Evaluation of VHF-FM Shore-Based Direction Finding Triangulation System in Massachusetts Bay Area

Charles J. Murphy
LTJG James C. Preisig

Transportation Systems Center
Cambridge MA 02142

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16. Abstract

This report describes the evaluation of a VHF-FM Direction Finding Triangulation System in the Massachusetts Bay Area of the First Coast Guard District during the 1982 boating season. The evaluation consisted of the following phases:

(1) System definition and site selection;

(2) System calibration;

(3) Operational evaluation;

(4) Cost/benefit analysis.

It was concluded that properly implemented shore-based direction finding systems in either single line-of-bearing or triangulation configurations are valuable potential tools in accomplishment of SAR mission requirements.

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PREFACE

As an element of the program to develop concepts and technology applicable to improved emergency distress location, the U.S. Coast Guard (USCG) directed the Transportation Systems Center (TSC) to procure, install and evaluate a VHF-FM direction finding (DF) triangulation system in the Massachusetts Bay Area during the 1982 boating season. This document describes an operational evaluation (OPEVAL) of the technical performance and cost-effectiveness of that system. Based on the results of the OPEVAL, as described in this report, TSC will prepare a technical specification for use by the Coast Guard in procurement of additional VHF-FM DF triangulation systems. This specification will be published as a separate document.

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EXECUTIVE SUMMARY

As an element of the program to develop concepts and technology applicable to improved emergency distress location, the U.S. Coast Guard (USCG) directed the Transportation Systems Center (TSC) to procure, install, and evaluate a VHF-FM direction finding (DF) triangulation system in the Massachusetts Bay Area during the 1982 boating season. This document describes an operational evaluation (OPEVAL) of the technical performance and cost-effectiveness of that system.

The desired system was required to provide position determination for VHF-FM transmissions originating anywhere in the Massachusetts Bay/Cape Cod Bay Area utilizing remote DF receiving antennas to be located on existing Coast Guard structures.

The system chosen for the evaluation consists of three remotely located DF receiving systems connected by communication links to a Control/Display Unit at the Group Boston Communications Center. The three remote receiving sites are located at Cape Ann Light on Thacher Island, COMMSTA Boston in Marshfield, MA and Highland Light in North Truro, MA. Upon receiving a VHF-FM transmission at a minimum of two of the three receiving sites, the system presents an estimate of the transmitter's position along with an estimate of the accuracy of the position calculation.

Following system installation, a system calibration was performed utilizing test transmissions from SAR vessels and Class-C EPIRBs from known locations throughout the area of coverage. It was determined that the system provided position determination coverage for the entire Massachusetts Bay/Cape Cod Bay Area with an accuracy of 1-2 nautical miles for 25-watt ship transmissions. Due to the lower transmitted power, only line-of-bearing coverage was obtained for Class-C EPIRB transmissions.

The system has been in operational service since July 1982, and has been used successfully on several SAR cases. Operational personnel have found the system easy to use and reliable.

1. INTRODUCTION

As an element of the program to develop concepts and technology applicable to improved emergency distress location, the U.S. Coast Guard (USCG) directed the Transportation Systems Center (TSC) to procure, install, and evaluate a VHF-FM direction finding (DF) triangulation system in the Massachusetts Bay Area during the 1982 boating season. This document describes an operational evaluation (OPEVAL) of the technical performance and cost-effectiveness of that system.

The desired system was required to provide position determination for VHF-FM transmissions originating anywhere in the Massachusetts Bay/Cape Cod Bay Area utilizing remote DF receiving antennas to be located on existing Coast Guard structures.

The system chosen for the evaluation consists of three remotely located DF receiving antennas with associated receiver-processors, connected by communication links to a Control/Display Unit at the Group Boston Communications Center. The system was designed and manufactured by Southwest Research Institute (SwRI) of San Antonio, TX, and is described in detail in reference 1. The three remote receiving sites are located at Cape Ann Light on Thacher Island, COMMSTA Boston in Marshfield, MA and Highland Light in North Truro, MA and are shown in Figure 1-1. The five channel system receives on channels 6, 12, 15, 16 and 22A of the VHF-FM band with channel selection controlled from Group Boston. Upon receiving a VHF-FM transmission at a minimum of two of the three receiving sites, the system presents an estimate of the transmitter's position along with an estimate of the accuracy of the position calculation.

