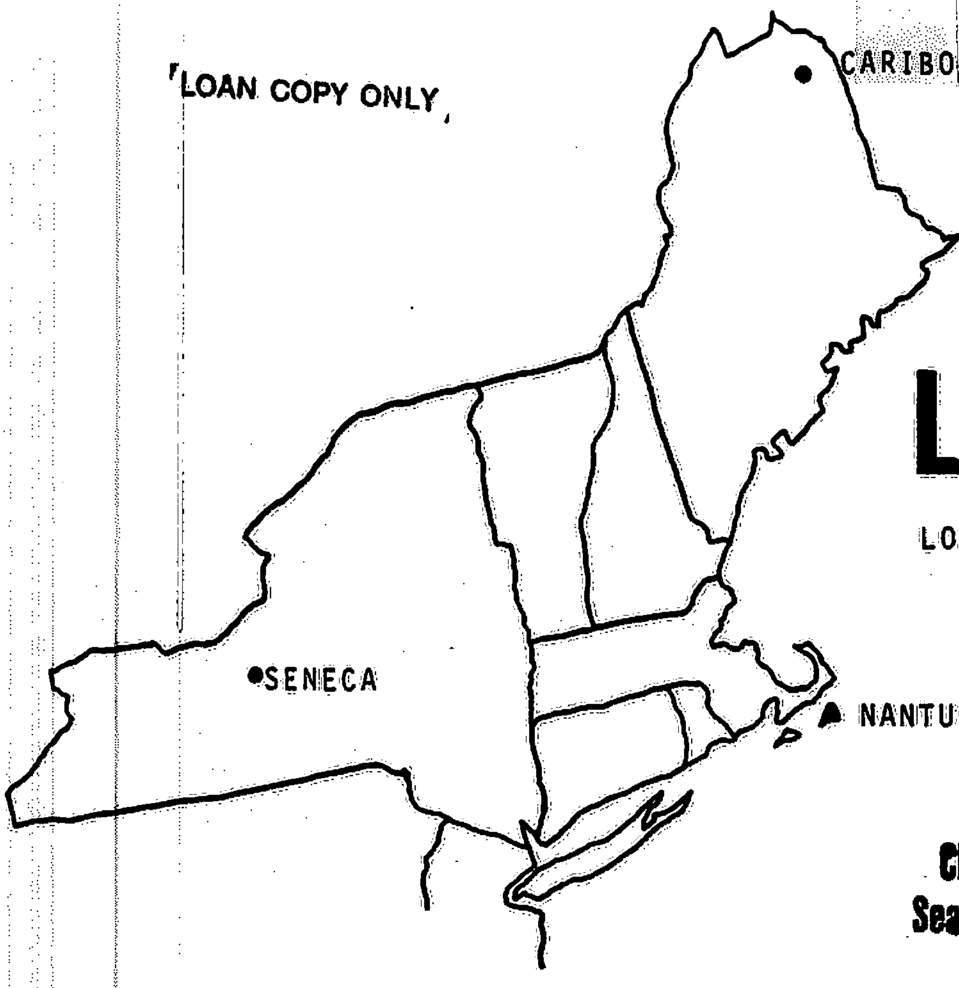
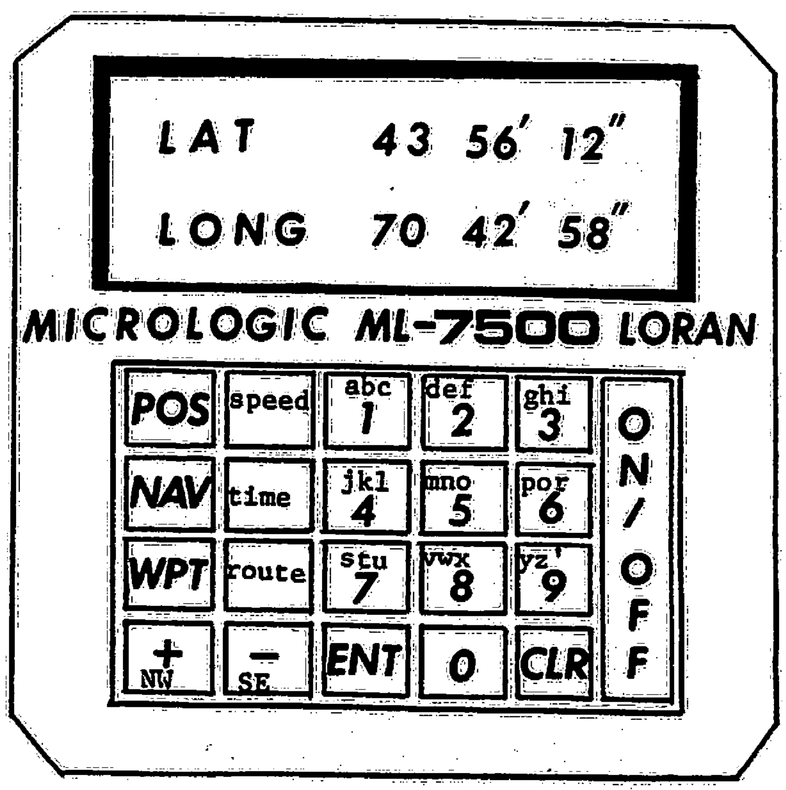


LORAN-C

LONG RANGE NAVIGATION

1984-1985 SEA GRANT PROJECTS



VOLUME I

Project Advisor:

Professor Albert Frost

Project Team:

Steve Rossi
Jill Belon
Tom Schmottlach

LORAN-C

Long Range Navigation

OCEAN PROJECTS
SEA GRANT
1984 - 1985

UNIVERSITY OF NEW HAMPSHIRE

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ABSTRACT

The LORAN-C is a widely used receiver in sea navigation today. A project team was formed at the University of New Hampshire to produce local LORAN-C grid maps to be available for the New Hampshire coast area where the Coast Guard specifies an accuracy of + or - .25 miles (1320 feet). The new maps were to have this accuracy or better. Also, LORAN-C navigation signals (using Nantucket, MA, Caribou, ME, and Seneca, NY as primary stations) in the New Hampshire coastal region exhibit an excellent signal to noise ratio and the geometry of the three stations provide good crossing angles for the line of position determination.

Our first task for this project was to acquire a LORAN-C receiver, then design and build a mobile power supply and data collective unit. During the period between November and April, we traveled regularly along the southern Maine, New Hampshire, and northern Massachusettes coasts as well as along the Great Bay region, inland up to 10 or 15 miles, and out to the Isle of Shoals. LORAN-C time delays, latitude and longitude, and the signal to noise ratio for selected points was collected.

Eleven Geological Survey maps produced by the government were used to select points from. These selected points were revisited to maintain a repeatable accuracy of + or - 25 feet to + or - 100 feet. The data was then brought back to our lab where with the use of computers, it became stored and used to calculate the localized LORAN-C grid maps. The completed maps were then taken out into the field where they were compared at arbitrary points with the LORAN-C receiver output.

TABLE OF CONTENTS

I. Introduction

The major instrument that is used in this senior project is a LORAN-C receiver (LOng RAnge Navigation). It is an electronic navigation system using shore based radio transmitters on both East and West coasts of the United States, the Gulf of Mexico as well as inland for use in many rivers and the Great Lakes.

