi_s, \lambda_s)$, Slave

$T = \beta + \Delta + T_s - T_m$

Figure 1. Method for Computing LORAN Hyperbolic Lattice.

Place Latitude Longitude	Rate	M-W	M-X	M-Y	M-Z
Athens, OH. 39° 19' 30"	9930	15971.836 15979.0	42354.859 42353.1	53738.113 53734.8	67801.313 67797.9
82° 06' 15"	9960	16591.750 16593.2	28539.574 28538.3	42594.543 42596.5	56775.641 56774.1
Lamar, PA. 41° 07' 00"	9930	16355.363 16362.0	40578.895 40574.4	52022.266 52016.7	68816.563 68811.3
77° 28' 00"	9960	16488.363 16489.6	28448.500 28447.4	44219.320 44223.8	59415.660 59414.8
Corning, N.Y. 42° 10' 00"	9930	16361.043 16367.4	39928.367 39923.0	51536.559 51530.4	68586.563 68580.9
77° 06' 00"	9960	16559.109 16560.5	28759.621 28759.4	45016.137 45022.0	59982.484 59982.6
Logan, OH. 39° 31' 30"	9930	15952.5 15958.2	42286.7 42281.2	53690.5 53686.4	67605.6 67602.6
82° 22' 55"	9960	16594.6 16594.4	28585.9 28583.3	42688.4 42690.5	56673.8 56671.9

Note: The computer results are obtained by using the complete algorithm of Figure 1.

Table 1. Supporting Data. HP-25 program results are listed below each computer result.

VIII. APPENDICES

A. Program and Instructions

HP-25 Program Form

Title LORAN TIME DIFFERENCE Page 1 of 2

Switch to PRGM mode, press [f] [PRGM], then key in the program.

LINE	CODE	KEY ENTRY	X	Y	Z	T	COMMENTS
00							
01	2406	RCL 6	C				
02	2401	RCL 1	Φ_T	C			Computing β_T
03	1406	f tan	tanΦ_T	C			
04	61	X	C tanΦ_T				
05	1506	g tan^{-1}	β_T				
06	2406	RCL 6	C	β_T			
07	2403	RCL 3	Φ_R	C			Computing β_R
08	1406	f tan	tan Φ_R	C			
09	61	X	CtanΦ_R	β_T			
10	1506	g tan^{-1}	β_R	β_T			Computing X
11	1405	f cos	COSβ_R	β_T			in degrees
12	21	X ⪌ Y	β_T	COSβ_R			
13	1473	Last X	β_R	β_T	COSβ_R		
14	1404	f sin	Sinβ_R	β_T	COSβ_R		
15	21	X ⪌ Y	β_T	Sinβ_R	COSβ_R		Manipulating the
16	1404	f sin	sinβ_T	Sinβ_R	COSβ_R		stack maintains
17	1473	Last X	β_T	Sinβ_T	Sinβ_R	COSβ_R	an open register (T)
18	1405	f cos	COSβ_T	Sinβ_T	Sinβ_R	COSβ_R	
19	22	R ↓	Sinβ_T	Sinβ_R	COSβ_R	COSβ_T	
20	61	X	S	COSβ_R	COSβ_T	COSβ_T	$S = \sin\beta_T \sin\beta_R$
21	22	R ↓	COSβ_R	COSβ_T	COSβ_T	S	
22	61	X	COSβ_RCOSβ_T	COSβ_T	S	S	
23	21	X ⪌ Y	COSβ_T	COSβ_RCOSβ_T	S	S	
24	22	R ↓	COSβ_RCOSβ_T	S	S	COSβ_T	
25	2404	RCL 4	λ_R	COSβ_RCOSβ_T	S	S	
26	2402	RCL 2	λ_T	λ_R	COSβ_RCOSβ_T	S	
27	41	−	$\lambda_R - \lambda_T$	COSβ_RCOSβ_T	S	S	
28	1405	f cos	$\cos(\lambda_R - \lambda_T)$	COSβ_RCOSβ_T	S	S	
29	61	X	R	S	S	S	$R = \cos\beta_R \cos\beta_T \cos(\lambda_R - \lambda_T)$
30	51	+	R + S	S	S	S	
31	1505	g cos^{-1}	X	S	S	S	
32	01	1	1	X	S	S	Change X from
33	08	8	18	X	S	S	degrees to radians
34	00	0	180	X	S	S	
35	1573	g π	π	180	S	S	
36	71	÷	180/π	X	S	S	
37	71	÷	X (rad)	S	S	S	
38	2405	RCL 5	A	X (rad)	S	S	
39	61	X	d	S	S	S	If Master, STO 0
40	74	R/S	d	S	S	S	If Slave, R/S
41	2400	RCL 0	Tm	Ts			
42	41	−	Ts − Tm				
43	1300	GTO 00	Ts − Tm				Add β + Δ to
44							find T
45							
46							
47							
48							
49							