During a three-week period following system installation, a system calibration was performed utilizing test transmissions from SAR vessels and Class-C EPIRBs from known locations throughout the area of coverage. During this calibration, personnel of the

MERRIMACK RIVER

THACHER ISLAND

GLOUCESTER

MASSACHUSETTS BAY

BOSTON

PT. ALLERTON

SCITUATE

MARSHFIELD TOWER

PROVINCETOWN

HIGHLAND LIGHT

□ DF Receiving Site
△ Control/Display Console

CAPE COD BAY

CAPE COD CANAL
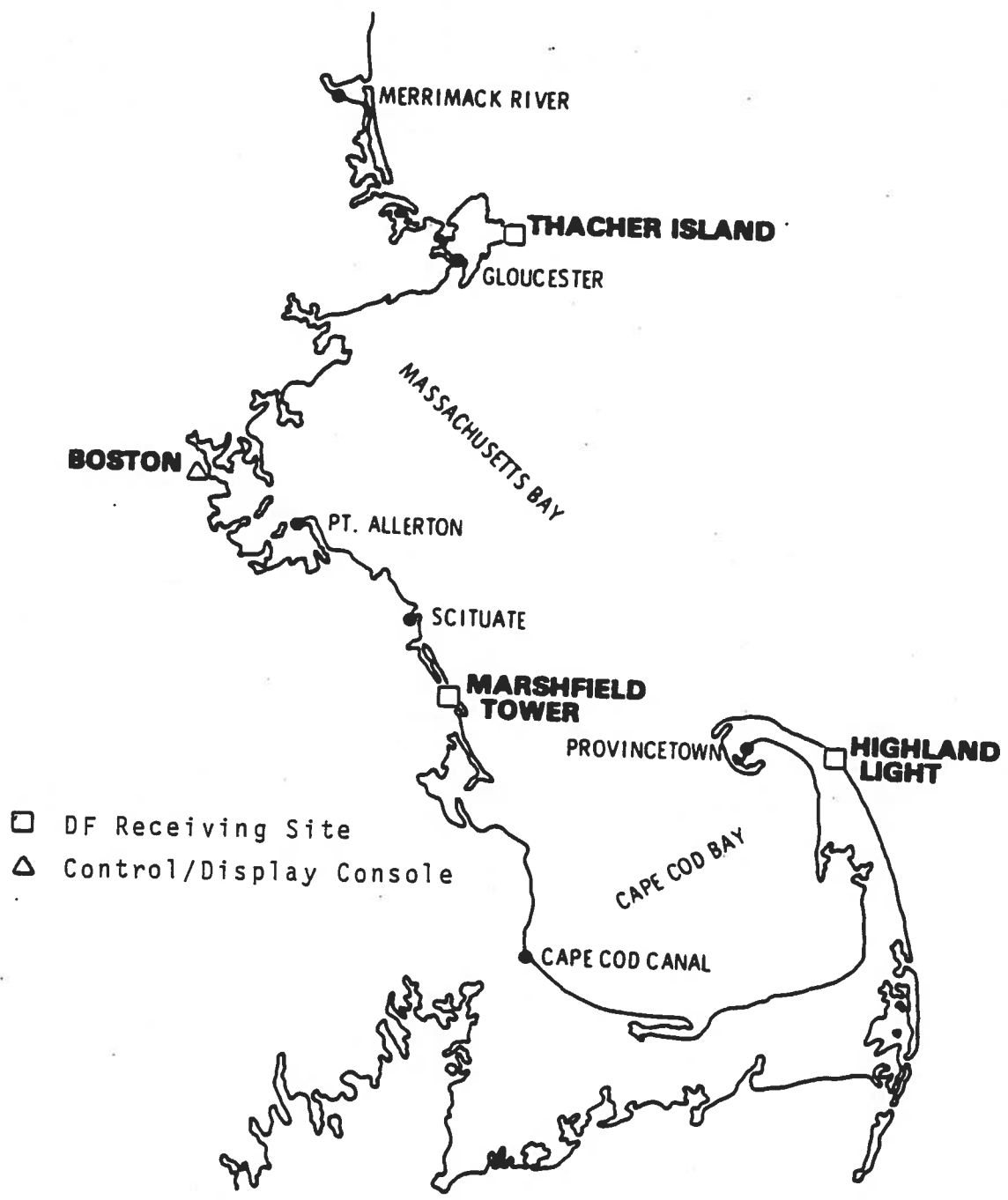
FIGURE 1-1.   DF SITE LOCATIONS

1-3/1-4

2. PRELIMINARY SYSTEM DESIGN AND SITE SELECTION

In designing a position locating system based on inputs from remotely located (bearing only) direction finding equipment, receiving antenna locations and heights must be chosen so that:

1. transmission from any point in the coverage area is received with adequate signal strength from at least two remote sites;

2. the resulting bearings to the transmitter from the sites should be no closer than 30° from being parallel.

The second requirement is necessary since each DF bearing is subject to such inaccuracies as site reflections and received noise, and a given bearing error translates into a larger position error as the intersection angle with the remaining LOP approaches the parallel alignment (at which point the position error becomes infinitely large). Thus the relative locations and heights of the DF sites and the relative location of the target transmitter influence the accuracy of location estimation. With any chosen set of antenna locations, the system accuracy over the required coverage area will be a constantly changing function of the number of LOPs obtained, the signal strengths and accuracy of the bearings, and the bearing intersection angles.

