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NPS55-82-022

**NAVAL POSTGRADUATE SCHOOL**  
**Monterey, California**



POSITION DETERMINATION WITH  
LORAN-C TRIPLETS AND THE HEWLETT-PACKARD  
HP-41CV PROGRAMMABLE CALCULATOR

by

Rex H. Shudde

September 1982

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Prepared for:  
Chief of Naval Research  
Arlington, VA 22217

NAVAL POSTGRADUATE SCHOOL  
MONTEREY, CALIFORNIA


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The work reported herein was supported by the Office of Naval Research, Fleet Activity Support Division, Code 230.

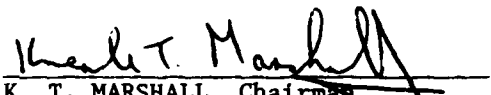
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### CORRECTION

The coding delay for 7970W, given on page 61 of NPS55-82-022 should be 26000 microseconds.

### ADDENDA

1. On 9 June 1982, the Defense Mapping Agency issued upgraded WGS-72 coordinates for the Loran-C stations. This update includes positions measured to the nearest 0.001", the \*7930 Northwest Pacific Reconfiguration and the addition of the 5970 Commando Lion Chain. The upgraded coordinates are listed on the following page.
2. The HP-41CV program may be modified to display the station coordinates to the nearest 0.001" by changing line 953 to FIX7.

### STATION COVERAGE

<u>Station</u>	<u>No. of Pairs</u>	<u>Location</u>
4990	2	Central Pacific
5930	2	Canadian East Coast
5970	3	Commando Lion
5990	3	Canadian West Coast
7930	3	North Atlantic
*7930	3	Northwest Pacific, Reconfigured
7960	2	Gulf of Alaska
7970	4	Norwegian Sea
7980	4	Southeast U.S.A.
7990	3	Mediterranean Sea
8970	3	Great Lakes
9940	3	West coast, U.S.A.
9960	4	Northeast U.S.A.
9970	4	Northwest Pacific
9990	3	North Pacific

22 November 1982

LORAN-C STATIONS

<u>ID</u>	<u>CD</u>	<u>MS LAT</u>	<u>MS LON</u>	<u>SS LAT</u>	<u>SS LON</u>
4990X	11000	16.4443950	169.3031200	20.1449160	155.5309700
4990Y	29000	16.4443950	169.3031200	28.2341770	178.1730200
5930X	11000	46.4827199	067.5537713	41.1511930	069.5839090
5930Y	25000	46.4827199	067.5537713	46.4632180	053.1028160
5970W	11000	36.1105797	-129.2027279	42.4437104	-143.4309245
5970X	31000	36.1105797	-129.2027279	35.0223871	-126.3226741
5970Z	42000	36.1105797	-129.2027279	26.3624975	-128.0856445
5990X	11000	51.5758780	122.2202240	55.2620851	131.1519648
5990Y	27000	51.5758780	122.2202240	47.0347990	119.4439530
5990Z	41000	51.5758780	122.2202240	50.3629731	127.2129043
7930W	11000	59.5917270	045.1027470	64.5426580	023.5521750
7930X	21000	59.5917270	045.1027470	62.1759640	007.0426538
7930Z	43000	59.5917270	045.1027470	46.4632180	053.1028160
*7930X	11000	24.1707888	-153.5853232	42.4437104	-143.4309245
*7930Y	30000	24.1707888	-153.5853232	26.3624975	-128.0856445
*7930Z	49000	24.1707888	-153.5853232	09.3245789	-138.0954970
7960X	11000	63.1942814	142.4831900	57.2620210	152.2211225
7960Y	26000	63.1942814	142.4831900	55.2620851	131.1519648
7970W	26000	62.1759640	+007.0426538	54.4829872	-008.1736312
7970X	11000	62.1759640	+007.0426538	68.3806150	-014.2747000
7970Y	46000	62.1759640	+007.0426538	64.5426580	+023.5521750
7970Z	60000	62.1759640	+007.0426538	70.5452610	+008.4358690
7980W	11000	30.5938740	085.1009305	30.4333018	090.4943600
7980X	23000	30.5938740	085.1009305	26.3155006	097.5000093
7980Y	43000	30.5938740	085.1009305	27.0158393	080.0653429
7980Z	59000	30.5938740	085.1009305	34.0346081	077.5446654
7990X	11000	38.5220587	-016.4306159	35.3120787	-012.3130245
7990Y	29000	38.5220587	-016.4306159	40.5820950	-027.5201520
7990Z	47000	38.5220587	-016.4306159	42.0336515	-003.1215512
8970W	11000	39.5107540	087.2912140	30.5938740	085.1009305
8970X	28000	39.5107540	087.2912140	42.4250603	076.4933862
8970Y	44000	39.5107540	087.2912140	48.3649844	094.3318469
9940W	11000	39.3306621	118.4956370	47.0347990	119.4439530
9940X	27000	39.3306621	118.4956370	38.4656990	122.2944529
9940Y	40000	39.3306621	118.4956370	35.1918180	114.4817435
9960W	11000	42.4250603	076.4933862	46.4827199	067.5537713
9960X	25000	42.4250603	076.4933862	41.1511930	069.5839090
9960Y	39000	42.4250603	076.4933862	34.0346081	077.5446654
9960Z	54000	42.4250603	076.4933862	39.5107540	087.2912140
9970W	11000	24.4803597	-141.1930303	24.1707888	-153.5853232
9970X	30000	24.4803597	-141.1930303	42.4437104	-143.4309245
9970Y	55000	24.4803597	-141.1930303	26.3624975	-128.0856445
9970Z	75000	24.4803597	-141.1930303	09.3245789	-138.0954970
9990X	11000	57.0912265	+170.1506789	52.4944040	-173.1048974
9990Y	29000	57.0912265	+170.1506789	65.1440306	+166.5312550
9990Z	43000	57.0912265	+170.1506789	57.2620210	+152.2211225

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NPS55-82-022	2. GOVT ACCESSION NO. <b>AD-A222 499</b>	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) POSITION DETERMINATION WITH LORAN-C TRIPLETS AND THE HEWLETT-PACKARD HP-41CV PROGRAMMABLE CALCULATOR		5. TYPE OF REPORT & PERIOD COVERED Technical
7. AUTHOR(s) Rex H. Shudde		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, CA 93940		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS Chief of Naval Research Arlington, VA 22217		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 65155N;R0131 N0001482WR20070
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE September 1982
		13. NUMBER OF PAGES 71
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
Loran	Hyperbolic Fixing	Programmable Calculator
Loran-C	Radio Positioning	HP-41C
Navigation	Geodetics	HP-41CV
Position Determination	Geodetic Distances	
Fixing	Calculator	
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
This report presents an algorithm and HP-41CV programs for position determination with Loran-C chains. Additional computational routines include the ability to calibrate Loran station triplet data to a known benchmark and ITD's (Indicated Time Delay's), predict ITD's at given positions, compute the geodesic (similar to great circle) bearing and distance from a fix to the destination and to compute the geodesic bearing and distance from any one location to another. Utility routines allow the user to transfer station pair data between the HP-41CV and magnetic cards, magnetic tape and an extended		

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SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

function/memory module.

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by

R. H. Shudde

Naval Postgraduate School  
Monterey, California

September 1982

The programs in this report  
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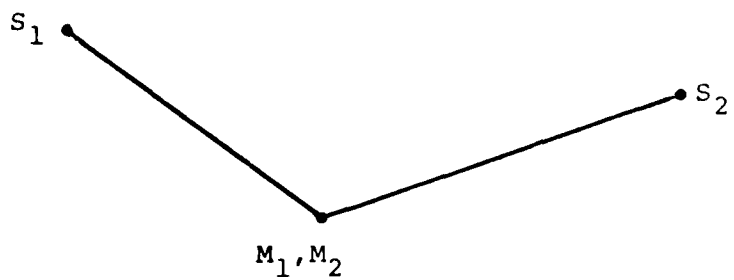
## ABSTRACT

This report presents an algorithm and HP-41CV programs for position determination with Loran-C chains. Additional computational routines include the ability to calibrate Loran station triplet data to a known benchmark and ITD's (Indicated Time Delay's), predict ITD's at given positions, compute the geodesic (similar to great circle) bearing and distance from a fix to the destination and to compute the geodesic bearing and distance from any one location to another. Utility routines allow the user to transfer station pair data between the HP-41CV and magnetic cards, magnetic tape and an extended function/ memory module.

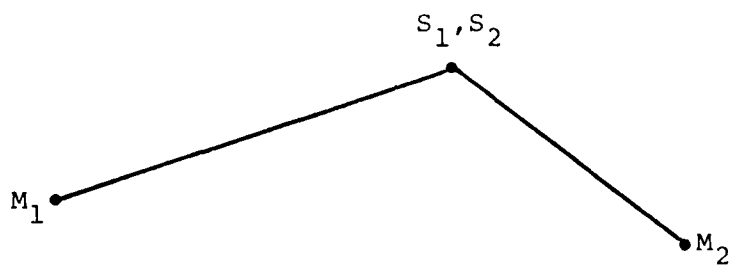
## A. Introduction

The Loran system is a radio aid to navigation which utilizes the principle of hyperbolic fixing. The locus of points for which the difference in arrival time of synchronized signals from a pair of transmitters is constant determines a hyperbolic line of positions. The intersection of two hyperbolic lines of position from two pairs of stations determines position or a hyperbolic fix. That two pairs of stations are required for a fix does not necessarily mean that there are four separate stations, for one station of one pair may be colocated with one station of the other pair forming a Loran triplet (Figure 1). Triplets may be joined "end-to-end" by station colocation to form a Loran chain (Figure 2). Loran chains are common on both the East and West coasts of the North American continent.

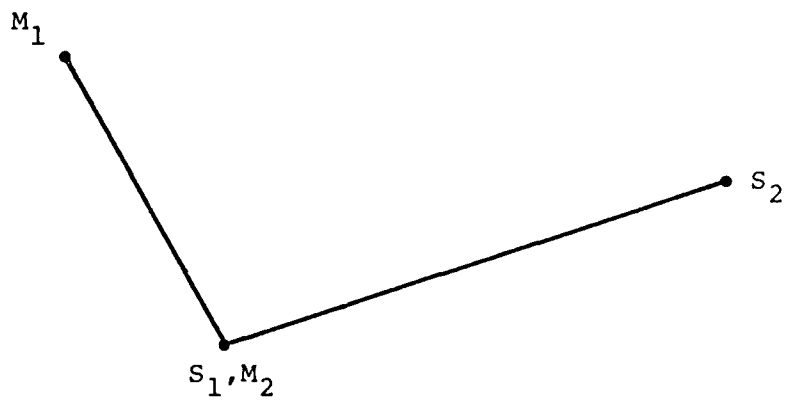
The present day Loran-C operates at 100-kHz and is in use in the Atlantic, Pacific and Mediterranean areas. The computational algorithm and programs described herein can be used for position determination with Loran-C triplets. Further information on the history, development and operation of the Loran systems may be found in References 1 and 2.



(a) Colocated Master Stations



(b) Colocated Slave Stations



(c) Colocated Master and Slave

Figure 1. Loran Triplets.