Although LORAN-C has been used for navigation for more than 15 years, there has been an incredible upswing in coverage, capabilities and applications, and a great reduction in the cost of user equipment during recent years. This growth can be attributed to the microcomputer boom of the seventies and eighties, and the recent decision of the U.S. Government to make LORAN-C the primary civil navigation system. Civil use of the LORAN-C should continue until the year 2000 and probably later.

A group of LORAN-C stations transmitting synchronised pulse signals is called a chain. One master station and at least two secondary stations are needed for a chain. The Northeast U.S. Chain is shown in Figure 1 and is comprised of a master at Seneca, NY, and four secondaries located at Caribou, ME, Nantucket, MA, Carolina Beach, NC, and Dana, IN. The Group Repetition Interval or GRI, for this group is 99600 microsections. A GRI is the time interval between successive master pulses as shown in Figure 4. Other chain configurations provide LORAN-C coverage for southeastern U.S., the Gulf Coast, the Pacific Coast and the Great Lakes. These stations are constructed and staffed by the U.S. Coast Guard which is a part of the U.S. Department of Transportation.

The LORAN-C user must select the chain of stations appropriate to their location by programming the LORAN-C receiver to look for and lock onto a designated GRI.

A LORAN-C receiver measures the time difference (TD) between arrival of master and secondary pulses. Each time difference between one master and one secondary defines a specific hyperbolic line of position. Figure 2 diagrams TD lines for a chain with one master(M) and three secondaries (TD1, TD2, and TD3). By using one master station and at least two secondary stations a LORAN-C receiver determines its position. The intersection of two (TD1 and TD2 as an example) specific TD lines is the receiver'a position.

LORAN-C signals are radio frequency pulses sent at 100KHZ. The pulse shape shown in Figure 3 is chosen to minimize bandwidth. The exact point which the receiver determines as the timing reference is the third zero crossing. This zero crossing time is precise to within ten nanoseconds. Approximately 99 percent of transmitter energy is contained within the 90-110KHZ bandwidth. As shown, the master has nine pulses and each secondary has eight. The ninth pulse of the master allows a receiver to distinguish the master from the secondaries and then start sorting the remaining signals and eventually finding each TD. Many receivers now use these values to provide a direct computation of receiver latitude and longitude using the same algorithms that are used to create a map.

Current LORAN-C maps available to a user are drawn from calculated values of TD's. They are fairly accurate ($\pm$ 1/4 mile) but in order to get a map with better precision it is best to go to the area of interest, select various points on the map, take data at each point (TD value) and draw a best fit map around this data. This method of drawing a localized LORAN-C map increases the local precision greatly. Large scale LORAN-C maps are based on the computation of distance to the stations and assumed "typical" propagation values. Early maps assumed over water propagation for most of the path between station and observer. This is adequate for the ocean user but not satisfactory for the in-shore or terrestial based user.

TD values vary from their calculated values because wave propagation speed varies. These variations can be accounted to changes in temperature, a seasonal variation. Wave propagation speed also depends on the surface over which it is traveling. Thus wave propagation speed over land is faster than that over water, and propagation speed over muddy wet land is slower than hard frozen land, thus there are small seasonal variations as well. Also, calculated TD values do not account for wave travel over mountains and lakes. In order to create a high precision map a local field study must usually be done.

Our study involves the area near the New Hampshire, Maine and Massachusettes shorelines. Three LORAN-C transmitting stations used are Seneca, New York, the chain's master, Caribou, Maine, a secondary, and Nantucket, Massachusettes, another secondary station. The geographical area included in the study enjoys a good signal to noise ratio from all three stations. Also, the intersection of TD lines of position are at a good angle (≈120 degrees) for optimum determination of one's location.

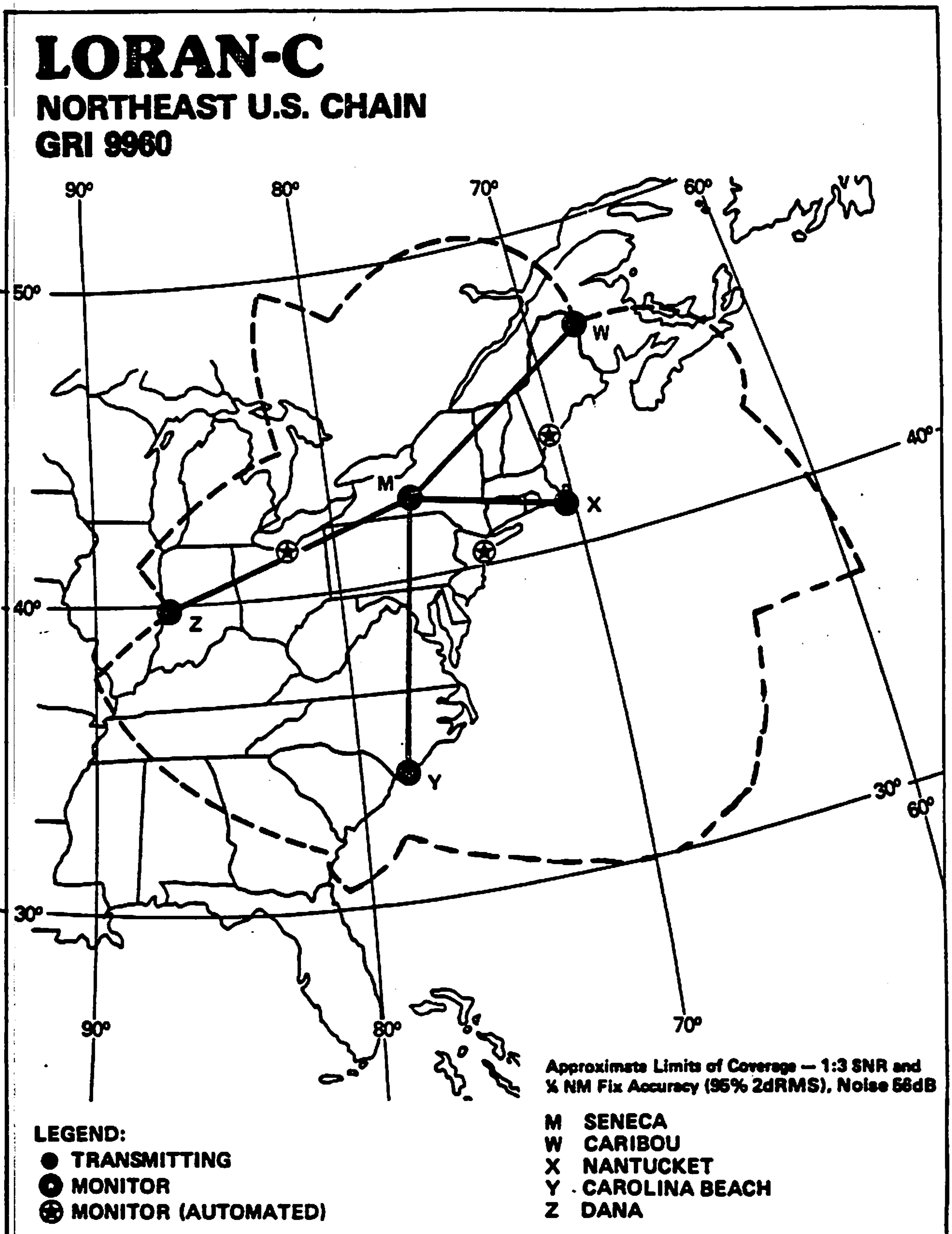
The LORAN-C Map Project involves taking data at selected locations which can be precisely indentified on geodetic maps. These maps show highways, roads, buildings, streams, river bridges and geodetic markers. The scale of the maps used is 1:24,000. By selecting a point on a map near some physical feature and then visiting the location we have established a data point. At each data point the mobile LORAN-C unit is set up and data is taken. This data includes TD1 and TD2, Latitude and Longitude, and the signal to noise ratio associated with each respective station. The data, time and weather conditions are noted as well.