A study of triangulation geometry for the Massachusetts Bay/Cape Cod Bay Area indicated that DF receivers should be located in the following areas: Gloucester/Cape Ann, MA; Scituate/Marshfield, MA; and Provincetown, MA and that antenna heights of at least 200 feet ASL would be required.

Two possible sites were identified in the Gloucester/Cape Ann region: Eastern Point Light (57 feet ASL) and the Cape Ann Light on Thacher Island (166 feet ASL). Because of its superior height and offshore location the Cape Ann light was the clear choice from DF signal considerations alone (Figure 2-1). However, telephone service to the island, provided by a submarine cable, was in poor condition and considered unsuitable for use in the

2-1

DF system. To overcome this problem a decision was made to purchase and install a full duplex UHF link between the Cape Ann Light and Group Boston for the experiment.

In the Scituate/Marshfield area an ideal antenna site was available at the top of the microwave relay tower at COMMSTA Boston. The top of the tower (240 feet ASL) is free of antennas and affords a clear view to sea (Figure 2-2).

For the third site two possible locations were identified; the Pilgrim Monument in Provincetown, MA (348 feet ASL) on which a USCG high site is installed, and the Highland Light in North Truro, MA (183 feet ASL). The Pilgrim Monument, although the clear choice from signal reception considerations, is privately owned and was not available for the experiment. Thus the third site is the Highland Light, located approximately ten miles south of Provincetown (Figure 2-3). This site and the Marshfield site are connected to the control unit by dedicated, voice-grade telephone lines.

Upon consideration of the distances between the sites and the antenna heights offered by the available sites, it was determined that sensitivity was a critical system parameter and that basic system r.f. sensitivity should be enhanced by a system of averaging successive bearings from the same transmission. The bearing standard deviation for a fixed signal-to-noise ratio is improved by a factor of $\sqrt{N}$ when N independent bearings are averaged. Therefore the system is designed to compute independent bearings at a rate of 10 bearings per 200-millisecond time period. The ten bearings are averaged; bearings outside a predetermined limit are thrown out, and the resulting average bearing and average signal strength are transmitted in a frequency-shift keyed (FSK) format to the Control/Display Unit, where additional averaging is performed prior to calculation of position.

FIGURE 2-3. HIGHLAND LIGHT AT NORTH TRURO, MA

2-5/2-6

3. SYSTEM DESCRIPTION

3.1 SYSTEM OVERVIEW

This chapter presents a system description of moderate detail following the system block diagram presented in Figure 3-1. For a more detailed description, see references 1 and 5.

3.2 DF ANTENNA

The DF antenna is a fixed four-element dipole Adcock, designed for center frequency operation of 160 MHz. The antenna is designed to allow the mounting of a separate symmetrical antenna above it and includes a hollow mast to carry the cables to the upper antenna. This would allow installation at a Coast Guard high site with the communications antenna on top. A photograph of the antenna is shown in Figure 3-2. A hybrid electronics package in the DF antenna provides simultaneous signals proportional to $\sin\phi$, $\cos\phi$, and omnidirectional with respect to the azimuth angle(ϕ) of the incident signal. The three antenna outputs are routed by phase-matched cables to the DF processor unit.

3.3 DF PROCESSOR UNIT

A DF Processor Unit (Figure 3-3) is located at each remote site and performs the following functions:

1. five-channel VHF-FM receiver;

2. bearing determination;

3. bearing averaging;

4. signal strength measurement;

5. communications link interface.

The DF Processor Unit provides full local control of the remote site with three digit bearing readout, channel select switch, readout, and audio headphone output.