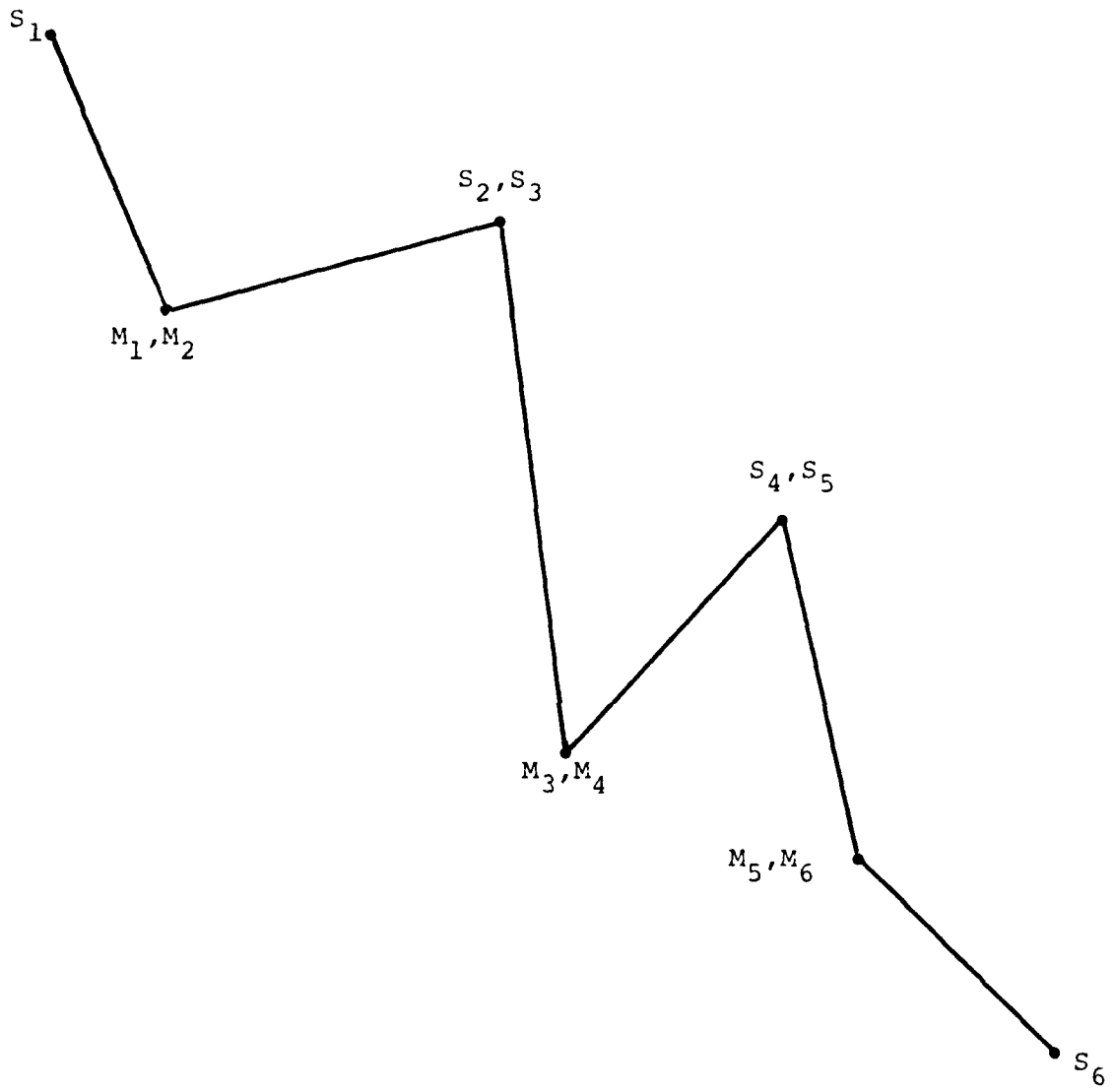


Figure 2. Loran Chain of Five Loran Triplets.

## B. User Routines

### 1. Computational Routines:

FI - The FIxing routine is the main program for calculating a Loran-C fix from indicated time delays.

AS - The Alternate Solution routine will allow the second Loran fix solution to be computed. This routine toggles Flag 3 so that on subsequent fixes the FI routine will calculate the alternate solution.

DN - The DestiNation routine stores the latitude and longitude of a fixed destination.

HD - Computes the Heading and Distance from the current fix to the destination stored by the DN routine.

### 2. Manual Mode Routines:

MI - Manual Input allows station data to be input and stored via the calculator keyboard.

ED - Echo Data is a utility routine for validating station triplet information stored in the calculator.

### 3. Card Reader Routines:

CS - Card Store records station data onto magnetic cards.

CR - Card Read inputs station data from magnetic cards.

CE - Card Echo is a utility routine for validating station information stored on data cards.

### 4. Extended Memory Routines:

XS - XMEM Store records station data onto the extended memory module.

XR - XMEM Recall inputs station data from the extended memory module.

**XD** - **XMEM Delete** erases station data from the extended memory module.

5. Tape Cassette Routines:

**TS** - **Tape Store** records station data onto the tape cassette.

**TR** - **Tape Recall** inputs station data from the tape cassette.

**TD** - **Tape Delete** erases station data from the tape cassette.

6. Utility Routines:

**DH** - This routine is similiar to the HD option except that it computes the heading and distance from any origin to any destination.

**PR** - PR is used to **PR**edict the station ITD's that will be received at a given latitude and longitude.

**CA** - CA is the **CA**libration option. Given the latitude and longitude of a **known** position and the indicated time delays from a Loran-C triplet, the stored station data are modified so that the FI routine (or AS) will compute the known position from the same time delays.

**SW** - **SW**itch data swaps the data of the two Loran stations stored in memory.

**Note:** There are no specific routines that relate to HP-41CV printer operations. However, all input and output will be recorded on a printer if one is attached.





D. User Instructions with Examples

1. Manual Input Routine - MI

This routine can be used to enter station data (Appendix C) to prepare data to be transferred to cards, extended memory, or tape cassette. It can also be used to enter station data manually if alternate data storage media are not available.

Example using 9940W and 9940Y. (Note: The notation <9>, for example, means that you must press the gold shift key and then the 9 key.)

<u>See</u>	<u>Key in</u>	<u>Press</u>
1.	XEQ"MI"	
2. ID?	<9><9><4><0>W	R/S
3. CODE DELAY?	11000	R/S
4. MS LAT?	39.330662	R/S
5. MS LON?	118.495637	R/S
6. SS LAT?	47.034799	R/S
7. SS LON?	119.443953	R/S

If desired, these station parameters can now be transferred to card, extended memory or tape using the CS, XS, or TS routines, respectively. Otherwise, repeat the steps above with the 9940Y station data. These two stations will be used in the remaining examples.

<u>See</u>	<u>Key in</u>	<u>Press</u>
1.	XEQ"MI"	
2. ID?	<9><9><4><0>Y	R/S
3. CODE DELAY?	40000	R/S
4. MS LAT?	39.330662	R/S

5. MS LON?	118.495637	R/S
6. SS LAT?	35.191818	R/S
7. SS LON?	114.481743	R/S
8. NEXT OPTION?		

At this point the station data for 9940W and 9940Y are stored in the calculator. The 9940Y data can be transferred to card, extended memory or tape cassette using the CS, XS or TS routines, respectively.

[Advanced User Note: The first action taken in the MI routine is to XEQ"SW". SW is the data swap routine which exchanges to content of R16 - R25 with R26 - R35. The incoming data are then stored in the R16 - R25 registers. The CS, XS and TS routines transfer the content of R16 - R25 to card, extended memory or tape cassette, respectively. If desired, the content of these registers can be swapped once more by using the SW utility routine.]

## 2. Echo Data Routine - ED

This routine allows the user to review the station data resident in the calculator.

Example: Load the station pairs 9940W and 9940Y using either the MI, CR, XR or TR routines.

<u>See</u>	<u>Key in</u>	<u>Press</u>
1.	XEQ"ED"	
2. ID: 9940W		R/S
3. CD: 11000		R/S
4. MLT: 39.330662		R/S
5. MLN: 118.495637		R/S
6. SLT: 47.034799		R/S
7. SLN: 119.443953		R/S
8. BL: 2796.903		R/S
9. ID: 9940Y		R/S
10. CD: 40000		R/S
11. MLT: 39.330662		R/S
12. MLN: 118.495637		R/S
13. SLT: 35.191818		R/S
14. SLN: 114.481743		R/S
15. BL: 1967.302		R/S
16. NEXT OPTION?		

Notation: CD = coding delay, M = master, S = slave, LT = latitude, LN = longitude and BL is the station pair baseline plus the secondary phase correction in microseconds.

3a. Card Store Routine - CS

With the card reader attached, station data (in R16 - R25), which has been input using the MI, XR or TR routine, can be transferred to magnetic card using the XEQ"CS" command or by pressing the appropriate user defined key.

Example using 9940W.

- | <u>See</u>      | <u>Key in</u>   | <u>Press</u> |
|-----------------|---|--------------|
| 1.              | XEQ"PD"   |              |
| 2. WRITE: 9940W | (Pass a blank card through the card reader. Label the card track "9940W") |              |
| 3. NEXT OPTION? |   |              |

To proceed with the remaining examples it is recommended that you also prepare a card for the 9940Y station pair.

3b. Card Read Routine - CR

With the card reader attached, XEQ"CR" or press the appropriate user defined key. This routine can be used to input the data for two station pairs, which must form a triplet.

Example using 9940W and 9940Y.

- | <u>See</u>      | <u>Key in</u>   | <u>Press</u> |
|-----------------|---|--------------|
| 1.              | XEQ"CR"   |              |
| 2. 1ST CARD     | (Pass the data card for 9940W through the card reader.) |              |
| 3. 2ND CARD     | (Pass the data card for 9940Y through the card reader.) |              |
| 4. NEXT OPTION? |   |              |

3c. Card Echo Routine - CE

With the card reader attached, XEQ"CE" or press the appropriate user defined key. This routine is used to validate the content of data cards against the table in Appendix C.

Example using 9940W.

<u>See</u>	<u>Key in</u>	<u>Press</u>
1.	XEQ"CE"	
2. STA. CARD	(Pass one side of a data card [9940W] through the card reader).	
3. ID: 9940W		R/S
4. CD: 11000		R/S
5. MLT: 39.330662		R/S
6. MLN: 118.495637		R/S
7. SLT: 47.034799		R/S
8. SLN: 119.443953		R/S
9. BL: 2796.903		R/S
10. NEXT OPTION?		

Notation: CD = coding delay, M = master, S = slave, LT = latitude, LN = longitude and BL is the station pair baseline plus the secondary phase correction in microseconds.

4a. Store Data in Extended Memory - XS

With the extended memory module in the HP-41CV, station data (in R16 - R25), which has been input using the MI, CR, XR or TR routine, can be transferred to the module using the XEQ"XS" command or by pressing the appropriate user defined key. Example using 9940W.

<u>See</u>	<u>Key in</u>	<u>Press</u>
1.	XEQ"XS"	
2. NEXT OPTION?		

Should the station pair already be in extended memory, the message DUP FL (duplicate file) will be displayed. If needed, the duplicate file may be erased using the XD routine.

To proceed with the remaining examples it is recommended that you also store the 9940Y station pair.

4b. Recall Data from Extended Memory - XR

With the extended memory module installed, XEQ"XR" or press the appropriate user defined key to input the data for a station pair.