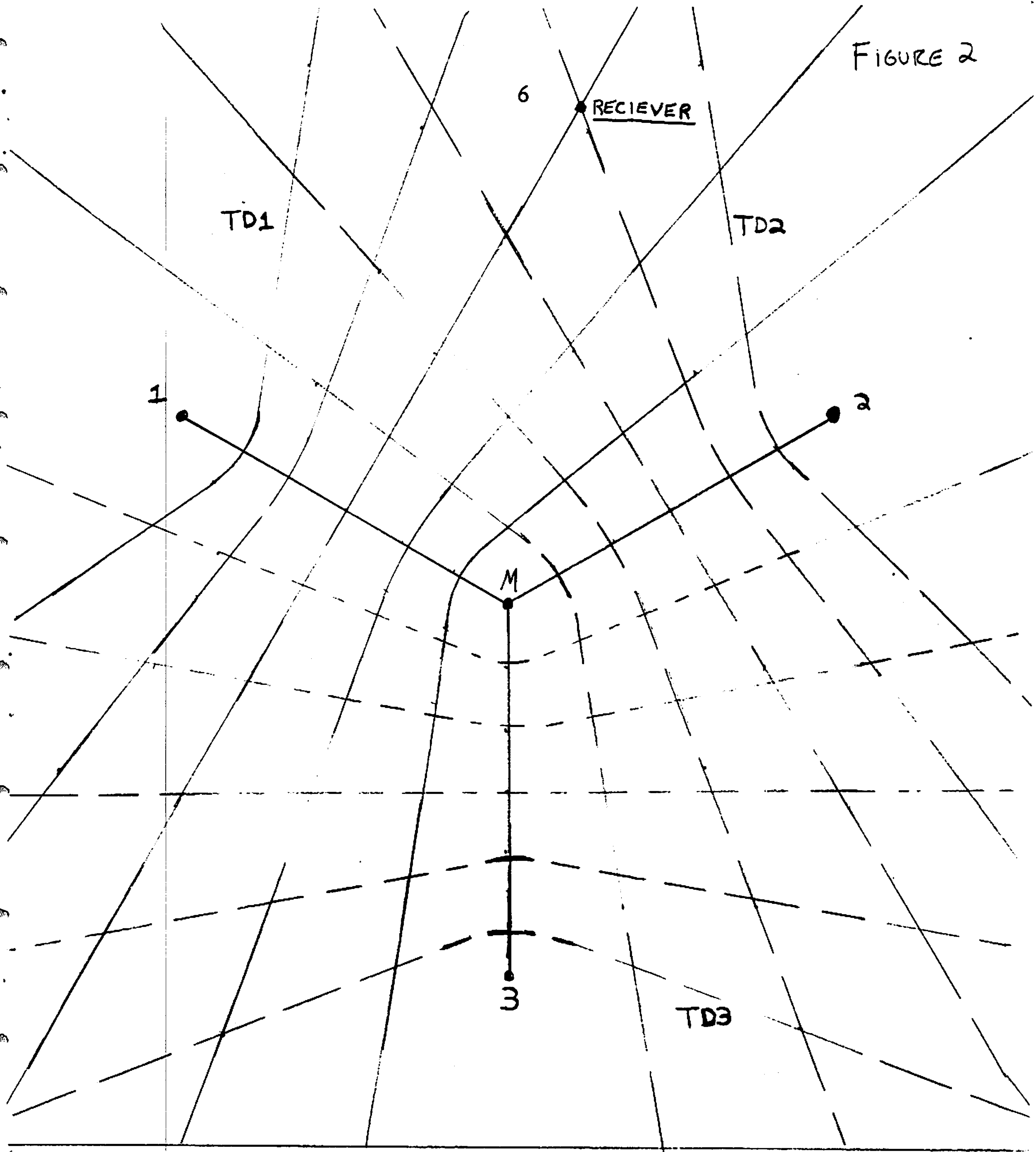
The mobile LORAN-C unit includes a LORAN-C Micrologic 7500 receiver. In a recent comparative study of LORAN-C receivers currently available to the user community, this receiver was rated as among the best. The 12 volt DC power supply is a motorcycle battery which is recharged after each field trip.

Travel to and from each data point was furnished by using a UNH car or a group member's car. The average time spent at any given data point was approximately 15 minutes. This includes setting up equipment, allowing time for the receiver to acquire track and identify each TD, taking data and disassembly of equipment. The time for our receiver to settle and display TD values can vary between two and five minutes, but once signal lock has been achieved the unit is stable and data can be taken.

Between ten and thirty points were taken on each geodetic map. These points are chosen at strategic locations easily located on each map and distributed over the entire area. The data is then processed as discussed in section two of the report into our creation of a local area LORAN-C map.

Figure 1


LORAN-C
NORTHEAST U.S. CHAIN
GRI 9960
90°
80°
70°
60°
50°
40°
30°
M
W
X
Y
Z
Approximate Limits of Coverage — 1:3 SNR and ½ NM Fix Accuracy (95% 2dRMS), Noise 56dB
LEGEND:
TRANSMITTING
MONITOR
MONITOR (AUTOMATED)
M SENECA
W CARIBOU
X NANTUCKET
Y CAROLINA BEACH
Z DANA