3-1
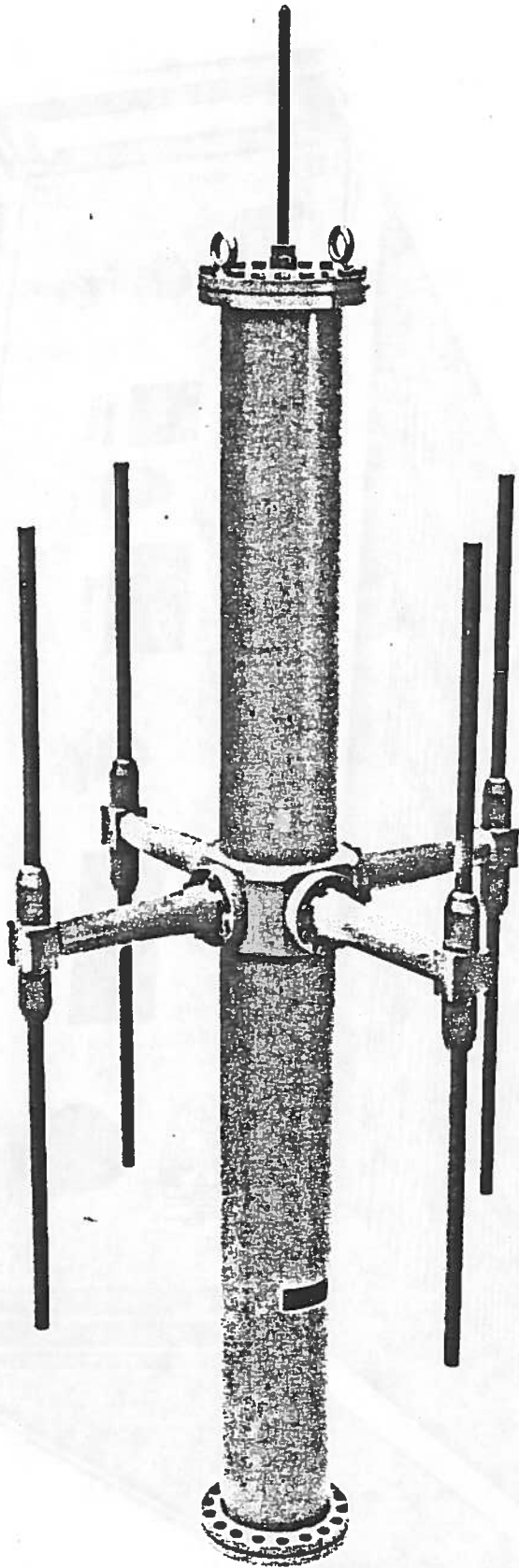
FIGURE 3-2.   ANTENNA ASSEMBLY (from Ref 1)

However, its primary mode of operation is as a slave receiver for the control console, and as such it receives and carries out channel change commands received on the communications link. The three antenna inputs to the DF Processor are used to compute the angle of arrival (bearing) of the signal using an electronic goniometer and a power (sense) combiner. Bearings are computed at a rate of 10 per 200-ms period and averaged in a microprocessor. Individual bearings differing substantially from the computed average are thrown out. The resulting average bearing, and the average received signal strength are encoded in a frequency-shift keyed (FSK) format and combined with the demodulated audio. The resultant signal is transmitted over a single dedicated voice-grade telephone line (or equivalent communication channel) to the Control/Display Unit.

3.4 CONTROL/DISPLAY UNIT

The Control/Display Unit, shown in Figure 3-4, provides operator control of the remote DF sites, as well as processing and display of the received bearing information and derived position information. The Control/Display Unit is composed of the following subunits:

1. Control Interface Unit;

2. Apple II Plus Computer;

3. SMD Color Video Display;

4. Epson MX-80 Printer.

The Control Interface Unit receives simultaneous inputs from the three remote sites containing audio and digital data. Notch filters are used to separate the audio and digital data and the audio can be selected from a single site, or any combination of sites, for monitoring through a loudspeaker. The data stream is then monitored and sampled in real time by the Apple computer.

The only data transmitted to the remote sites is the receiver channel select command which is encoded in an FSK format and transmitted simultaneously to the three remote DF sites. The sites,

upon complying with the "channel select" command, transmit an "acknowledge" signal back to the control console.

The FSK encoded bearing and signal strength data from each remote site is individually time tagged and input to the computer. The computer compares the arrival times of the bearing data from the three channels via the time tags and if two or all three of the inputs fall within a 60-millisecond time window, the signals are considered to have originated from the same transmitter. Signals thus qualified are used to compute a position which is presented to the operator. Bearings from signals falling outside of the 60-ms window are presented to the operator as bearing only information.

Due to the fact that each bearing received from a remote site has errors associated with it, the lines-of-position (LOPs) from three sites will not intersect in a single point but will intersect in three points, forming a triangle. In determining a statistical best point estimate to be used as the target position, the contractor utilized a least squares method, first described by Stansfield (ref. 6). The position is calculated by selecting the point that minimizes the weighted distance to each LOB. The weighting emphasizes bearing data from DF sites that are nearer the estimated position and those having the smallest bearing standard deviations.

· Typical system operation will now be described. The operator first configures the system utilizing a display on the video monitor called the "OPTION MENU" which is shown in Figure 3-5. The operator makes the following choices:

1. Channel Selected: 6, 12, 15, 16, 22

2. Fix Time: 2, 5, 10 or 15 seconds. The computer will collect bearing data for the selected fix time or until the end of transmission, whichever occurs first, before presenting an averaged bearing.

3. Printer: ON/OFF. If the printer is selected "ON", all data appearing on the video monitor will be printed. If

the printer is selected "OFF", the contents of the screen can be printed via a "PRINT SCREEN" key.