Example using 9940W. (Note: The notation <9>, for example, means that you must press the gold shift key and then the 9 key.)

<u>See</u>	<u>Key in</u>	<u>Press</u>
1.	XEQ"XR"	
2. ID?	<9><9><4><0>W	R/S
3. NEXT OPTION?		

4c. Delete Data from Extended Memory - XD

XEQ"XD" or press the appropriate user defined key to delete the specific station pair data from the extended memory module.

Example using 9940W.

<u>See</u>	<u>Key in</u>	<u>Press</u>
1.	XEQ"XD"	
2. ID?	<9><9><4><0>W	R/S
3. NEXT OPTION?		

The message FL NOT FOUND will be displayed if the file you wish to delete is not in the extended memory.

Note: The extended functions/ memory module will accommodate the data for 11 station pairs. The extended memory module will accommodate the data for an additional 22 station pairs.

5a. Store Data in the Tape Cassette - TS

With the tape cassette attached to the HP-41CV, station data (in R16 - R25), which has been input using the MI, CR, XR or TR routine, can be transferred to the tape using the XEQ"TS" command or by pressing the appropriate user defined key.

Example using 9940W.

<u>See</u>	<u>Key in</u>	<u>Press</u>
1.	XEQ"TS"	
2. NEXT OPTION?		

Should the station pair already be in extended memory, the message DUP FL NAME (duplicate file name) will be displayed. If needed, the duplicate file may be erased using the TD routine.

To proceed with the remaining examples it is recommended that you also store the 9940Y station pair.

5b. Recall Data from the Tape Cassette -TR

With the tape cassette attached, XEQ"TR" or press the appropriate user defined key to input the data for a station pair.

Example using 9940W. (Note: The notation <9>, for example, means that you must press the gold shift key and then the 9 key.)

<u>See</u>	<u>Key in</u>	<u>Press</u>
1.	XEQ"TR"	
2. ID?	<9><9><4><0>W	R/S
3. NEXT OPTION?		



5c. Delete Data from the Tape Cassette - TD

XEQ"TD" or press the appropriate user defined key to delete the specific station pair data from the tape cassette.

Example using 9940W.

<u>See</u>	<u>Key in</u>	<u>Press</u>
1.	XEQ"TD"	
2. ID?	<9><9><4><0>W	R/S
3. NEXT OPTION?		

The message FL NOT FOUND will be displayed if the file to be deleted is not on the tape.

6. Loran-C Fixing Routines FI and AS

Given the indicated time delay (ITD) from two station pairs which form a triplet, a Loran-C fix is obtained.

Example: Load 9940W and 9940Y into the calculator using the MI, CR, XR or TR routine. The ITD on 9940W is 16019 microseconds and the ITD of 9940Y is 42585 microseconds. Where are you?

<u>See</u>	<u>Key in</u>	<u>Press</u>
1.	XEQ"FI"	
2. ITD: 9940W	16019	R/S
3. ITD: 9940Y	42585	R/S
4. LAT: 39.1419		R/S
5. LON: 115.5052		R/S
6. NEXT OPTION?		

Since you are on a boat, you know that you cannot be in central Nevada at 39d14'19" North and 115d50'52" West. Every Loran-C fix has two solutions, so in this case you must use the alternate solution.

<u>See</u>	<u>Key in</u>	<u>Press</u>
7.	XEQ"AS"	
8. LAT: 35.0001		R/S
9. LON: 125.0009		R/S
10. NEXT OPTION?		

This is the proper solution at almost exactly 35 degrees North and 125 degrees West. Note that annunciator 3 (Flag 3) shows in the display indicating the alternate solution. If you should now repeat from Step 1, you will obtain the proper

solution immediately.

The message "E: NO TRIPLET" will appear following Step 1 if the data do not comprise a valid triplet. The latitudes and longitudes of each station pair at the vertex must agree exactly. Should this error occur, use the ED routine to review the resident station data.

The message "E: ITD ERROR" will appear following Step 2 or 3 indicating that the ITD you keyed in is inconsistent with the station parameters. Press R/S to be requeryed for the ITD.

7a. Distance and Heading Routines DN and HD

If you know the latitude and longitude of your destination, you may key these in and then see how far your fix is from your destination and what the geodesic heading (similar to great circle heading) is to your destination.

Example: Your destination is Moss Landing at about 36d48'N and 121d47'W. Your current fix is 35dN and 125dW (see the FI-SA example). First, key in your destination.

<u>See</u>	<u>Key in</u>	<u>Press</u>
1.	XEQ"DN"	
2. DEST LAT?	36.48	R/S
3. DEST LON?	121.47	R/S
4. NEXT OPTION?		R/S

The destination is now stored in the calculator and will remain unchanged until you use either the DN or DH options. Also, the latest fix is stored and will remain unchanged until you use either the FI, AS or DH options. Now, find the distance and bearing from the latest fix (see the FI-AS example) to Moss Landing.

<u>See</u>	<u>Key in</u>	<u>Press</u>
1.	XEQ"HD"	
2. N.MI: 190.38		R/S
3. BRG: 54.3411		R/S
4. NEXT OPTION?		R/S

So the distance to Moss Landing is 190.38 nautical miles at a heading of 54d34'11".

7b. Distance and Heading Routine - DH

Given the latitude and longitude of an origin and destination, this routine will find the distance and heading from one to the other.

Example: How far, and in what direction, is Corvallis, Oregon (44d34'N, 123d16'W) from Cupertino, California (37d19N, 122d02'W)?

<u>See</u>	<u>Key in</u>	<u>Press</u>
1.	XEQ"DH"	
2. ORIG LAT?	37.19	R/S
3. ORIG LON?	122.02	R/S
4. DEST LAT?	44.34	R/S
5. DEST LON?	123.16	R/S
6. N.MI: 438.32		R/S
7. BRG: 353.0259		R/S
8. NEXT OPTION?		

Thus the distance is 438.32 nautical miles and the direction of Corvallis from Cupertino is 353d02'59".

8. ITD Prediction Routine - PR

As an aid to identification, this routine will allow the user to determine what ITD's should be received at a given location.

Example: Suppose that you know you are somewhere near latitude 35 North and longitude 125 West but are not sure what ITD's you should be receiving from 9940W and 9940Y. To determine these ITD's, proceed as follows:

<u>See</u>	<u>Key in</u>	<u>Press</u>
1.	XEQ"PR"	
2. LAT?	35	R/S
3. LON?	125	R/S
4. 9940W: 16019.35		R/S
5. 9940Y: 42584.71		R/S
6. NEXT OPTION?		

You should expect to receive an ITD of 16019.35 from 9940W and an ITD of 42584.71 from 9940Y.

9. Calibration Routine - CA

This routine will allow the user to calibrate the Loran data in the calculator to a known position when the indicated time delay (ITD) is known for each station pair.

Example: Suppose you are receiving an ITD of 16308 from 9940W and 42800 from 9940Y. These ITD's would tell you that your location is 36d47'55"N and 121d47'11"W. However, you know that your position is bench marked to be at 36d47'36"N and 121d46'58"W, and you wish to calibrate your calculator so that the ITD's of 16308 and 42800 will give you the latter fix instead of the former. Proceed as follows:

<u>See</u>	<u>Key in</u>	<u>Press</u>
1.	XEQ"CA"	
2. LAT?	36.4736	R/S
3. LON?	121.4658	R/S
4. ITD 9940W:	16308	R/S
5. ITD 9940Y:	42800	R/S
6. NEXT OPTION?		

Entering 16308 and 42800 into the FI routine will now give you a fix at 36d47'35"N and 121d46'59"W. The small discrepancy between this fix and the bench mark is due to assumptions made in the fixing algorithm.

Calibration is achieved by modifying the Master/Slave baseline (BL in the CE and ED routines). See Section F.

10. Switch Data Registers Routine - SW

The SW utility allows the user to swap the station data stored in R16 - R25 with the data stored in R26 - R35. Whenever the MI, XR or TR routine is used, the SW routine is invoked prior to the loading of the data; the incoming data are then placed in R16 - R25. The consequence is that the first station pair data reside in R26 - R35 and the second station pair data reside in R16 - R25.

One user application of SW would be to change the order of the station ID query in the FI routine (this also affects the order of determination of the solution and alternate solution). Another user application would be to output both resident station pairs to card, extended memory or tape cassette using the CS, XS or TS routines, respectively. To accomplish this, first use the CS, XS, or TS routine; then XEQ"SW" (note that the ID of the station data in R16 - R25 appears in the display instead of the NEXT OPTION? prompt); and finally use the CS, XS or TS routine once more.



**11a. Recording the Loran-C Program onto Magnetic Cards**

- (1) Attach the card reader to the HP-41CV.
- (2) Place the calculator in the USER mode.
- (3) Press the PRGM key to place the calculator in the program mode.
- (4) Pass one side of a blank magnetic card through the card reader. Then follow the display prompts until nine program cards (17 tracks) have been recorded.
- (5) Press the PRGM key once more to leave the program mode.
- (6) To record a status card, XEQ"WSTS". Then pass a blank card through the card reader following the display prompts.

**11b. Recording the Loran-C Program onto Magnetic Tape**

- (1) Attach the tape cassette to the HP-41CV.
- (2) Place the calculator in the USER mode.
- (3) Press the alpha key, key in the word LORANC, press the alpha key once more, and then XEQ"WRTP".
- (4) To record the program status, press the alpha key, key in the word STATUS, press the alpha key once more, and then XEQ"WRTS".

**12a. Loading the Loran-C Program from Magnetic Cards**

- (1) Attach the card reader to the HP-41CV.
- (2) Clear program memory: Turn the calculator off, then, while pressing the left arrow (erase) key down, turn the calculator on.
- (3) Place the calculator in the USER mode.
- (4) Read in the STATUS card. The status card will set the calculator to SIZE 42.
- (5) Read in the nine program cards (17 tracks).

**12b. Loading the Loran-C program from Tape Cassette**

- (1) Attach the tape cassette to the HP-41CV.
- (2) Clear program memory. (See Step 2 above).
- (3) Place the calculator in the USER mode.
- (4) Press the alpha key, key in the word STATUS, press the alpha key once more, and then XEQ"READS". The status file will set the calculator to SIZE 42.
- (5) Press the alpha key, key in the word LORANC, press the alpha key once more, and then XEQ"READP".

#### E. The Loran-C Fixing Algorithm

The principles of Loran lines of position (LOP's) and fixing are adequately covered in Reference 1 and will not be repeated here.

The basic Loran-C equation [Ref. 4] can be written as

$$\text{ITD} = [T_S + p(T_S)] - [T_M + p(T_M)] + [T_B + p(T_B)] + \delta \quad (1)$$

where

ITD is the "indicated time difference" in microseconds,

$T_M$  is the distance, in microseconds, from the master to the receiver,

$T_S$  is the distance, in microseconds, from the slave to the receiver,

$T_B$  is the distance, in microseconds, between the master and the slave,

$\delta$  is the assigned station pair coding delay, in microseconds, and

$p(T)$  is the secondary phase correction, in microseconds, for a surface seawater path of length  $T$ .

The quantity

$$\Delta t = T_B + p(T_B) + \delta$$

is a constant for each master/slave pair. The quantity  $T_B$  is computed from the positions of the master and slave using the reverse solution algorithm (Section H) at the time of manual data input (Routine MI).