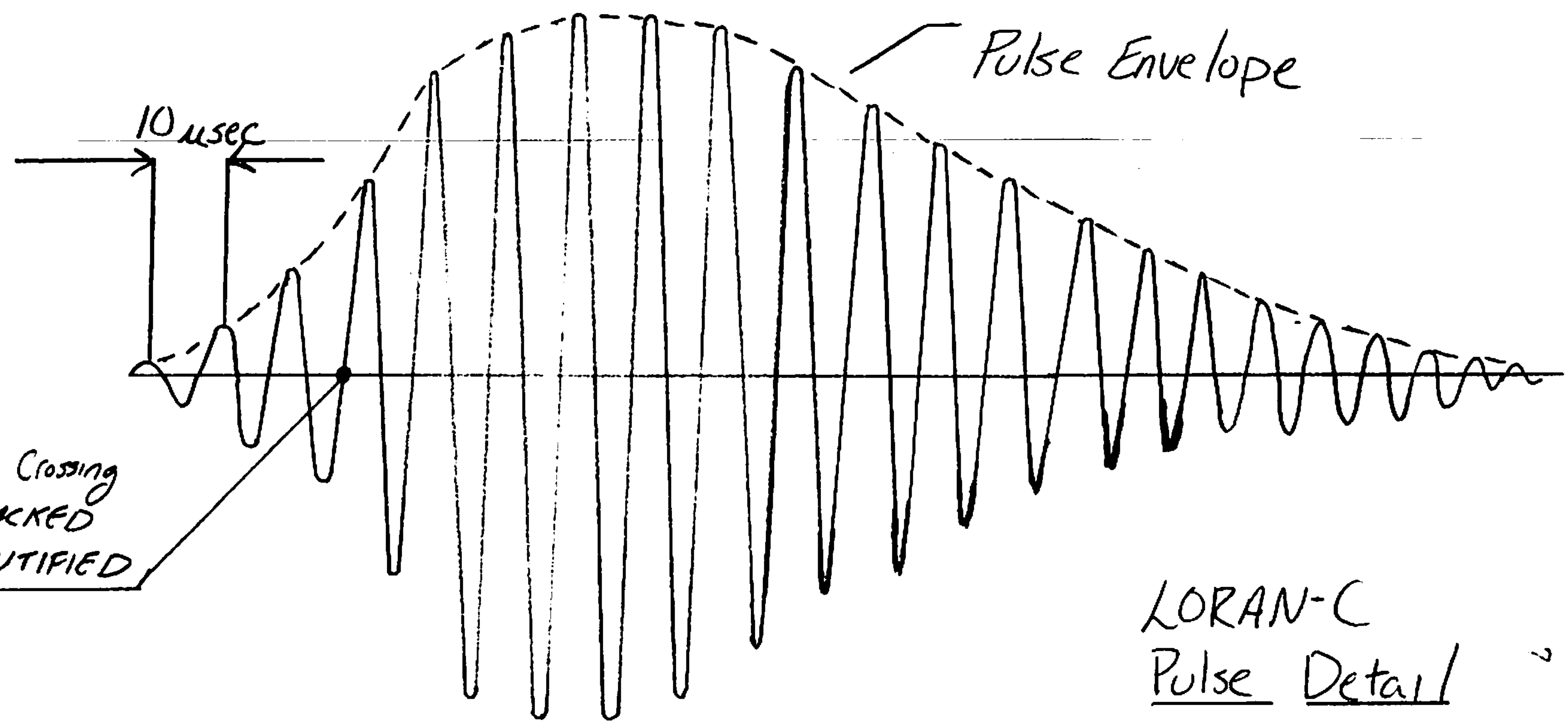


LORAN-C Time Delay Diagram For 1 MASTER AND 3 SECONDARIE

M- MASTER STATION
1- SECONDARY #1
2- SECONDARY #2
3- SECONDARY #3

——— TD1 LINES
— — TD2 LINES
— — — TD3 LINES

FIGURE 3

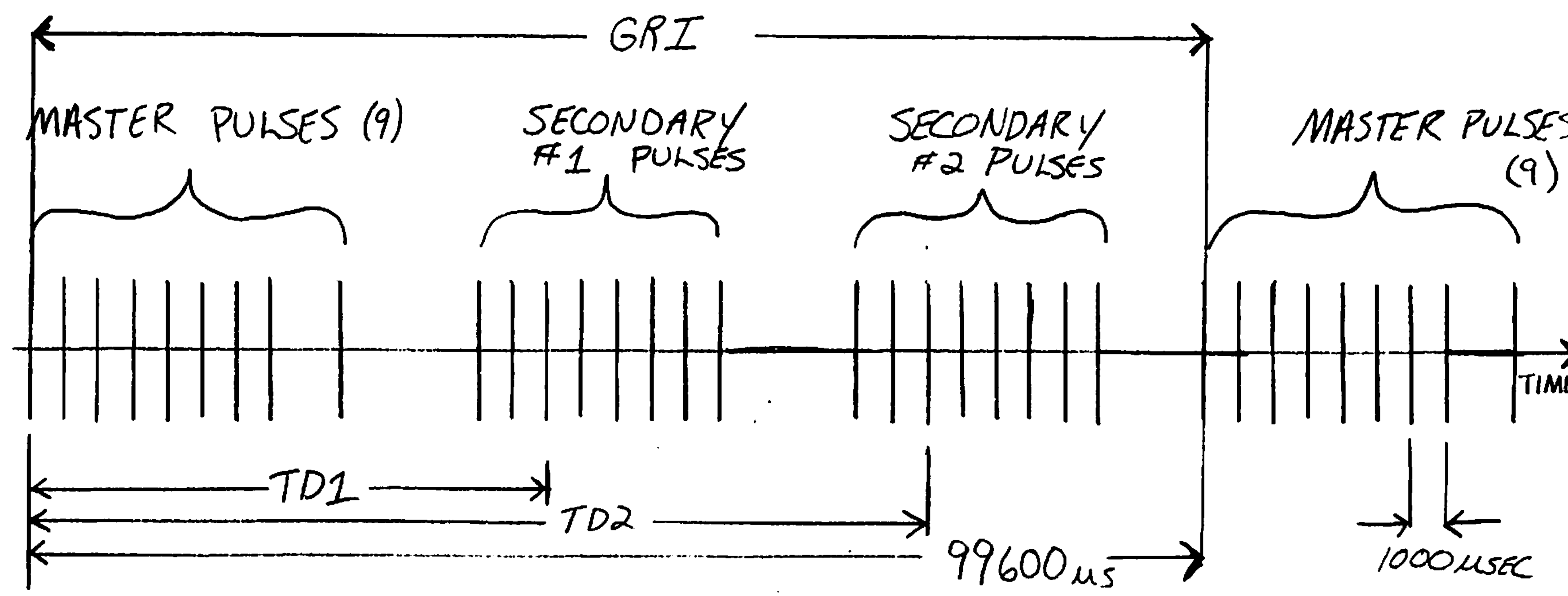


LORAN-C
Pulse Detail

FIGURE 4

EAST COAST
GROUP
REPITITION
INTERVAL

(NOT TO SCALE)



II. Field Measurement Procedures

The initial task after procurement of the receiver, was to select data points on each map. Initially, ten points were plotted on each map. Selection criteria was based on the need to find a wide spread so that the data would not be biased for one location of the map.

Additional points were needed that were easily located on the maps and recognizable in the field. It was found that highway overpasses, railroad tracks crossing roads, roads crossing streams and rivers, and road intersections were the best choice. When a chosen point was reached, an inspection was made for overhead wires. If a wire was within a 45 degree angle, it was considered by the team to be sufficiently far enough away not to influence the data.

When the survey team was satisfied with the point, data was collected (see Figure 5). A typical day of collecting data points consisted of:

1. Loading the equipment.
2. Picking points to be visited and deciding on the order of visitation.
3. Unloading the equipment at the specified point.
4. Setting up the equipment.
5. Collecting data.
6. Explaining to the curious passerby about the project.
7. Packing up and moving on.

It was possible to get an average of six points, depending on location, within four hours.