4. <u>Disk Storage</u>. Allows data to be stored on disk. Not normally used.

5. <u>DF Collection Mode: MANUAL/AUTO</u>. In "MANUAL," the computer will display position and bearing information on a transmission only if a "MANUAL DF" key is pressed prior to or during a transmission. In "AUTO", data will be displayed for all received transmissions.

Once the configuration is complete, the operator receives data on the video monitor (and printer, if selected) in the format shown in Figure 3-6.

Referring to the upper left hand corner of Figure 3-6, the date, time, and channel number are presented for a typical transmission. Below this the latitude and longitude of the calculated position are presented along with the major axis (MJ), minor axis (MN) and the orientation to true north (TLT in degrees) of a 95 percent confidence error ellipse. Opposite this information is presented the average bearings from the sites (TI = Thacher Island; MT = Marshfield; HL = Highland Light) used in the position calculation. Also presented for each bearing (BRG) are the standard deviation (SD) of the average bearing, the average received signal strength (SS), and the number of bearings used to compute the average (#B). Note that the overall number of bearings averaged is ten times greater than indicated due to the previous averaging before transmission from the remote site.

System status information is presented in the bottom four lines of the display. Status of the communications links to the three sites is presented under the "ERROR" column. If the link is operating properly, bearing information from the sites is presented in real time in this column before being processed. The remaining columns contain, in addition to confirmation of the system configuration, date, time of day, and the number of transmissions the computer has received but has not had time to process yet (DATA STACK).

4. SYSTEM CALIBRATION

4.1 INSTALLATION AND CHECKOUT

During the week of May 24 the DF receivers were installed at the three remote sites (antennas having been previously installed). Each site was individually aligned to true north and checked out via test transmissions from local Coast Guard shore-based transmitters. These adjustments were made by the SwRI system engineer at the remote sites, before the units were connected to the communication links. After all three receiving sites were determined to be working properly, they were tied into the Control/Display Unit and exercised individually from Group Boston. Finally the position computation system was exercised for all local shore-based transmitters, and found to be working properly.

4.2 CALIBRATION PROCEDURES

Figure 4-1 presents the predicted coverage areas for the three sites, indicating that there are areas of coverage by all receiving sites and areas covered by only two sites. In addition, there are areas such as north of Plum Island and east of Cape Cod where single site coverage will be provided resulting in determination of a bearing only to the transmitter. All testing was supported by 41-foot utility boats from local SAR sations except for the eastern part of Massachusetts which required support more than 10 miles offshore. For these tests, a 95-foot cutter was utilized. The test schedule is presented in Table 4-1 and test vessel routes are shown in Figure 4-2.

On all tests, vessel position was determined by a calibrated LORAN-C receiver provided and operated by a TSC test engineer. The LORAN-C receiver was checked before and after each series of test transmissions by reference to known locations such as buoys and the dockside position. Test transmissions were of 1, 10 and 15 seconds duration to determine system accuracy dependence on length of transmission. All tests transmissions were on channel 22A.

TABLE 4-1. SYSTEM CALIBRATION TEST SCHEDULE

Test Sequence No.	Test Support	Date	Region Covered
1	STA Gloucester, 41' utility boat	7-13-82	Cape Ann to Nahant; to LNB, to Gloucester
2	STA Point Allerton, 41' utility boat	7-15-82	Nahant to Cohasset Harbor
3	STA Scituate, 41' utility boat	7-16-82	Scituate Harbor to Plymouth Harbor
4,5	STA Provincetown, 41' utility boat	7-30-82 7-21-82	Provincetown Harbor to Orleans
6	STA Cape Cod Canal, 41' utility boat	7-22-92	Plymouth Harbor to Orleans
7	STA Gloucester 41' utility boat	7-27-82	Newburyport Harbor to Cape Ann
8	STA Gloucester, 95' cutter	8-3-82	From Gloucester 40 nm at 135°M, south to latitude of Provincetown, to Gloucester

Additionally, at selected locations in each test sequence, the DF receiving channel was changed to Channel 15, and a Class-C EPIRB was used as the signal source.

Each test transmission resulted in a printout of bearings and position of the test vessel at the Group Boston Communications Center. The format of this printout is shown in Table 4-2. A test engineer annotated each printout with vessel position and determined that the DF system and communication links were functioning properly.

Detailed test procedures for each day were prepared in consultation with Coast Guard operational personnel. These procedures included course of vessel, transmission coordinates, length and number of transmissions at each location, and calibration points for the LORAN-C receiver.

4.3 CALIBRATION RESULTS

Detailed test results (tabulations from ref. 2) are included in Appendix A. This data is summarized below.