The following World Geodetic System 1972 (WGS 72) values have been adopted for Loran-C navigation [Ref. 4]:

$v_0 = 299792458$  meters/second is the velocity of light  
in free space,

$\eta = 1.000338$  is the index of refraction of the  
surface of the earth for standard atmosphere  
and 100 kHz electromagnetic waves,

$a_e = 6378135.000$  meters is the equatorial radius of  
the earth

and  $f = 1/298.26$  is the flattening factor ( $1-b/a_e$ , where  
 $b$  is the polar radius) of the earth.

Accurate formulas for computing the secondary phase correction  $p(T)$  are contained in Reference 4, but for use in the HP-41CV, the form

$$p(T) = a_0/T + a_1 + a_2T \quad (2)$$

is used, where  $T$  is in microseconds and

1. For  $T \geq 537 \mu\text{sec}$ :

$$a_0 = 129,$$

$$a_1 = -0.408, \text{ and}$$

$$a_2 = 0.0006458.$$

2. For  $T < 537 \mu\text{sec}$ :

$$a_0 = 2.74,$$

$$a_1 = -0.011, \text{ and}$$

$$a_2 = 0.00033.$$

On the surface of a sphere, a hyperbolic line of position (LOP) can be represented by the equation [Ref. 1, page 175]

$$\tan r = \frac{\cos 2a - \cos 2c}{\sin 2c \cos \omega + \zeta \sin 2a} \quad (3)$$

where the origin of the coordinate system is at the prime focus of the spherical hyperbola,  $2c$  is the spherical arc joining the foci,  $2a$  is a constant for any one hyperbola, and  $r$  and  $\omega$  are the spherical coordinates of a point on the hyperbola. If the base line of the coordinate system is the arc joining the foci the  $\omega$  is the spherical polar angle from the baseline to a point  $P$  on the spherical hyperbola and  $r$  is spherical polar distance (or arc) from the prime focus to  $P$ . Using the Loran system we take  $\zeta = +1$  if the prime focus is at a master station and  $\zeta = -1$  if the prime focus is at a slave station.

If we let  $v = v_0/\eta$  be the velocity of 100kHz electromagnetic radiation at the earth's surface then, for a spherical earth, we can relate the parameters in Equations 1 and 3 as follows:

$$2c = vT_B/a_e ,$$

and

$$2a = v(T_S - T_M)/a_e .$$

Using the spherical approximation for now, we see that  $2c$  is known for any Loran pair. The "indicated time delay" ITD is measured by the receiver at point  $P$ , and to determine a hyperbolic line of position we must determine  $2a$ , but  $T_S - T_M$  cannot be computed from Equations 1 and 2. If  $a_0$  were zero

in Equation 2, then it would be possible to determine  $T_S - T_M$  uniquely. As an approximation we use the following parameters in Equation 2:

$$a_0 = 0 ,$$

$$a_1 = -0.321 ,$$

and

$$a_2 = 0.000635 .$$

These values have been obtained by setting  $a_0 = 0$  and determining  $a_1$  and  $a_2$  by linear regression of the  $T > 537$  values over the interval of  $1000 < T < 8000$ . This approximation is quite good (within  $0.03 \mu s$ ) for distances up to 10,000 microseconds where small changes in the LOP's can cause large position errors. At short distances the error increases from  $0.05 \mu s$  at 1000  $\mu s$  to  $0.58 \mu s$  at 10  $\mu s$ ; although these errors are large for small distances, the LOP's are not as sensitive to these changes as they would be at large distances. When this approximation is substituted into Equation 1, we obtain

$$[T_S + a_1 + a_2 T_S] - [T_M + a_1 + a_2 T_M] = ITD - \Delta t ,$$

or

$$T_S - T_M = (ITD - \Delta t)/(1 + a_2) \quad (4)$$

and hence  $2a = v(T_S - T_M)/a_e$  is determined for use in the spherical approximation.

Consider a Loran-C triplet with the master stations co-located. Let  $\xi_1$  and  $\xi_2$  denote the azimuth angles of slave 1 ( $S_1$ ) and slave 2 ( $S_2$ ), respectively, measured from North toward the East from the master stations (M) (see Figure 3).

Further, let  $\alpha$  and  $r$  be the azimuth and spherical polar arc (distance) of the receiver (R) from M. For this geometry, Equation 3 can be written in the form

$$\tan r_i = \frac{B_i}{C_i \cos(\alpha - \xi_i) + A_i} , \quad (5)$$

where

$$A_i = \zeta_i \sin 2a_i ,$$

$$B_i = \cos 2a_i - \cos 2c_i ,$$

and

$$C_i = \sin 2c_i$$

for the  $i^{\text{th}}$  Loran pair,  $i = 1, 2$ . Since  $r_1 = r_2 = r$ , we can eliminate  $\tan r$  between the two equations. The resulting equation can be rewritten as

$$C \cos \alpha + S \sin \alpha = K , \quad (6)$$

where

$$C = B_1 C_2 \cos \xi_2 - B_2 C_1 \cos \xi_1 ,$$

$$S = B_1 C_2 \sin \xi_2 - B_2 C_1 \sin \xi_1 ,$$

and

$$K = B_2 A_1 - B_1 A_2 .$$

If we define  $\rho > 0$  and  $\gamma$  by the equations

$$\rho \cos \gamma = C , \quad (7)$$

and

$$\rho \sin \gamma = S ,$$

then

$$\rho = \sqrt{C^2 + S^2} ,$$

and

$$\gamma = \text{qatn}(S, C) .$$

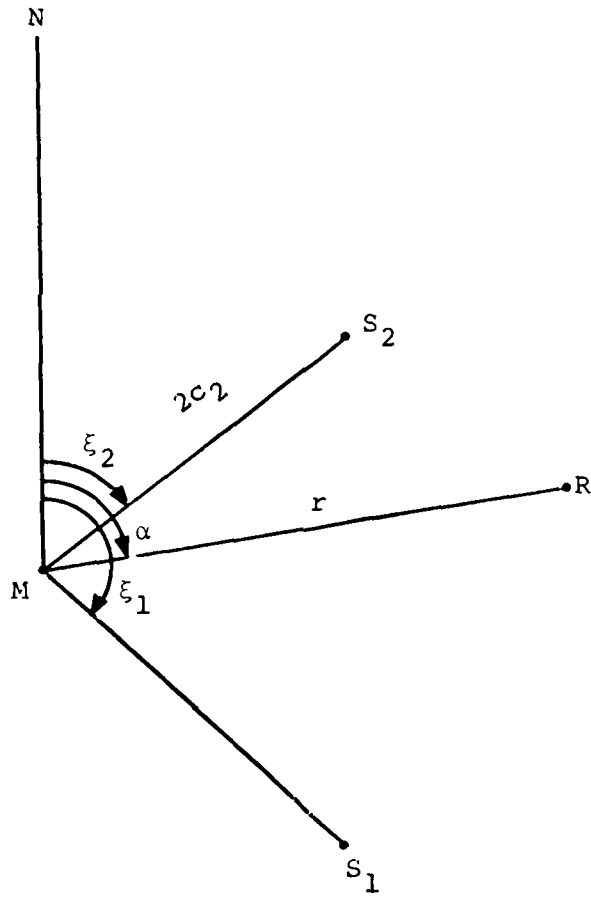


Figure 3. Geometry of a Loran Triplet and a Receiver.



Here the function  $\text{qatn}(y,x)$  is the arctangent of  $y/x$  adjusted for the proper quadrant according to the signs of  $x$  and  $y$ . A compact form of this function is

$$\text{qatn}(y,x) = \tan^{-1} \frac{y}{x + 10^{-9} t(x = 0?)} + \pi t(x < 0?)$$

where  $t(z) = 1$  when  $z$  is true  
and  $t(z) = 0$  when  $z$  is false.

When convenient we will use the notation  $\text{qatn}(y/x)$  interchangeably with  $\text{qatn}(y,x)$ . Now we can substitute Eq. (7) into Eq. (6) and solve for

$$\alpha = \gamma \pm \cos^{-1}(K/\rho) \quad (8)$$

to obtain the azimuth angle  $\alpha$  of the two points of intersection of the spherical hyperbolic LOP's. Finally we can obtain a value for  $r$  by substituting each  $\alpha$  into Eq. (5) for either  $i = 1$  or  $i = 2$ . We find that

$$r = \text{qatn} \left[ \frac{B_i}{C_i \cos(\alpha - \xi_i) + A_i} \right] \text{ for } i = 1 \text{ or } 2. \quad (9)$$

The distance and azimuth from  $M$  or the triplet vertex can be converted into the latitude and longitude of the two possible positions of  $r$ .

The fixing algorithm then uses  $\alpha$  and  $r$  in the direct solution algorithm of spheroidal geodesy (Section G).

## F. The Calibration and ITD Prediction Algorithms

Calibration can be achieved when an ITD is measured at a known bench marked position. From the bench marked position and the known master and slave positions, the quantities  $T_M + p(T_M)$  and  $T_S + p(T_S)$  can be computed using the reverse solution algorithm (Section H) and the accurate secondary phase correction formula (Eq. 2). Equation 1 can then be solved for  $T_B + p(T_B)$  to obtain a modified baseline. This modified baseline is stored and then used instead of the true baseline in subsequent computations. The affect on the accuracy of fixes using this modified baseline with positions far removed from the bench mark has not studied.

The ITD prediction algorithm is a direct application of Equation 1. A known position, together with the known master and slave positions, is used to compute the quantities  $T_M + p(T_M)$  and  $T_S + p(T_S)$ . When these values, along with a computed or calibrated baseline,  $T_B + p(T_B)$ , are substituted into Equation 1, a predicted ITD is obtained.

### G. The Direct Solution Algorithm

This direct solution algorithm is a modification of the second order in flattening (f) algorithm given by Thomas [Ref. 5, pp. 7-8]. Thomas' notation has been followed as closely as possible for ease of comparison of the algorithms. The qatn function is defined in a previous section. East longitudes and South latitudes are negative. We are given the point  $P_1(\phi_1, \lambda_1)$  on the spheroid, where  $\phi_1, \lambda_1$  are the geodetic latitude and longitude (geographic coordinates); the forward azimuth  $\alpha_{12}$  and distance  $S$  to a second point  $P_2(\phi_2, \lambda_2)$ ; and from these we are to find the geographic coordinates  $\phi_2, \lambda_2$  and the back azimuth  $\alpha_{21}$ . The given quantities are  $\phi_1, \lambda_1, \alpha_{12}$  and  $S$ . No assumptions about the relative location of  $P_1$  and  $P_2$  are required. The modified direct solution algorithm is:

$$\begin{aligned} \theta_1 &= \tan^{-1}[(1-f)\tan \theta_1], \quad M = -\sin \alpha_{12} \cos \theta_1, \\ C_1 &= fM, \quad C_2 = f(1-M^2)/4, \\ D &= (1-C_2)(1-C_2 - C_1M), \quad P = C_2[1 + (1/2)C_1M]/D, \\ N &= \cos \theta_1 \cos \alpha_{12}, \quad \sigma_1 = \text{qatn}(N, \sin \theta_1), \\ d &= S/(a_e D), \quad u = 2(\sigma_1 - d), \quad W = 1 - 2P \cos u, \\ V &= \cos(u+d), \quad X = C_2^2 \sin d \cos d(2V^2 - 1), \\ Y &= 2PVW \sin d, \quad \Delta\sigma = d + X - Y, \\ K &= [M^2 + (N \cos \Delta\sigma \sin \theta_1 \sin \Delta\sigma)^2]^{1/2}, \\ \theta_2 &= \tan^{-1}[(\sin \theta_1 \cos \Delta\sigma + N \sin \Delta\sigma)/K], \\ \Delta\eta &= \text{qatn}(-\sin \Delta\sigma \sin \alpha_{12}, \cos \theta_1 \cos \Delta\sigma - \sin \theta_1 \sin \Delta\sigma \cos \alpha_{12}), \\ H &= C_1(1-C_2) \Delta\sigma - C_1 C_2 \sin \Delta\sigma \cos(2\sigma_1 - \Delta\sigma), \\ \lambda_2 &= \lambda_1 + \Delta\eta - H, \end{aligned}$$

$$\alpha_{21} = \text{qatn}[-M, - (N \cos \Delta\sigma - \sin \theta_1 \sin \Delta\sigma)] ,$$
$$\phi_2 = \tan^{-1}[\tan \theta_2 / (1-f)]$$

Details of the modifications made to Thomas' algorithm are contained in Reference 3. The algorithm above has been further modified so that Eastern longitudes, rather than Western longitudes, are negative.