Geodetic markers were also located on the maps and data was collected at these points. Geodetic markers are markers or points of known latitude and longitude. By comparing the receiver's

Figure 5 MAP D PORTSMOUTH, NH

Date	Time	Location	Latitude	Longitude	TD1	TD2	SNR	Weather	Ground
2/10	3:30	Point 20 Center of Portsmouth traffic circle	43 04" 24'	70 46" 51'	13719.60 .59 .54 .65	26023.71 .75 .63 .68	92 86 92	Clear Sunny 35-40 degrees	No
4/13	1:30	Point 1D Left side of Fox Point Road heading west across Knight Brook	43 06" 39'	70 50" 39'	13731.83 .86 .87 .90	26058.97 59.00 58.95 58.97	89 92 93	Sunny Windy 50 degrees	Yes

TD1 - Time Delay 1
TD2 - Time Delay 2
SNR - signal to noise ratio (Seneca, NY Master Station, Caribou, ME 1st Secondary, Nantucket, MA 2nd Secondary)

calculation of latitude and longitude with those of the geodetic markers, it was possible to tell the accuracy of the LORAN-C time delay conversion to latitude and longitude.

Data was entered into the 1022 Database which is resident on the Dec System 10. The process consisted of three parts. First, a UNHFRM program was used to enter the data into the computer. Once the data was entered, another program was used to load the data into the database and put it in a readable form to print out. It was then possible to print out a listing of all the data points. (See Figure 6. Also see the program listings in Appendix A).

At this point there was a collection of data points on a map. Each point had a measured TD1 and TD2. To make the grid, it was required to connect all the points with the same TD's (See Figure 7). To do this a least squares "best fit" curve fitting program was used. This method was used because it accounts for scatter in data points better than the mathematical approach of connecting lines through each data point. This algorithm smooths the line so that it fits the data in the best way.

Specifically, for this project, it was necessary to find the angle that best fit the TD lines and gradients between them. A straight line equation $TD1 = TD0 + kd_i'$ was solved, where given a point (h,v: h=horizontal distance from the reference point and v=vertical distance from the reference point), TD1 was the measured TD(1 or 2) and d_i' was the distance from the point h,v to the reference line TD0, which was specified by the team. The reference line was drawn from the 0,0 mark on the map (lower left corner), and was drawn at an angle close to a 60 degrees angle because the TD line

Figure 6

===

DATE: 2/17/1985 TIME: 4:20:00 PM GEO. MARKER?: N MAP: A

LOCATION: POINT 2
MADBURY, NH NORTH CORNER OF MILL HILL ROAD AND HAYES ROAD
25 FEET NORTH OF THE NORTH SIDE OF THE LARGE WHITE HOUSE

LATITUDE: 43 10' 30" LONGITUDE: 70 56' 56"
CALC LAT: ' " CALC LON : ' "
GEO. LAT: ' " GEO. LON : ' "

TIME DELAY 1A: 13751.63 TIME DELAY 2A: 26117.94
TIME DELAY 1B: 13751.56 TIME DELAY 2B: 26118.03
TIME DELAY 1C: 13751.62 TIME DELAY 2C: 26118.03
TIME DELAY 1D: 13751.58 TIME DELAY 2D: 26117.97

TIME DELAY AV: 13751.60 TIME DELAY AV: 26118.00

GROUND: N NUMBER OF TIMES VISITED: 2 SNR: 91 89 88

WEATHER: CLEAR SKIES, DUSK, 45 DEGREES

===

DATE: 4/16/1985 TIME: 3:11:00 PM GEO. MARKER?: N MAP: A

LOCATION: POINT 2A
DURHAM, NH HEADING WEST ON ROUTE 4, ON THE RIGHT-CENTER SIDE OF
BRIDGE OVER ROUTE 108.

LATITUDE: 43 08' 20" LONGITUDE: 70 54' 42"
CALC LAT: ' " CALC LON : ' "
GEO. LAT: ' " GEO. LON : ' "

TIME DELAY 1A: 13749.18 TIME DELAY 2A: 26092.63
TIME DELAY 1B: 13749.21 TIME DELAY 2B: 26092.58
TIME DELAY 1C: 13749.17 TIME DELAY 2C: 26092.55
TIME DELAY 1D: 13749.21 TIME DELAY 2D: 26092.61

TIME DELAY AV: 13749.19 TIME DELAY AV: 26092.59

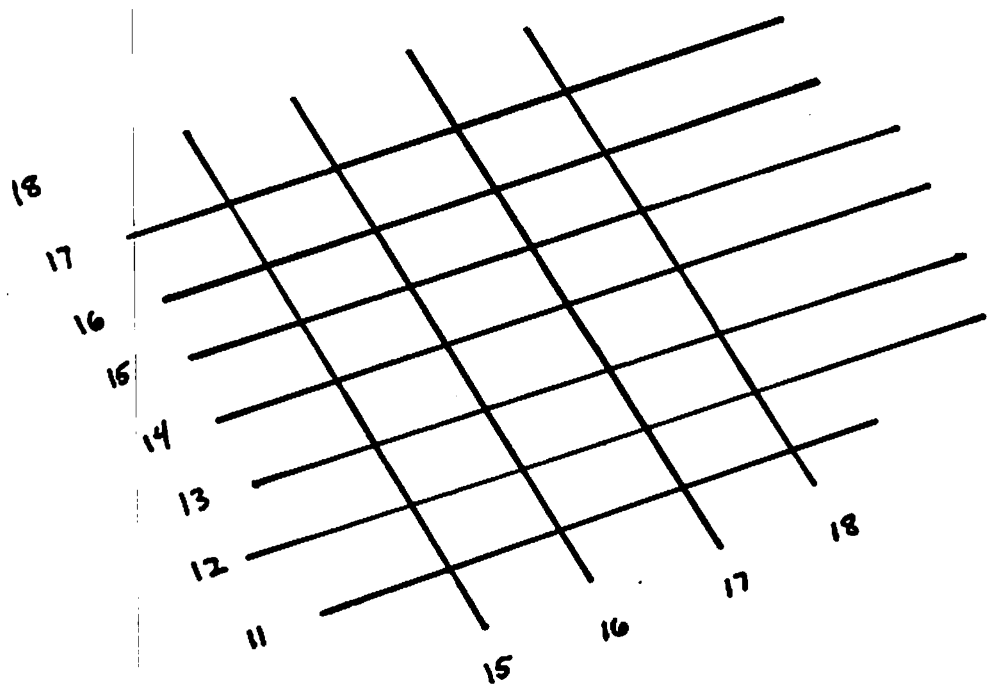
GROUND: Y NUMBER OF TIMES VISITED: 1 SNR: 93 86 93

WEATHER: 65 DEGREES, HUMID, OVERCAST SKIES.

===

Figure 7

LORAN-C GRID DESIGN



angle for this area is known to be approximately 60 degrees. The unknowns, TDO (time delay of reference line) and k (the gradient-how far apart the TD lines should be), would be solved at the end of the least-squares program used.

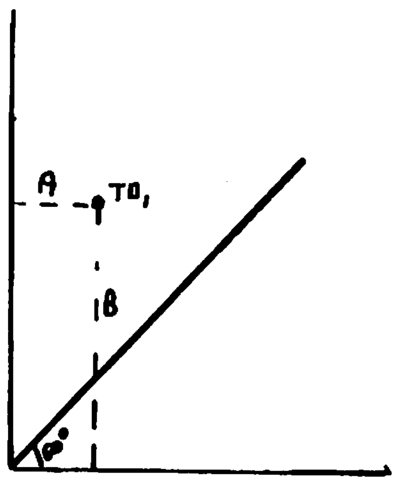
The method used to prepare the data for the least square program was as follows. The points were plotted on the map. For each point, the horizontal distance and the vertical distance from the 0,0 mark to the point were measured. Using program one (Appendix B), these two values were entered along with the TD1 and TD2 for each point. These values were then stored on tape.