4.3.1 Tests Conducted with 25-Watt Transmitter

With the standard 25-watt VHF-FM transmitter as a test source, position location was possible throughout the intended coverage area with the exception of the extreme southeastern region of Cape Cod Bay, where a bearing only was obtainable. The average position error was approximately one nautical mile. Average received signal strengths for the test positions are indicated in Figures 4-3 through 4-5 (from ref.2). Towards the conclusion of the test program the sensitivities of the Marshfield Tower and Highland Light DF receivers were increased by 6 dB. Thus system coverage and accuracy is somewhat better than the test results indicate (the receiver sensitivity had been reduced to mitigate the decorrelation problem).

4.3.2 Tests Conducted with Class-C EPIRB

A limited number of tests were conducted utilizing a Class-C EPIRB deployed in the water as the signal source. The Class-EPIRB
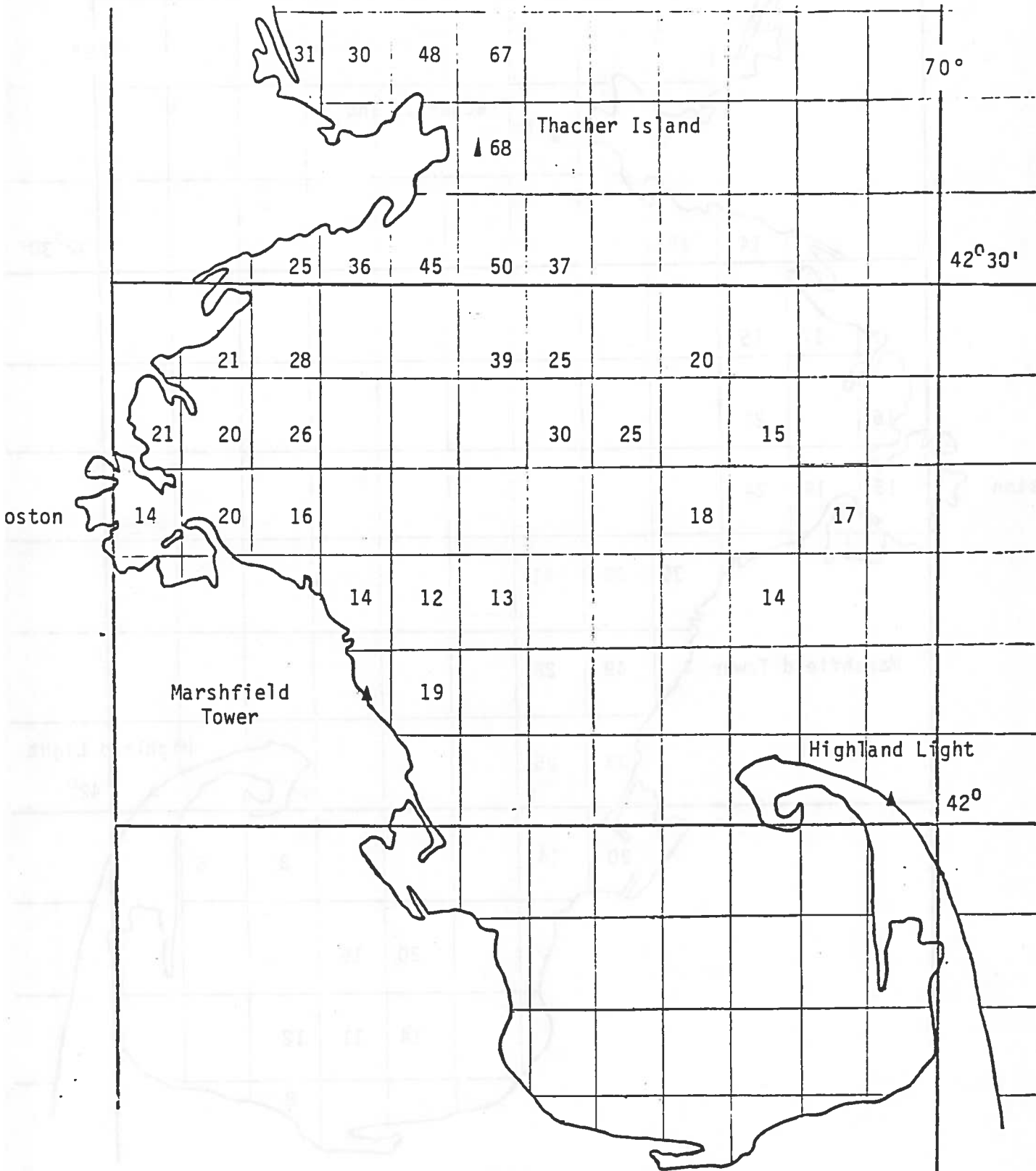
FIGURE 4-3.   SIGNAL STRENGTH AVERAGES FROM TEST POSITIONS
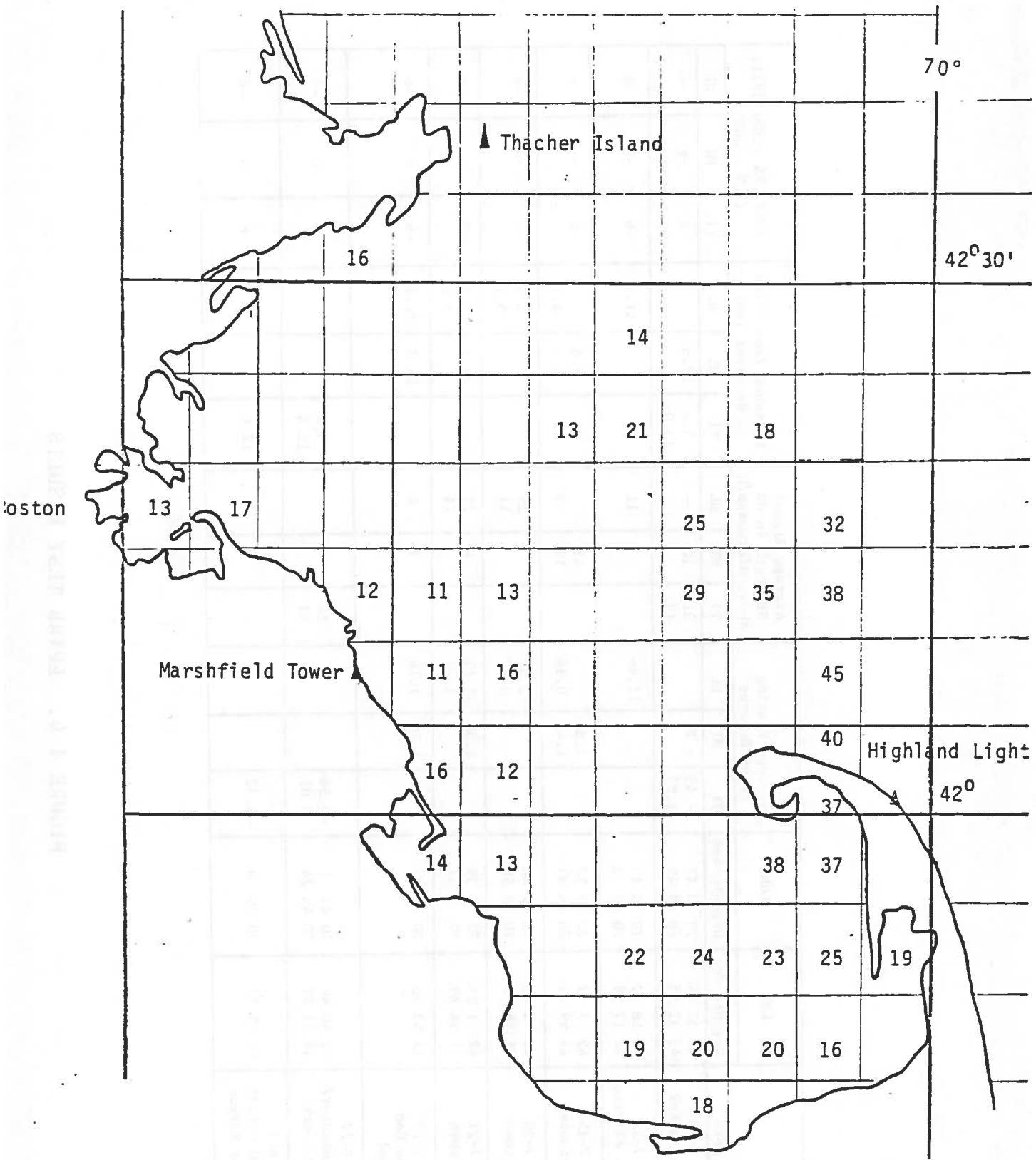AT THACHER ISLAND (from Ref 2)