#### H. The Reverse Solution Algorithm

This reverse solution algorithm is a modification of the second order in flattening (f) algorithm given by Thomas [Ref. 5, pp. 8-10]. Thomas' notation has been followed as closely as possible for ease of comparison of the algorithms. The gathn function is defined in a previous section. East longitudes ( $\lambda$ ) and South latitudes ( $\phi$ ) are negative. We are given the points  $P_1(\phi_1, \lambda_1)$ ,  $P_2(\phi_2, \lambda_2)$  on the spheroid and are to find the distance  $S$  between the points and the forward and back azimuths,  $\alpha_{12}$  and  $\alpha_{21}$ . Given quantities are  $\phi_1$ ,  $\lambda_1$ ,  $\phi_2$  and  $\lambda_2$ . No assumptions about the relative location of  $P_1$  and  $P_2$  are required. The modified reverse solution algorithm is:

$$\begin{aligned} \theta_i &= \tan^{-1}[(1-f)\tan \phi_i] , \quad i = 1, 2 , \\ \Delta\lambda &= \lambda_2 - \lambda_1 , \quad \Delta\theta_m = (\theta_2 - \theta_1)/2 , \quad \theta_m = (\theta_1 + \theta_2)/2 , \\ H &= \cos^2 \Delta\theta_m - \sin^2 \theta_m , \quad L = \sin^2 \Delta\theta_m + H \sin^2(\Delta\lambda/2) , \\ d &= 2 \sin^{-1}\sqrt{L} , \quad U = 2 \sin^2 \theta_m \cos^2 \Delta\theta_m / (1-L) , \\ V &= 2 \sin^2 \Delta\theta_m \cos^2 \theta_m / L , \quad X = U + V , \quad Y = U - V , \\ T &= d/\sin d , \quad D = 4T^2 , \quad E = 2 \cos d , \quad A = DE , \\ C &= T - (A-E)/2 , \quad n_1 = X(A+CX) , \\ B &= 2D , \quad n_2 = Y(B+EY) , \quad n_3 = DXY , \\ \delta_2 d &= f^2(n_1 - n_2 + n_3)/64 , \quad \delta_1 d = f(TX-Y)/4 , \\ S/a_e &= (T - \delta_1 d + \delta_2 d) \sin d , \quad M = 32T - (20T-A)X - (B+4)Y , \\ F &= 2Y - E(4-X) , \quad G = fT/2 + f^2 M/64 , \quad Q = - (FG \tan \Delta\lambda)/4 , \\ \Delta\lambda'_m &= (\Delta\lambda + Q)/2 , \end{aligned}$$

$$\begin{aligned}
t_1 &= \text{qatn}(\sin \Delta\theta_m \cos \Delta\lambda'_m, \cos \theta_m \sin \Delta\lambda'_m) , \\
t_2 &= \text{qatn}(-\cos \Delta\theta_m \cos \Delta\lambda'_m, \sin \theta_m \sin \Delta\lambda'_m) , \\
\alpha_{12} &= t_1 + t_2 , \quad \alpha_{21} = t_1 - t_2
\end{aligned}$$

Details of the modifications made to Thomas' algorithm are contained in Reference 3. The algorithm above has been further modified so that Eastern longitudes, rather than Western longitudes, are negative.

## I. Program Accuracy

The direct and reverse solution algorithms are equivalent to the second order flattening algorithms given by Thomas (Ref. 5); the parameters of the WGS 1972 spheroid are used. The reverse solution algorithm reproduces the baselines provided by the Defense Mapping Agency for all 40 Loran-C stations to within 0.15 meters (the average deviation is -0.031 meters, DMA minus HP-41CV, with a standard deviation of 0.037 meters) and to within 0.01 microseconds, including the secondary phase correction for an all seawater path. The reverse solution algorithm is also used to generate predicted ITD's; these are presumed to be within 0.01 microseconds, also.

The fixing algorithm uses the direct solution algorithm with the azimuth and distance of the fix from the vertex of the Loran-C triplet computed from Equations 8 and 9 as inputs. Equations 8 and 9 are based upon spherical geometry and include an approximation to the secondary phase correction for an all seawater path. The largest source of error is the assumption that the azimuth and distance to the fix are accurately represented by this spherical approximation. This approximation has not been rigorously tested, however it is possible to use the reverse solution algorithm to predict the ITD's that will be received at a given position and then to enter these ITD's into the fixing algorithm to determine how accurately the fixing algorithm reproduces the original position. The distance between the fix and the original position can be determined using the HD algorithm. Tables 1, 2 and 3 were produced in this manner. Similiar tables with different station

pairs are given in References 3, 6 and 7. It is felt that the results are accurate enough to not warrant the inclusion of an iterative improvement routine. Of the samples in Tables 1, 2 and 3, the largest error, 0.22 n.mi., is the first entry in Table 1. From the chart LCNC-2, it estimated that the angle of intersection of the two hyperbolic lines of position is about 5 degrees and so an error of 0.22 n.mi. should not be unexpected.



Table 1. Colocated Master Stations

Position		Predicted ITD's		HP-41CV Fix		Error n.mi
Lat	Long	9940W	9940X	Lat(N)	Long(W)	
31°	123°	16413.28	27570.93	30°59'47"	123°00'03"	0.22
37°	126°	15610.11	27020.50	36°59'53"	126°00'09"	0.17
42°	129°	13881.78	27285.58	42°00'00"	129°00'00"	0
44°	132°	13180.89	27371.19	44°00'00"	132°00'01"	0.01
48°	135°	12301.25	27552.06	48°00'01"	135°00'03"	0.03
50°	138°	12068.67	27584.22	50°00'01"	138°00'04"	0.05

Table 2. Colocated Slave Stations

Position		Predicted ITD's		HP-41CV Fix		Error n.mi
Lat	Long	9940W	5990Y	Lat(N)	Long(W)	
31°	123°	16413.28	27177.18	31°00'03"	122°59'58"	0.06
37°	126°	15610.11	27403.20	37°00'01"	125°59'59"	0.01
42°	129°	13881.78	27955.45	42°00'00"	129°00'00"	0
44°	132°	13180.89	28512.90	44°00'00"	132°00'00"	0
48°	135°	12301.25	29413.61	48°00'00"	134°59'59"	0.01
50°	138°	12068.67	29816.84	50°00'00"	137°59'59"	0.02

Table 3. Colocated Master and Slave Stations

Position		Predicted ITD's		HP-41CV Fix		Error n.mi
Lat	Long	5930Y	9960W	Lat(N)	Long(W)	
44°	63°	29864.46	11685.15	44°00'00"	63°00'00"	0
41°	66°	30585.61	12946.91	41°00'00"	66°00'00"	0
39°	69°	31020.46	14111.31	39°00'00"	69°00'00"	0
35°	72°	31064.57	15139.48	35°00'00"	72°00'00"	0
30°	75°	31040.82	15610.46	29°59'59"	75°00'01"	0.02
26°	78°	31106.20	15858.46	25°59'57"	78°00'02"	0.05

J. References

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Appendix A: Program Storage Allocations, Flag Usage  
and Program Listing

Program Size: 42

Registers:

R00 - R13: Scratch storage

R14: Flattening

<u>2nd Sta. Pair</u>	<u>Variable</u>	<u>1st Sta. Pair</u>
R15:	2a	
R16:	ID	:R26
R17:	$T_B + p(T_B)$	:R27
R18:	2c	:R28
R19:	CD	:R29
R20:	$\theta$ master	:R30
R21:	$\lambda$ master	:R31
R22:	$\alpha$ master-slave	:R32
R23:	$\theta$ slave	:R33
R24:	$\lambda$ slave	:R34
R25:	$\alpha$ slave-master	:R35
	2a	:P36
R37:	$\theta$ fix	
R38:	$\lambda$ fix	
R39:	$\alpha$ fix-dest	
R40:	$\theta$ dest	
R41:	$\lambda$ dest	

Flag Usage:

- F00: 1. Requery erroneous ITD at LBL06  
2. Echo two data sets at LBL ED
- F01: PR and CA interlock
- F03: Set for 2nd solution
- F05: Set if slave at vertex of 2nd station pair
- F06: Set if slave at vertex of 1st station pair
- F07: Set for XMEM functions, clear for tape functions
- F08: DN and DH interlock
- F09: Set if DMS conversion required
- F10: 1. SW and AS interlock  
2. Input interlock in FI vertex check
- F14: PR and CA loop control

<pre> 01 * LBL "LOK AME" 02 * LBL 90 03 STO 00 04 /LX 05 06 P-R 07 STO 01 08 RDN 09 CHS 10 STO 02 11 RDN 12 STO 03 13 CLX 14 1 15 P-R 16 STO 04 17 RCL 02 18 * 19 STO 06 20 X&lt;&gt;Y 21 STO 05 22 X&lt;&gt;Y 23 RCL 14 24 * 25 STO 07 26 1 27 RCL 06 28 X+2 29 - 30 4 31 / RCL 14 32 * 33 * STO 08 34 STO 08 35 1 36 - 37 CHS </pre>	<p>DIRECT SOLUTION</p> <p><math>\theta_1, \lambda_1, \alpha_{12}</math> and <math>S/a_e</math> are in the T, Z, Y and X registers</p> <p>cos <math>\alpha_{12}</math></p> <p>- sin <math>\alpha_{12}</math></p> <p><math>\lambda_1</math></p> <p>cos <math>\theta_1</math></p> <p>M</p> <p>sin <math>\theta_1</math></p> <p>f</p> <p><math>c_1</math></p> <p><math>c_2</math></p>	<pre> 38 * ENTER↑ 39 RCL 07 40 RCL 07 41 RCL 06 42 * 43 - 44 * 45 STO 09 46 1/X 47 RCL 08 48 * 49 1 50 RCL 07 51 RCL 06 52 * 53 2 54 / 55 + 56 * STO 10 57 RCL 04 58 RCL 04 59 RCL 01 60 * 61 STO 11 62 RCL 05 63 RAD 64 R-P 65 X&lt;&gt;Y 66 STO 12 67 RCL 00 68 RCL 09 69 / 70 STO 09 71 RCL 12 72 - 73 CHS 74 ENTER↑ 75 + </pre>	<p>D</p> <p>P</p> <p>N</p> <p>01</p>
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Program Listing