Using program two, the d_1' (distance from the point to the reference line) was calculated for each point (see Figure 8). This was done for a spedified angle (60 degrees). Since the as umed 60 degree angle was a preliminary estimate, the calculations were repeated for several angles and each set was stored on tape.(see program two in Appendix B and an example of map D in Appendix D). At this point, the least squares program was required.

This program read in the TD's and the d_1' for each angle given and produced the following output: the time delay of the reference line based on the given data points, the gradient of the grid lines (in microsec/cm) which had to be inverted to cm/microsec, and the residual error which is the standard error of the estimate. The best angle was selected by minimizing the residual error. The program also provided a graph with all the data points on it and a "best fit" line going through the data. Ninety-five percent confidence bands were also plotted (see figure 9).

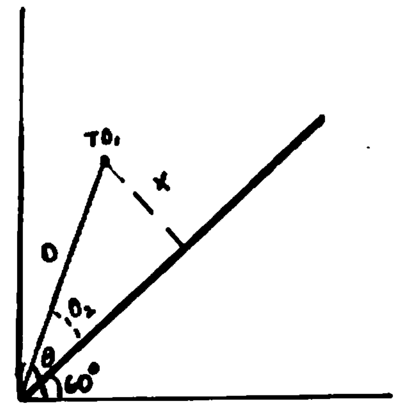
With this information, the best angle, time delay gradient and time delay of the reference line, it was possible to draw the maps.