REGISTERS
R_0
R_1 Φ_T (dec. deg.)
R_2 λ_T (dec. deg)
R_3 Φ_R (dec. deg)
R_4 λ_R (dec. deg)
R_5 21282.33435
R_6 0.99664767
R_7

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HP-25 Program Form

Title LORAN Time Difference Page 2 of 2

Programmer

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS				OUTPUT DATA/UNITS
1	Key in program						
2	Store constants						
	A	21282	STO	5			
	C	0.99665	STO	6			
3	Store the receiver coordinates						
	Latitude, Φ_R	Φ_R, D.MS	g	→H	STO	3	Φ_R, dec.deg
	Longitude, λ_R	λ_R, D.MS	g	→H	STO	4	λ_R, dec.deg
4	Store the primary transmitter coordinates						
	Latitude, Φ_T	Φ_T, D.MS	g	→H	STO	1	Φ_T, dec.deg
	Longitude, λ_T	λ_T, D.MS	g	→H	STO	2	λ_T, dec.deg
5	Compute T_m		f	PRGM	R/S		
6	Store T_m		STO	0			
7	Store the secondary transmitter coordinates						
	Latitude, Φ_T	Φ_T, D.MS	g	→H	STO	1	Φ_T, dec.deg
	Longitude, λ_T	λ_T, D.MS	g	→H	STO	2	λ_T, dec.deg
8	Return to top of memory		f	PRGM			
9	Compute T_s		R/S				T_s, μsec
10	Compute $T_s - T_m$		R/S				$T_s - T_m$, μsec
11	Compute T by	Δ	+				$\beta + T_s - T_m$ μsec
	adding the coding	β	+				T, μsec
	delay (Δ) Baseline						
	length β for the secondary						
12	To compute T for another:						
	secondary, go to step 7;						
	chain, go to step 4;						
	receiver position, to						
	to step 3; etc...						

B. LORAN Chain Data.

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U.S. East Coast Chain - Rate 9930 (SS7)

Station	Coordinates Latitude & Longitude	Station Function	Coding Delay & Baseline Length	Radiated Peak Power
Carolina Beach, NC	34-03-46.04N 77-54-46.76W	Master	---	700 kW
Jupiter, Florida	27-01-58.49N 80-06-53.52W	W Secondary	11.000μs 2695.57μs	300 kW
Cape Race, Newfoundland	46-46-32.18N 53-10-28.16W	X Secondary	28,000μs 8389.55μs	1.8MW
Nantucket, Massachusetts	41-15-11.93N 69-58-39.09W	Y Secondary	49,000μs 3541.27μs	300 kW
Dana, Indiana	39-51-07.54N 87-29-12.14W	Z Secondary	65,000μs 3560.68μs	400 kW

For Jupiter, Florida
Coding delay $\Delta = 11000\ \mu s$
Baseline $\beta = 2695.57\ \mu s$

Northeast U.S.A. Chain (reconfigured 7/78) - Rate 9960 (SS4)

Station	Approximate Latitude & Longitude	Station Function	Coding Delay & Baseline Length	Radiated Peak Power
Seneca, New York	42-42-50.60 76-49-33.86	Master	---	1.0 MW
Caribou, Maine	46-48-27.20N 67-55-37.71W	W Secondary	11,000μs 2797.20	350 KW
Nantucket, Massachusetts	41-15-11.93N 69-58-39.09W	X Secondary	25,000μs 1969.93	300 KW
Carolina Beach, N. Carolina	34-03-46.04N 77-54-46.76W	Y Secondary	39,000μs 3221.65	700 KW
Dana, Indiana	39-51-07.54N 87-29-12.14W	Z Secondary	54000 3162.06	400 KW