<pre> 76 STO 13 77 COS 78 RCL 10 79 * ENTER↑ 80 + 81 1 82 - 83 CHS 84 RCL 13 85 RCL 09 86 + 87 COS 88 STO 13 89 X↑2 90 ENTER↑ 91 + 92 1 93 - 94 RCL 09 95 1 96 P-R 97 * 98 * 99 RCL 08 100 X↑2 101 * 102 X&lt;&gt;Y 103 RCL 13 104 * 105 RCL 10 106 * 107 RCL 09 108 SIN 109 * 110 ENTER↑ 111 + 112 - 113 </pre>	<p>u</p>	
<pre> 114 RCL 09 115 + 116 STO 13 117 1 118 P-R 119 RCL 11 120 * 121 X&lt;&gt;Y 122 RCL 05 123 * 124 - 125 STO 10 126 X↑2 127 RCL 06 128 X↑2 129 + 130 SQR↑ 131 1/X 132 RCL 13 133 1 134 P-R 135 RCL 05 136 * 137 X&lt;&gt;Y 138 RCL 11 139 * 140 + 141 * 142 ATAN 143 R-D 144 STO 09 145 RCL 13 146 SIN 147 RCL 02 148 * 149 RCL 13 150 1 151 P-R </pre>	<p>w</p>	
<pre> 114 RCL 09 115 + 116 STO 13 117 1 118 P-R 119 RCL 11 120 * 121 X&lt;&gt;Y 122 RCL 05 123 * 124 - 125 STO 10 126 X↑2 127 RCL 06 128 X↑2 129 + 130 SQR↑ 131 1/X 132 RCL 13 133 1 134 P-R 135 RCL 05 136 * 137 X&lt;&gt;Y 138 RCL 11 139 * 140 + 141 * 142 ATAN 143 R-D 144 STO 09 145 RCL 13 146 SIN 147 RCL 02 148 * 149 RCL 13 150 1 151 P-R </pre>	<p>v</p>	
<pre> 114 RCL 09 115 + 116 STO 13 117 1 118 P-R 119 RCL 11 120 * 121 X&lt;&gt;Y 122 RCL 05 123 * 124 - 125 STO 10 126 X↑2 127 RCL 06 128 X↑2 129 + 130 SQR↑ 131 1/X 132 RCL 13 133 1 134 P-R 135 RCL 05 136 * 137 X&lt;&gt;Y 138 RCL 11 139 * 140 + 141 * 142 ATAN 143 R-D 144 STO 09 145 RCL 13 146 SIN 147 RCL 02 148 * 149 RCL 13 150 1 151 P-R </pre>	<p>d</p>	
<pre> 114 RCL 09 115 + 116 STO 13 117 1 118 P-R 119 RCL 11 120 * 121 X&lt;&gt;Y 122 RCL 05 123 * 124 - 125 STO 10 126 X↑2 127 RCL 06 128 X↑2 129 + 130 SQR↑ 131 1/X 132 RCL 13 133 1 134 P-R 135 RCL 05 136 * 137 X&lt;&gt;Y 138 RCL 11 139 * 140 + 141 * 142 ATAN 143 R-D 144 STO 09 145 RCL 13 146 SIN 147 RCL 02 148 * 149 RCL 13 150 1 151 P-R </pre>	<p>x</p>	
<pre> 114 RCL 09 115 + 116 STO 13 117 1 118 P-R 119 RCL 11 120 * 121 X&lt;&gt;Y 122 RCL 05 123 * 124 - 125 STO 10 126 X↑2 127 RCL 06 128 X↑2 129 + 130 SQR↑ 131 1/X 132 RCL 13 133 1 134 P-R 135 RCL 05 136 * 137 X&lt;&gt;Y 138 RCL 11 139 * 140 + 141 * 142 ATAN 143 R-D 144 STO 09 145 RCL 13 146 SIN 147 RCL 02 148 * 149 RCL 13 150 1 151 P-R </pre>	<p>v</p>	
<pre> 114 RCL 09 115 + 116 STO 13 117 1 118 P-R 119 RCL 11 120 * 121 X&lt;&gt;Y 122 RCL 05 123 * 124 - 125 STO 10 126 X↑2 127 RCL 06 128 X↑2 129 + 130 SQR↑ 131 1/X 132 RCL 13 133 1 134 P-R 135 RCL 05 136 * 137 X&lt;&gt;Y 138 RCL 11 139 * 140 + 141 * 142 ATAN 143 R-D 144 STO 09 145 RCL 13 146 SIN 147 RCL 02 148 * 149 RCL 13 150 1 151 P-R </pre>	<p>p</p>	
<pre> 114 RCL 09 115 + 116 STO 13 117 1 118 P-R 119 RCL 11 120 * 121 X&lt;&gt;Y 122 RCL 05 123 * 124 - 125 STO 10 126 X↑2 127 RCL 06 128 X↑2 129 + 130 SQR↑ 131 1/X 132 RCL 13 133 1 134 P-R 135 RCL 05 136 * 137 X&lt;&gt;Y 138 RCL 11 139 * 140 + 141 * 142 ATAN 143 R-D 144 STO 09 145 RCL 13 146 SIN 147 RCL 02 148 * 149 RCL 13 150 1 151 P-R </pre>	<p>d</p>	
<pre> 114 RCL 09 115 + 116 STO 13 117 1 118 P-R 119 RCL 11 120 * 121 X&lt;&gt;Y 122 RCL 05 123 * 124 - 125 STO 10 126 X↑2 127 RCL 06 128 X↑2 129 + 130 SQR↑ 131 1/X 132 RCL 13 133 1 134 P-R 135 RCL 05 136 * 137 X&lt;&gt;Y 138 RCL 11 139 * 140 + 141 * 142 ATAN 143 R-D 144 STO 09 145 RCL 13 146 SIN 147 RCL 02 148 * 149 RCL 13 150 1 151 P-R </pre>	<p>y</p>	

<p>152 RCL 04  153 *  154 X&lt;&gt;Y  155 RCL 05  156 *  157 RCL 01  158 *  159 -  160 R-P  161 CLX  162 1  163 RCL 08  164 -  165 RCL 07  166 *  167 RCL 13  168 *  169 RCL 12  170 ENTER↑  171 +  172 RCL 13  173 -  174 COS  175 RCL 13  176 SIN  177 *  178 RCL 07  179 *  180 RCL 08  181 *  182 -  183 -  184 R-D  185 RCL 03  186 +  187 DEG  188 1  189 P-R</p>	<p>Δn</p>	<p>190 R-P  191 CLX 06  192 RCL 10  193 CHS  194 RCL 10  195 CHS  196 R-P  197 RDN  198 X&lt;&gt;Y  199 RCL 09  200 RTN 00  201 ♦LBL 00  202 X&lt;&gt;Y  203 RDN  204 -  205 CHS  206 STO 00  207 RDN  208 -  209 LASTX  210 X&lt;&gt;Y  211 2 /  212 ENTER↑  213 ENTER↑  214 ENTER↑  215 1  216 P-R  217 STO 01  218 X12  219 RDN  220 STO 02  221 RDN  222 +  223 1  224 P-R  225 STO 03  226 RDN  227 STO 04</p>	<p>α21, λ2 and θ2 are in the Z, Y and X registers  <u>REVERSE SOLUTION</u>  Stack contains θ1, λ1, θ2 and λ2 in the T, Z, Y and Δλ X registers</p>
<p>H</p>	<p>Δθ</p>	<p>cos Δθ<sub>m</sub>  sin Δθ<sub>m</sub></p>	<p>cos θ<sub>m</sub>  sin θ<sub>m</sub></p>
<p>λ2</p>			



<p>H</p> <p>228 X↑2  229 - RCL 00  230 RCL 00  231 2  232 /  233 SIN  234 X↑2  235 *  236 RCL 02  237 X↑2  238 +  239 STO 05  240 SQRT  241 RAD  242 ASIN  243 ENTER↑  244 +  245 STO 06  246 RCL 04  247 RCL 01  248 *  249 X↑2  250 ENTER↑  251 +  252 1  253 RCL 05  254 -  255 /  256 STO 07  257 RCL 02  258 RCL 03  259 *  260 X↑2  261 ENTER↑  262 +  263 RCL 05  264 /  265 ST+ 07</p>	<p>L</p> <p>d</p> <p>U</p> <p>V X</p>	<p>266 - STO 08  267 RCL 06  268 RCL 06  269 ENTER↑  270 SIN  271 /  272 STO 05  273 ENTER↑  274 +  275 X↑2  276 STO 09  277 RCL 06  278 COS  279 ENTER↑  280 +  281 STO 10  282 *  283 STO 11  284 RCL 10  285 -  286 2  287 /  288 RCL 05  289 -  290 CHS  291 RCL 07  292 *  293 RCL 11  294 +  295 RCL 07  296 *  297 RCL 09  298 ENTER↑  299 +  300 STO 12  301 RCL 10  302 RCL 08  303 *</p>	<p>Y</p> <p>T</p> <p>D</p> <p>E</p> <p>A</p> <p>C</p> <p>n1</p> <p>B</p>
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<pre> 380 + 381 / 382 STO 09 383 1 384 P-R 385 RCL 02 386 * 387 X&lt;&gt;Y 388 RCL 03 389 * 390 R-P 391 RDN 392 STO 12 393 RCL 09 394 1 395 P-R 396 RCL 01 397 * 398 CHS 399 X&lt;&gt;Y 400 RCL 04 401 * 402 R-P 403 RDN 404 ST+ 12 405 - 406 1 407 P-R 408 RCL 12 409 X&lt;&gt;Y 410 P-R 411 CLX 412 RCL 13 413 RTN </pre>	<p><math>\Delta \lambda'</math> m</p>	<p>MANUAL INPUT ROUTINE Swap registers, then input data CARD INPUT ROUTINE Clear AVIEW flag RDTAX - wait for data card</p>
<pre> 417 LBL "MI" 418 XEQ "SM" 419 XEQ 15 420 GTO 50 421 LBL "CR" 422 CF 21 423 26.035 424 "1ST CAR D" 425 AVIEW 426 XROM 30, 03 427 16.025 428 "2ND CAR D" 429 AVIEW 430 XROM 30, 03 431 SF 10 432 GTO 50 433 LBL 35 434 SF 21 435 RCL 16 436 RCL 26 437 X*Y? 438 GTO 11 439 TONE 1 440 "E: ID1 = ID2" 441 AVIEW 442 GTO 50 443 LBL 11 444 CF 05 445 CF 06 446 RCL 20 447 RCL 30 448 - 449 RCL 21 </pre>	<p>t1</p>	<p>RDTAX - wait for data card Set input interlock FIND TRIPLET VERTEX Set AVIEW flag ID2 = ID1 ? Error if "yes". ----- Master 2 and Master 1 collocated?</p>
<p>Stack contains <math>\alpha_{21}</math>, <math>\alpha_{12}</math> and <math>S/a_e</math> in the Z, Y and X registers</p>	<p>t2 <math>\alpha_{12}</math> <math>\alpha_{21}</math></p>	