Figure 8



Input
A B TD1

Output
A B TD1



Input
A B TD1

Output
Y or TD1

$d_1 = X$ - distance from point to reference line

$D = \sqrt{a^2 + b^2}$

$\theta = \arctan b/a$

$\theta_2 = 60° - \theta$

$X = D \cdot \sin(\theta_2)$

Figure 9

Y = A + B*X

A =
26078.7925599

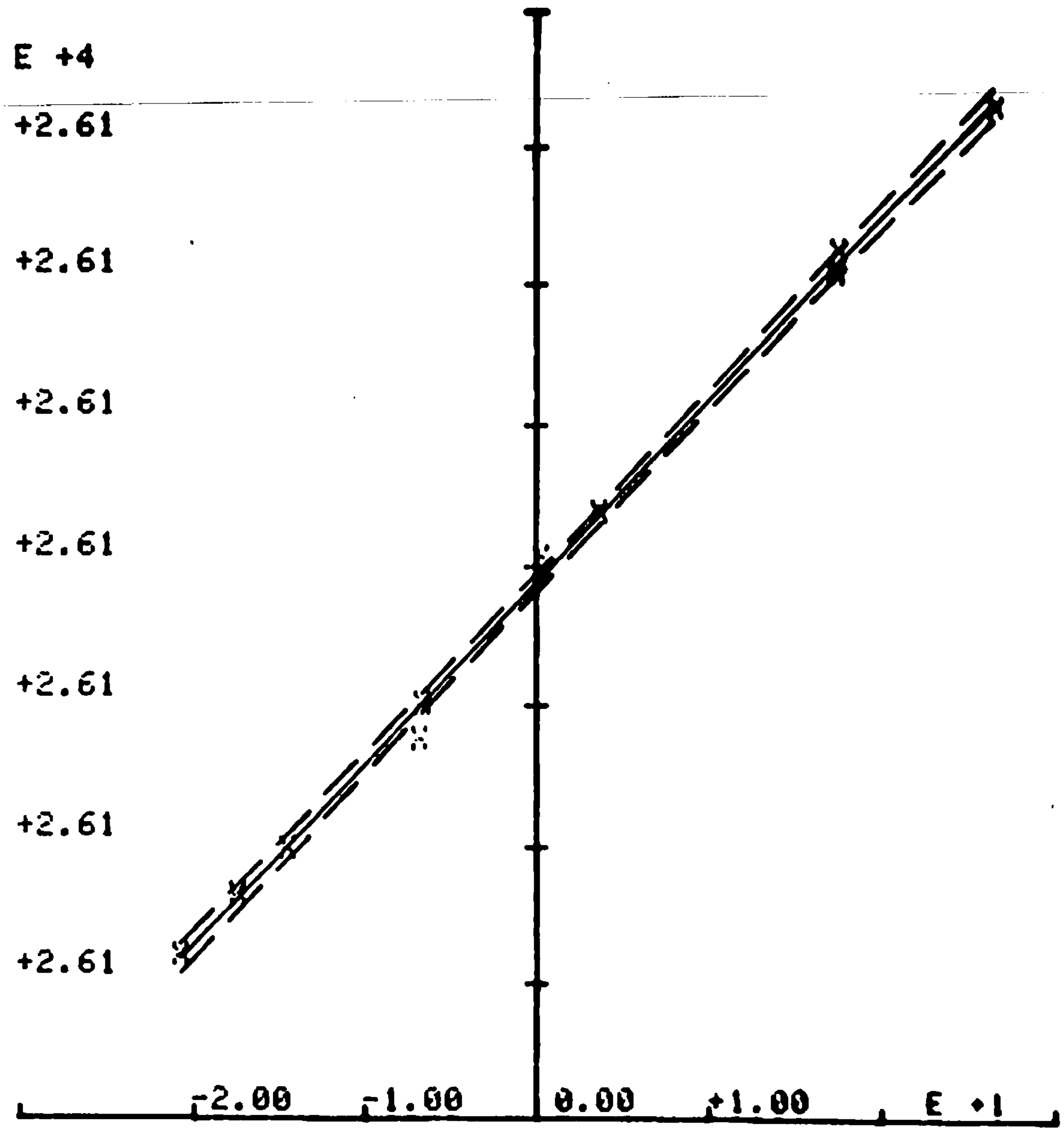
B =
1.30131700456

R-SQUARE =
0.997987430142

RES ERROR
0.894430635132

MAX(ABS(RESIDUAL))
2.24104545087

Map C
55.5°



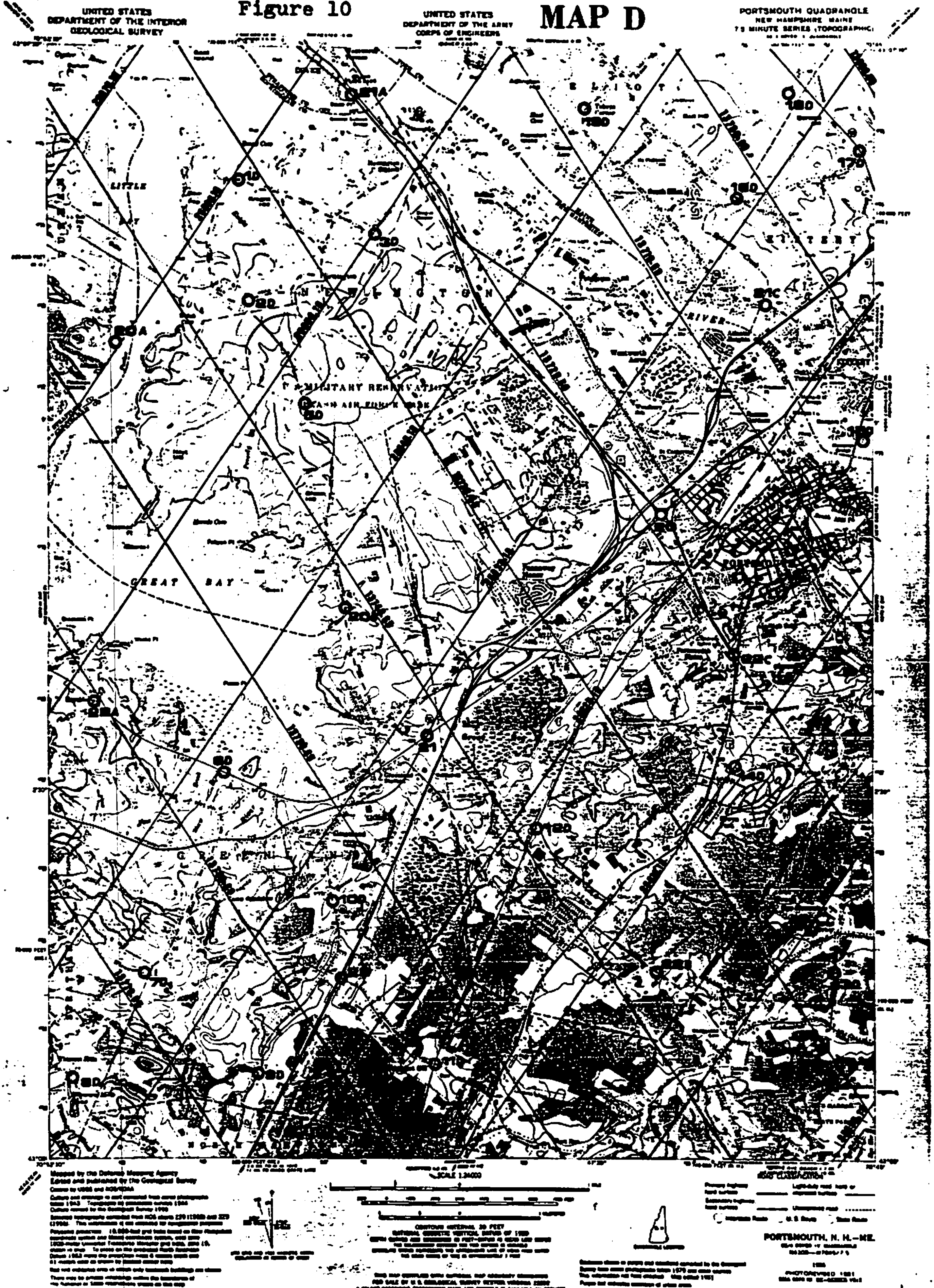
Drawing the maps was the final and most exciting stage in the project because now it was possible to see if the endless hours of collecting data and processing it turned out to be accurate on the maps themselves.

As mentioned previously, the least squares program gave all the information needed to produce the LORAN-C time delay grid. For simplicity, the positive y-axis was the left side of the map and the positive x-axis was the bottom side. The lower left-hand corner or origin of each map was the starting point for drawing the grid lines and measuring the best-fit angle. We kept the color coordination consistent so that TD1's were green lines and TD2's were blue lines.

Using map D as an example (see Figure 10); since TD2 was 26033.18 and the best-fit angle was 56 degrees, then a line would be drawn from the origin with an angle of 56 degrees with the x-axis. Using gradient #2, or the equal spacing between consecutive time delay lines, the tens' values were found (ie. 26030.18, 26020.18, etc.) and these lines were drawn with the appropriate color. The results of how well the measured values matched up with the predicted values from the grid, will be explained in the next section.

Figure 10

MAP D



III. Results

With all the data collected, processed and utilized in the LORAN-C grid making process, it is necessary to examine how well the results turned out. It should be reiterated here that we are looking for accuracy within the finalized maps.

To help with the understanding of our project results, a listing of the final statistics will follow. Our project team collected information from the data points over a wide territory; as far north as Cape Neddick in York, Maine, as far south as Newbury, Mass., and inland up to 15 miles. A few visits were made to the Isle of Shoals off the coast of New Hampshire. Points were taken during the months of November thru April in all kinds of weather conditions.

From this large area, information was collected at a total of 134 locations. From this distribution, 16 points were revisited twice and 3 of the 16 were revisited three times as shown in Figure 11. Numerous studies have shown that repeatable accuracies of from ±25 feet to ±100 feet are possible with the LORAN-C. Our repeatable accuracies ranged from 0 feet to ±150 feet.

Due to their difficult location only six geodetic markers were found. When compared to the U.S. Department of Commerce results, as shown in Figure 12, our values of the latitude and longitude matched very well. The degrees and minutes comparing exactly and the seconds varying from 1 to 7 seconds.

Eleven U.S. Geological Survey maps were used out in the field. They showed in great detail the towns used to select our locations from. Each map was given a letter from A to L and Figure 13 shows a table of which map corresponds to which towns. Final map making was concentrated on six principle, shore-oriented maps: C, D, F, H, I and L. With more time, the other five maps can be reproduced.

As with any long-term project, questions are raised and small problems occur that must be answered and adjusted for in order for the project to continue. In our case, we kept asking ourselves the best way to choose points, how many points per map would be needed, and how many revisited points should be obtained. It was decided that in order to spread out the points evenly to cover the map region, a minimum of 10 points would be required. The question remained as to whether 10 would really be enough for accuracy. Therefore, map D was used as our test case map. To aid in one's understanding, follow Appendix D since it gives the results for map D.

After collecting the first ten points, the data was entered in the computers and the results stored. Data was collected from a second set of ten points combined with the first group and it was discovered that results from a total of 20 points were similar to those from just ten points. To check further, another set of ten points was collected for a total of 30 and were satisfactory since the results were consistent again. It was concluded that since ten, twenty or thirty points all give the same final TD's and angles for the maps, and time was important, ten points per map as a minimum was sufficient.

From Appendix A, the TD's show that some flutter was present at each site so an average TD had to be calculated in order to run the computer programs. Since one data collection interval at each site was no more than 15 minutes, it was necessary to determine if the TD flutter would ever settle down to a constant value. At point 34, Little Boars Head (a geodetic marker), data was collected at 20 second intervals for three hours. After this laborous process, the TD flutter had not settled to a constant value but remained changing with the same scatter pattern which had been seen in 15 minute intervals. Therefore, it was concluded that results collected during the 15 minute time span were representative and satisfactory for our project.

To explain the reproduced maps and their accuracies in detail, map D will be used again as shown in Figure 10. All the other LORAN-C grids reproduced here follow the same basic format and their accuracies will be shown following this discussion.

The U.S. Coast Guard specifies a $\pm 1/4$ mile accuracy for the LORAN-C. Our goal was to produce maps accurate from measured TD values to less then $\pm 1/4$ mile. After the TD values are drawn on map D, the predicted location of each point using their corresponding average TD's compared to those drawn on the map is determined. Appendix D (page) gives this predicted location as well as the measured location for each point on map D. The difference in feet between the two is given also and these numbers are used to determine the accuracy of the map. For map D, the best accurate position one can obtain is ± 50.94 feet and the worst is ± 551.63 feet. This is less than $\pm 1/8$ mile and is therefore well within the goals' accuracy range.