<pre> 450 RCL 31 451 - 452 + 453 X=0? 454 RTN 455 SF 05 456 RCL 23 457 RCL 30 458 - 459 RCL 24 460 RCL 31 461 - 462 + 463 X=0? 464 RTN 465 SF 06 466 RCL 23 467 RCL 33 468 - 469 RCL 24 470 RCL 34 471 - 472 + 473 X=0? 474 RTN 475 CF 05 476 RCL 20 477 RCL 33 478 - 479 RCL 21 480 RCL 34 481 - 482 + 483 X=0? 484 RTN 485 TONE 1 486 -E: NO T RIPLET-</pre>	<pre> ----- Slave 2 and Master 1 Colocated? ----- Slave 2 and Slave 1 Colocated? ----- Master 2 and Slave 1 Colocated? ----- No triplet found -----</pre>	<pre> 487 AVIEW 488 GTO 50 489*LBL "PR" 490 SF 01 491 GTO 02 492*LBL "CA" 493 CF 01 494*LBL 02 495 FIX 4 496 XEQ 51 497 SF 21 498 SF 14 499 ADV 500 "LAT? " 501 XEQ 99 502 XEQ 14 503 STO 37 504 "LON? " 505 XEQ 99 506 STO 38 507*LBL 66 508 FS? 01 509 GTO 02 510 " : " 511 ASTO 00 512 BEEP " 513 "ITD " 514 ARCL 26 515 ARCL 00 516 XEQ 99 517 STO 39 518 CLX 519 GTO 08 520*LBL 02 521 CLX 522 STO 39 523*LBL 08 524 RCL 37</pre>	<pre> PREDICT ITD ROUTINE  CALIBRATE ROUTINE CA and PR input routine Flattening Factor Set AVIEW flag Set loop control Input latitude Input longitude Begin loop Transfer if PR input  Input benchmark ITD.  Initialize CA calculation Transfer Initialize PR calculation CA and PR computations</pre>
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<p>525 RCL 38 526 RCL 33 527 RCL 34 528 XEQ 80 529 XEQ 03 530 ST- 39 531 RCL 37 532 RCL 38 533 RCL 30 534 RCL 31 535 XEQ 80 536 XEQ 03 537 RCL 39 538 + 539 FS? 01 540 GTO 02 541 RCL 29 542 - 543 STO 27 544 GTO 08 545 LBL 02 546 CHS 547 RCL 27 548 + 549 RCL 29 550 + 551 " : " 552 ASTO 00 553 CLA 554 ARCL 26 555 ARCL 00 556 FIX 2 557 ARCL X 558 BEEP 559 AVIEW 560 LBL 08 561 XEQ -SM- 562 FS?C 14</p>	<p>Load stack. Reverse solution from Slave. Secondary phase corr.  Load stack. Reverse solution from Master Secondary phase correction.  Branch for PR Correct baseline to benchmark  Compute predicted ITD.  Display predicted ITD  Swap station data</p>	<p>563 GTO 66 564 CF 01 565 GTO 50 566 LBL "CS" 567 16.025 568 CF 21 569 "WRITE : " 570 ARCL 16 571 AVIEW 572 XROM 30, 08 573 LBL 50 574 CF 21 575 TONE 6 576 "NEXT OP TION?" 577 AVIEW 578 STOP 579 GTO 50 580 LBL 51 581 DEG 582 298.26 583 1/X 584 STO 14 585 RTN 586 LBL 44 587 LBL 14 588 TAN 589 1 590 RCL 14 591 - 592 * 593 ATAN 594 RTN 595 LBL 15 596 ADV 597 FIX 0</p>	<p>Loop for second station Done CARD STORE ROUTINE  Prompt with station ITD WDATX "NEXT OPTION?" Query  STORE FLATTENING FACTOR  CONVERT GEOGRAPHIC LATITUDE TO PARAMETRIC LATITUDE  STATION DATA INPUT PROMPTS</p>
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<p>598 SF 21  599 CF 23 -  600 "ID? -  601 RDN  602 PROMPT  603 RSTO X  604 CLA  605 ROFF  606 FC? 23  607 RTN  608 SF 09  609 XEQ 01  610 STO 16  611 -CODE DE  LAY? "  612 XEQ 00  613 STO 19  614 FIX 6  615 "MS LAT?  616 XEQ 00  617 XEQ 14  618 STO 20  619 "MS LON?  620 XEQ 00  621 STO 21  622 "SS LAT?  623 XEQ 00  624 XEQ 14  625 STO 23  626 "SS LON?  627 XEQ 00  628 STO 24  629 RCL 20  630 RDN</p>	<p>Clear alpha entry flag    Input station ID    Input Coding  delay    Input master  station latitude.    Convert to Parametric.    Input master  station longitude.    Input Slave  station latitude.    Convert to parametric.    Input Slave  station longitude.</p>	<p>631 XEQ 00  632 STO 18  633 RDN  634 STO 22  635 RDN  636 STO 25  637 RCL 18  638 XEQ 03  639 STO 17  640 RTN  641 LBL 99  642 LBL 00  643 PROMPT  644 LBL 01  645 ARCL X  646 SF 25  647 FS? 55  648 PRA  649 CF 25  650 FC?C 09  651 HR  652 RTN  653 LBL 03  654 21282.36  655 *  656 ENTER↑  657 ENTER↑  658 537  659 X&gt;Y?  660 GTD 04  661 CLX  662 129  663 X&lt;&gt;Y  664 /  665 LASTX  666 6458 E-7  667 *  668 +</p>	<p>Compute reverse solution to  determine baseline and  master-slave forward and  reverse azimuths.    Add secondary phase correc-  tion to baseline.    DATA INPUT PROMPT AND  PRINT    Set error ignore flag  Print  Clear error ignore flag  Convert DMS to DEG if  F09 clear.    SECONDARY PHASE CORRECTION  <math>a_e \frac{n}{V} o</math>    -----  T &gt; 537 <math>\mu</math>S</p>
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<pre> 669 .408 670 - 671 + 672 RTN 04 673 LBL 04 674 CLX 675 2.74 676 X&lt;&gt;Y 677 / 678 LASTX 679 33 E-5 680 * 681 + 682 .011 683 - 684 + 685 RTN 686 LBL 05 687 CF 00 688 LASTX 689 X&lt;=Y? 690 GT0 06 691 CHS 692 X&gt;Y? 693 GT0 06 694 CLX 695 21295.87 696 / 697 RTN 698 LBL 06 699 SF 21 700 SF 00 701 TONE 1 702 -E: ITD ERROR 703 AVIEW 704 RTN </pre>	<pre> 705 LBL "FI" 706 FS?C 10 707 XEQ 35 708 SF 21 709 ADV 710 LBL 10 711 XEQ 51 712 SF 09 713 FIX 2 714 " " 715 ASTO 01 716 -ITD: " 717 ASTO 00 718 ARCL 26 719 ARCL 01 720 XEQ 00 721 RCL 29 722 - 723 RCL 27 724 - 725 XEQ 05 726 FS?C 00 727 GT0 10 728 STO 36 729 LBL 07 730 SF 09 731 CLA 732 ARCL 00 733 ARCL 16 734 ARCL 01 735 XEQ 00 736 RCL 19 737 - 738 RCL 17 739 - 740 XEQ 05 741 FS?C 00 742 GT0 07 </pre>	<pre> ----- T &lt; 537 μS ----- TIME DELAY VALIDITY CHECK ----- Okay if  TD  &lt; T<sub>B</sub> + p(T<sub>B</sub>) a p 2a in X-register ITD input error Set F00 to requery. ----- </pre>	<pre> FIXING ALGORITHM Find vertex if interloc flag l0 is set. ----- Generate flattening No DMS conversion Input ITD of lst pair Compute TD TD validity check Requery ITD Store 2a1 No DMS conversion Input ITD of 2nd pair Compute TD TD validity check Requery ITD </pre>
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<p>743 STO 15  744 LBL 18  745 FS? 10  746 GTO "FI"  747 XEQ 51  748 RAD  749 RCL 15  750 I  751 P-R  752 X&lt;&gt;Y  753 FS? 05  754 CHS  755 STO 01  756 CLX  757 RCL 18  758 I  759 P-R  760 X&lt;&gt;Y  761 STO 03  762 RDN  763 -  764 STO 02  765 RCL 36  766 I  767 P-R  768 X&lt;&gt;Y  769 FS? 06  770 CHS  771 STO 04  772 CLX  773 RCL 28  774 I  775 P-R  776 X&lt;&gt;Y  777 STO 06  778 RDN  779 -  780 STO 05</p>	<p>Store 2a2  ALTERNATE SOLUTION entry.  Input ITD's if vertex  interlock set.  Regenerate flattening</p> <p>Station 2 vertex flag</p> <p>A2</p> <p>C2</p> <p>B2</p> <p>Station 1 vertex flag</p> <p>A1</p> <p>C1</p> <p>B1</p>	<p>781 RCL 01  782 *  783 RCL 02  784 RCL 04  785 *  786 - STO 07  787 DEG  788 DEG 22  789 RCL 22  790 FS? 05  791 RCL 25  792 STO 11  793 RCL 05  794 RCL 03  795 *  796 P-R  797 STO 08  798 RDN  799 STO 09  800 RCL 32  801 FS? 06  802 RCL 35  803 RCL 02  804 RCL 06  805 *  806 P-R  807 RCL 08  808 - X&lt;&gt;Y  809 RCL 09  810 RCL 09  811 - X&lt;&gt;Y  812 X&lt;&gt;Y  813 R-P  814 RCL 07  815 X&lt;&gt;Y  816 /  817 ACOS  818 FS? 03</p>	<p>K</p> <p>Station 2 vertex flag</p> <p><math>B_1 C_2 \cos \xi_2</math>  <math>B_1 C_2 \sin \xi_2</math>  Station 1 vertex flag</p> <p>C</p> <p>S</p> <p><math>\rho</math> and <math>\gamma</math></p> <p><math>\cos^{-1}(K/\rho)</math>  Alternate solution?</p>
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<p>819 CHS</p> <p>820 + STO 10</p> <p>821 STO 11</p> <p>822 RCL 11</p> <p>823 -</p> <p>824 COS</p> <p>825 RCL 03</p> <p>826 *</p> <p>827 RCL 01</p> <p>828 +</p> <p>829 RCL 02</p> <p>830 X&lt;&gt;Y</p> <p>831 R-P</p> <p>832 RDN</p> <p>833 D-R</p> <p>334 STO 12</p> <p>835 RCL 20</p> <p>836 RCL 21</p> <p>837 FC? 05</p> <p>838 GT0 09</p> <p>839 RCL 23</p> <p>840 RCL 24</p> <p>841 LBL 09</p> <p>842 RCL 10</p> <p>843 RCL 12</p> <p>844 XEQ 90</p> <p>845 STO 37</p> <p>846 FIX 4</p> <p>847 XEQ 19</p> <p>848 SF 21</p> <p>849 "LAT: "</p> <p>850 ARCL X</p> <p>851 BEEP</p> <p>852 AVIEW</p> <p>853 RDN</p> <p>854 STO 38</p> <p>855 XEQ 20</p> <p>856 "LON: "</p>	<p><math>\alpha = \gamma + \cos^{-1}(K/\rho)</math></p> <p><math>C_2 \cos(\alpha - \xi_2) + A_2</math></p> <p>r</p> <p>Station 2 vertex flag</p> <p>-----</p> <p>Compute direct solution</p> <p><math>\theta</math> fix</p> <p><math>\theta</math> fix</p> <p>Display latitude</p> <p><math>\lambda</math> fix</p>	<p>857 ARCL X</p> <p>858 AVIEW</p> <p>859 GT0 50</p> <p>860 LBL 19</p> <p>861 TAN</p> <p>862 1</p> <p>863 RCL 14</p> <p>864 -</p> <p>865 /</p> <p>866 ATAN</p> <p>867 LBL 20</p> <p>868 HMS</p> <p>869 RND</p> <p>870 0</p> <p>871 HMS+</p> <p>872 RTN</p> <p>873 LBL "DH"</p> <p>874 SF 21</p> <p>875 ADV</p> <p>876 XEQ 51</p> <p>877 "ORIG LA</p> <p>T? "</p> <p>878 XEQ 99</p> <p>879 XEQ 44</p> <p>880 STO 37</p> <p>881 "ORIG LO</p> <p>N? "</p> <p>882 XEQ 99</p> <p>883 STO 38</p> <p>884 SF 08</p> <p>885 LBL "DN"</p> <p>886 SF 21</p> <p>887 FC? 08</p> <p>888 ADV</p> <p>889 XEQ 51</p> <p>890 "DEST LA</p> <p>T? "</p> <p>891 XEQ 99</p>	<p>Display longitude</p> <p>CONVERT</p> <p>PARAMETRIC LATITUDE</p> <p>TO</p> <p>GEOGRAPHIC LATITUDE</p> <p>DMS ROUNDING ROUTINE</p> <p>DISTANCE AND HEADING</p> <p>Any origin to</p> <p>any destination</p> <p>Input origin latitude</p> <p>Convert to parametric</p> <p>Input origin longitude</p> <p>Set F08 to compute</p> <p>STORE DESTINATION</p> <p>Input destination latitude</p>
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<pre> 892 XEQ 44 893 STO 40 894 "DEST LO N? " 895 XEQ 99 896 STO 41 897 FC?C 08 898 GTO 50 899 LBL "HD" 900 RCL 37 901 RCL 38 902 RCL 40 903 RCL 41 904 XEQ 80 905 3443.917 906 * 907 BEEP 908 SF 21 909 "N.MI: " 910 FIX 2 911 ARCL X 912 AVIEW 913 RDN 914 FIX 4 915 360 916 MOD 917 STO 39 918 XEQ 20 919 "BRG: " 920 ARCL X 921 AVIEW 922 GTO 50 923 LBL "AS" 924 FS?C 03 925 GTO 18 926 SF 03 927 GTO 18 </pre>	<pre> Convert to parametric Input destination longitude Return if F08 not set to compute. <u>COMPUTE DISTANCE AND</u> HEADING Compute reverse solution Convert distance to n. mi.  Display distance  0° ≤ bearing &lt; 360° Round DMS Display bearing <u>COMPUTE ALTERNATE</u> SOLUTION Toggle F03 </pre>	<pre> 928 LBL "ED" 929 SF 00 930 XEQ "SW" 931 XEQ 13 932 XEQ "SW" 933 XEQ 13 934 LBL "CE" 935 CF 21 936 16.025 937 "STA. CA RD" 938 AVIEW 939 XROM 30, 03 940 LBL 13 941 FIX 0 942 XEQ 51 943 SF 21 944 ADV 945 "ID: " 946 ARCL 16 947 AVIEW 948 "CD: " 949 ARCL 19 950 AVIEW 951 "MLT: " 952 RCL 20 953 FIX 6 954 XEQ 19 955 ARCL X 956 AVIEW 957 "MLN: " 958 RCL 21 959 XEQ 20 960 ARCL X 961 AVIEW 962 "SLT: " 963 RCL 23 </pre>	<pre> ECHO DATA ROUTINE  CARD ECHO ROUTINE  RDTAX  Data review of R16-R25 Regenerate flattening  Display station ID  Display coding delay  Display master station latitude  Display master station longitude </pre>
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<pre> 964 XEQ 19 965 ARCL X 966 AVIEW " 967 "SLN: " 968 RCL 24 969 XEQ 20 970 ARCL X 971 AVIEW 972 FIX 3 973 "BL: " 974 ARCL 17 975 AVIEW 976 FS?C 00 977 RTN 978 GTO 50 979 LBL "SW" 980 SF 10 981 35.025 982 STO 01 983 25 984 STO 02 985 LBL 12 986 RCL IND 02 987 X&lt;&gt; IND 01 988 STO IND 02 989 DSE 02 990 " " 991 DSE 01 992 GTO 12 993 RTN 994 LBL "XR" 995 SF 07 996 GTO 02 997 LBL "TR" 998 CF 07 </pre>	<pre> Display slave station latitude  Display slave station longitude  Display base line in microseconds  SWAP STATION DATA Swaps R16-R25 with R26-R35  Begin loop </pre>	<pre> 999 LBL 32 1000 XEQ "SM" 1001 XEQ 60 1002 HSTO 16 1003 XEQ 08 1004 FS? 07 1005 XROM 25 1006 FC? 07 1007 XROM 28 1008 GTO 50 1009 LBL "XS" 1010 SF 07 1011 GTO 02 1012 LBL "TS" 1013 CF 07 1014 LBL 02 1015 CLA 1016 ARCL 16 1017 9 1018 FS? 07 1019 XROM 25 1020 FC? 07 1021 XROM 28 1022 XEQ 08 1023 FS? 07 1024 XROM 25 1025 FC? 07 1026 XROM 28 1027 GTO 50 </pre>	<pre> Swap data ID Prompt Store ID Set pointer  GETRX - Input from XMEM READRX - Input from tape  XMEM STORE  TAPE STORE  Recall ID  CRFLD - XMEM create  CREATE - Tape create  Set pointer &amp; register range  SAVERX-Save in XMEM  WRTRX - Save on tape </pre>
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<pre> 1028*LBL "XD .. 1029 SF 07 1030 GT0 02 1031*LBL "TD .. 1032 CF 07 1033*LBL 02 1034 XEQ 60 1035 FS? 07 1036 XROM 25 ,31. 1037 FC? 07 1038 XROM 28 ,04 1039 GT0 50 1040*LBL 60 1041 CF 21 1042 "ID?" 1043 AON 1044 PROMPT 1045 AOFF 1046 RTN 1047*LBL 08 1048 0 1049 FS? 07 1050 XROM 25 ,43 1051 FC? 07 1052 XROM 28 ,14 1053 17.025 1054 .END. </pre>	<pre> XMEM DELETE  TAPE DELETE -----  PURFL - Purge from XMEM  PURGE - Purge from tape  ID INPUT PROMPT  SET POINTER  SEEKPT - Set XMEM pointer to zero SEEKR - Set tape pointer to zero R17-R25 to be transmitted. </pre>
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Appendix B: STATION COVERAGE