The other five maps have similar accuracy intervals as shown by the table in Figure 14. These are very satisfactory results as they are representative of what the project sought out to accomplish. Appendix E also gives the predicted location and measured location, and the difference in feet for each point on the other maps.

Problems did occur with map J or the Isle of Shoals map when the reproduction of the LORAN-C grid began. With the islands being small, located at the center of the map, and surrounded by water, points could not be evenly distributed throughout the map region. For this reason, the reproduction of map J is not considered to be carried out.

For the final, valid check of the completed LORAN-C grid maps, maps C and D were taken out into the field where they were compared at arbitrary points to the LORAN-C receiver display output. As shown in Figure 15 , the results are very good. Of the three points established on map D, the approximate difference in feet ranged from ±50 feet to ±400 feet. For map C, with the three established points, the difference ranged from ±20 feet to ±400 feet. The remaining maps will be evaluated at a later date.

FIGURE 11

POINTS REVISITED

POINT	MAP	TD1	TD2	NUMBER OF TIMES VISITED
1	A	13762.03	26106.76	1
1	A	13761.97	26106.84	2
1	A	13762.00	26106.90	3
2	A	13751.59	26118.17	1
2	A	13751.60	26118.00	2
3	A	13744.20	26125.96	1
3	A	13744.63	26125.96	2
3A	A	13733.46	26139.32	1
3A	A	13733.46	26139.32	2
4	A	13734.76	26112.12	1
4	A	13734.74	26112.18	2
5	A	13729.68	26101.98	1
5	A	13729.69	26102.09	2
5	A	13729.69	26102.06	3
14	C	13781.78	26100.80	1
14	C	13781.61	26100.69	2
16	C	13796.07	26083.80	1
16	C	13796.32	26083.78	2
20	D	13719.54	26023.69	1
20	D	13719.60	26023.68	2
21	D	13742.64	26028.39	1
21	D	13742.67	26028.40	2
31	F	13795.65	26008.65	1
31	F	13795.73	26008.49	2
34	F	13756.24	25982.61	1
34	F	13756.15	25982.56	2
34	F	13756.36	25982.36	3

FIGURE 11

POINTS REVISITED

POINT	MAP	TD1	TD2	NUMBER OF TIMES VISITED
35	I	13688.50	26021.39	1
35	I	13688.45	26021.38	2
37	I	13691.07	26004.58	1
37	I	13691.27	26004.40	2
74	L	13644.87	26011.43	1
74	L	13644.78	26011.50	2
77	L	13663.63	26017.74	1
77	L	13663.56	26017.88	2

FIGURE 12

GEODETIC MARKERS

POINT	MAP	GEODETIC LATITUDE / LONGITUDE	MEASURED LATITUDE / LONGITUDE
42	J	43 00' 17" 70 36' 16"	43 00' 24" 70 36' 11"
43	J	42 59' 13" 70 36' 51"	42 59' 18" 70 36' 44"
34	F	42 57' 28" 70 46' 33"	42 57' 32" 70 46' 29"
34	F	42 57' 28" 70 46' 33"	42 57' 30" 70 46' 28"
15	I	43 02' 35" 70 42' 47"	43 02' 36" 70 42' 40"

FIGURE 13

MAP - TOWN LOCATIONS

MAP A DOVER WEST, NEW HAMPSHIRE

DURHAM, NH
MADBURY, NH
DOVER, NH
LEE, NH
BARRINGTON, NH

MAP B DOVER EAST, NEW HAMPSHIRE - MAINE

ELIOT, ME
SOUTH BERWICK, ME
ROLLINSFORD, NH
DOVER, NH

MAP C NEWMARKET, NEW HAMPSHIRE

DURHAM, NH
LEE, NH
NEWMARKET, NH
NEWFIELDS, NH
STRATHAM, NH
EXETER, NH

MAP D PORTSMOUTH, NEW HAMPSHIRE - MAINE

ELIOT, ME
KITTERY, ME
PORTSMOUTH, NH
RYE, NH
GREENLAND, NH
NEWINGTON, NH
DURHAM, NH

MAP E EXETER, NEW HAMPSHIRE - MASSACHUSETTES

EXETER, NH
STRATHAM, NH
HAMPTON FALLS, NH
KENSINGTON, NH
EAST KENSINGTON, NH
SOUTH HAMPTON, NH
SEABROOK, NH

MAP F HAMPTON, NEW HAMPSHIRE

RYE, NH
NORTH HAMPTON, NH
HAMPTON, NH
HAMPTON FALLS, NH
SEABROOK, NH

Figure 13

MAP G	NEWBURYPORT WEST, MASS. - NEW HAMPSHIRE
	AMESBURY, MA SALISBURY, MA NEWBURYPORT, MA NEWBURY, MA WEST NEWBURY, MA MERRIMAC, MA GROVELAND, MA
MAP H	NEWBURYPORT EAST, MASS. - NEW HAMPSHIRE
	SEABROOK, NH SALISBURY, MA NEWBURY, MA NEWBURYPORT, MA
MAP I	KITTERY, MAINE - NEW HAMPSHIRE
	KITTERY, ME YORK, ME RYE, NH PORTSMOUTH, NH
MAP J	ISLE OF SHOALS, MAINE - NEW HAMPSHIRE
	ISLE OF SHOALS
MAP L	YORK HARBOR, MAINE YORK BEACH, MAINE
	YORK, ME SOUTH BERWICK, ME KITTERY, ME

FIGURE 14

MAP	ACCURACY (FEET) WORST	BEST
C	±442.67	±50.98
D	±551.63	±50.94
F	±449.35	±66.82
H	±302.33	±43.71
I	±351.78	±10.30
L	±571.96	±24.37

FIGURE 15

MAP	MAP TD'S	LORAN TD'S
D	26021.18 13728.79	26020.79 13727.88
	26049.18 13718.69	26048.81 13718.59
	26017.18 13720.69	26017.83 13721.15
C	26080.19 13780.82	26080.25 13781.28
	26090.19 13797.90	26089.57 13798.02
	26045.19 13791.82	26045.95 13791.84

VIII. Conclusion

The LORAN-C project team is extremely pleased with the results. The accuracy was increased from the U.S. Coast Guard's ± 1320 feet to the project team's ± 571.96 feet. Therefore, the error is reduced by 50 per cent.

Although the maps produced were for coastal areas, additional data was collected from inland areas. Calculations and maps from this data can be completed in one week or two weeks at most.

One map which was not completed, was the Isle of Shoals map. The spread of the data points was too small to give accurate results in the least squares map-fitting method. A solution might be to obtain a map which contains both the Isle of Shoals and the coastal area. The increased number of points would create a more evenly distributed spread.

Seasonal variation is an additional aspect of LORAN-C navigation that may be investigated. Seasonal variation may be determined by collecting information at the previously determined data points used for this report. Comparing these new results with this projects' results would show whether there is any seasonal variation for the LORAN-C time delays. Depending on the difference in time delays, additional maps can be drawn for the various seasons.

The project team is very proud with the work completed and is satisfied that the new maps will permit safer navigation for the New Hampshire, Maine and Massachusettes coastal area.