<u>Station</u>	<u>No. of Pairs</u>	<u>Location</u>
4990	2	Central Pacific
5930	2	East Coast, Canada
5990	3	West Coast, Canada
7930	3	North Atlantic
7960	2	Gulf of Alaska
7970	4	Norwegian Sea
7980	4	Southeast U.S.A.
7990	3	Mediterranean Sea
8970	3	Great Lakes
9940	3	West coast, U.S.A.
9960	4	Northeast U.S.A.
9970	4	Northwest Pacific
9990	3	North Pacific

### Appendix C: LORAN-C STATION DATA

The following list contains the pertinent parameters for each Loran-C station pair. This list was compiled from the data in Reference 4. Each column contains the following information:

1. The Loran-C station pair designator.
2. The coding delay.
3. The master station latitude.
4. The master station longitude.
5. The slave station latitude.
6. The slave station longitude.

In this list, positive longitudes are West, negative longitudes are East, positive latitudes are North and negative latitudes are South. In columns 3 through 6 the latitudes and longitudes appear to be in decimal form, but the actual format is DDD.MMSSFF (which is compatible with the HP-41CV D.MS or H.MS input mode) where

- DDD designates degrees,
- MM designates minutes,
- SS designates seconds, and
- FF designates hundredths of seconds.

ID	CD	MS_LAT	MS_LON	SS_LAT	SS_LON
4990X	11000	16.44477	169.130120	20.144916	155.530970
4990Y	29000	16.44477	169.133120	28.234177	178.173020
5930X	11000	46.463218	067.553771	41.151193	069.583909
5930Y	25000	46.463218	067.553771	46.463218	053.102816
5990X	11000	51.575874	122.220224	55.262085	131.151965
5990Y	27000	51.575874	122.220224	47.034799	119.443953
5990Z	41000	51.575874	122.220224	50.362972	127.212935
7930W	11000	64.542658	045.102747	64.542658	023.552175
7930X	21000	64.542658	045.102747	62.175968	007.042671
7930Z	43000	64.542658	045.102747	46.463218	053.102816
7960X	11000	65.262021	122.220224	57.262021	152.221122
7960Y	26000	65.262021	122.220224	55.262085	131.151965
7970W	36000	64.542658	045.102747	54.482980	-008.173633
7970X	11000	64.542658	045.102747	58.380615	-014.274700
7970Y	46000	64.542658	045.102747	64.542658	+023.552175
7970Z	60000	64.542658	045.102747	70.545261	+008.435869
7980W	11000	30.593874	087.291214	30.433302	090.494360
7980X	23000	30.593874	087.291214	26.315501	097.500009
7980Y	43000	30.593874	087.291214	27.015849	080.065352
7980Z	59000	30.593874	087.291214	34.034604	077.544676
7990X	11000	38.582095	-016.430596	35.312088	-012.312996
7990Y	29000	38.582095	-016.430596	40.582095	-027.520152
7990Z	47000	38.582095	-016.430596	42.033649	-003.121590
8970W	11000	39.510754	087.291214	30.593874	085.100930
8970X	28000	39.510754	087.291214	42.425060	076.493386
8970Y	44000	39.510754	087.291214	48.364984	094.331847
9940W	11000	39.337682	118.495637	47.034799	119.443953
9940X	27000	39.337682	118.495637	38.465699	122.294453
9940Y	40000	39.337682	118.495637	35.191818	114.481743
9960W	11000	42.425060	076.493386	46.482720	067.553771
9960X	25000	42.425060	076.493386	41.151193	069.583909
9960Y	39000	42.425060	076.493386	34.034604	077.544676
9960Z	54000	42.425060	076.493386	39.510754	087.291214
9970W	11000	24.480047	-141.19290	24.17077	-153.58515
9970X	30000	24.480047	-141.19290	10.443700	-143.430906
9970Y	55000	24.480047	-141.19290	26.362499	-128.085621
9970Z	75000	24.480047	-141.19290	09.324566	-138.095523
9990X	11000	57.090988	+170.145981	52.494505	-173.105231
9990Y	29000	57.090988	+170.145981	65.141012	+166.531447
9990Z	43000	57.090988	+170.145981	57.262021	+152.221122

EAST AND SOUTH ARE MINUS '-'

Appendix D: COLOCATED STATIONS

5930 MASTER - 9960W  
5930X - 9960X  
5930Y - 7930Z  
5990X - 7960Y  
5990Y - 9940W  
7930W - 7970Y  
7930X - 7970 MASTER  
7960X - 9990Z  
7980Z - 9960Y  
7980 MASTER - 8970W  
8970X - 9960 MASTER  
8970 MASTER - 9960Z

Slave stations are denoted with a letter  
suffix. Master stations are so designated.



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