FIGURE 4-5. SIGNAL STRENGTH AVERAGES FROM TEST POSITIONS
AT HIGHLAND LIGHT (from Ref 2)

transmits a short VHF-FM signal format on channels 15 and 16 at one-watt output power. Since this is an operational EPIRB, precautions were taken to inform the boating public and other Coast Guard units before and after each test was run. Because of this only 15 EPIRB tests points were taken vs. approximately 100 total test points during the calibration. The test results indicated the expected lower reception range for the one-watt signal as compared to the 25-watt transmissions. The system was able to produce only line of bearing information for the EPIRB transmissions due to their lower power. EPIRB test results are tabulated in Figure 4-6.

4.3.3 Site Dependent Bearing Errors

Prior to acceptance testing, each DF antenna is tested on a near-ideal site and bearing errors due to the antenna pattern are corrected. When the antenna is installed on a typically imperfect receiving site, repeatable bearing errors due to nearby reflectors will usually be observed. These errors can then be reduced or eliminated by storing error information in a look-up memory table in the DF processor, thus increasing system accuracy. Examples of site induced error patterns are seen in Figures 4-7 through 4-9 (from ref. 2) for the three receiving sites. The Thacher Island and Marshfield sites show a sinusoidal pattern, whereas Highland Light shows a constant offset at all bearing angles, which was corrected by changing the north adjustment.
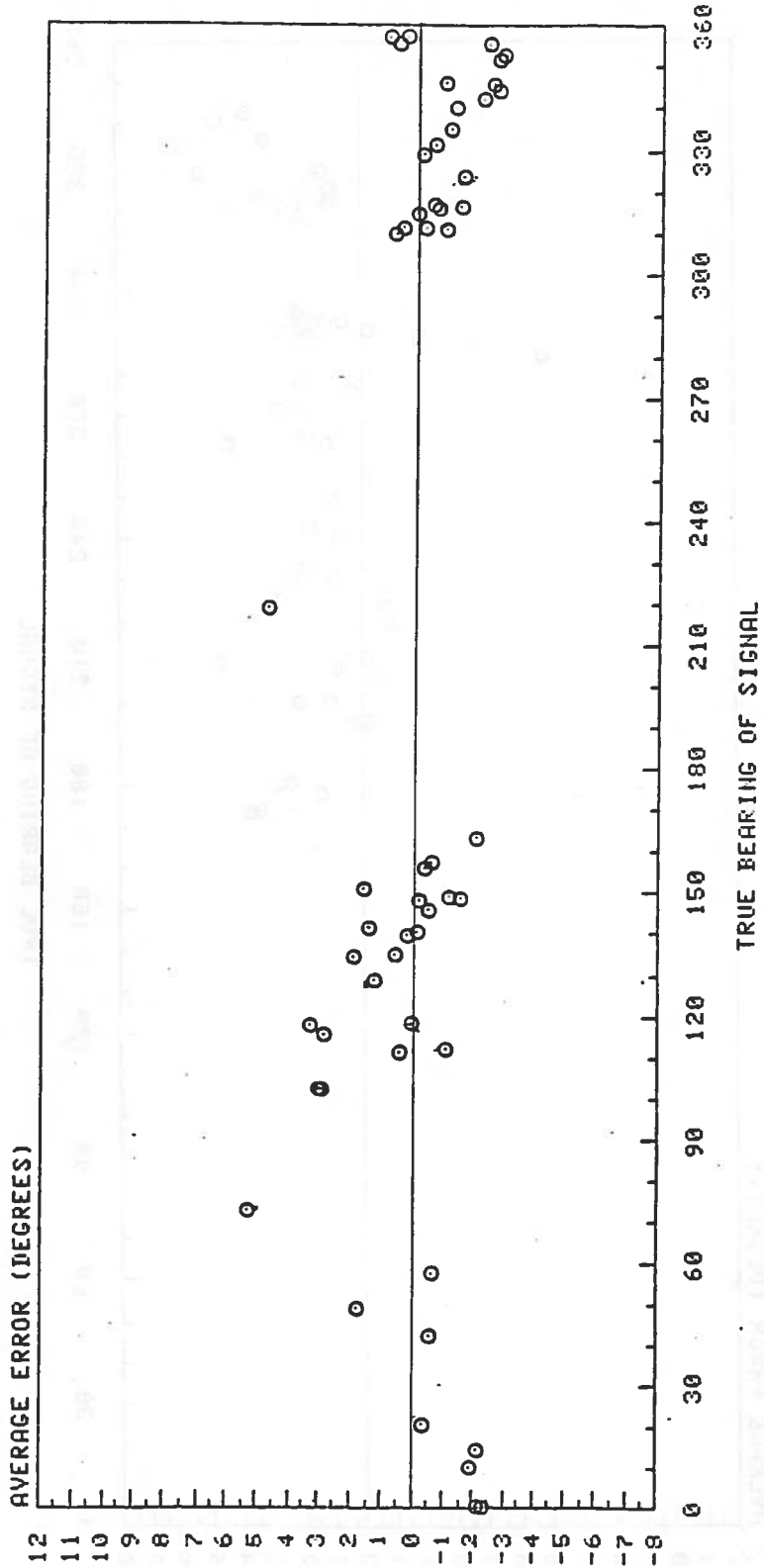
FIGURE 4-8. DF TRIANGULATION BEARING ERROR AVERAGES MARSHFIELD TOWER
(CHANNEL 22) (from Ref 2)

5. SUMMARY OF OPERATIONAL USE

Having shown via the calibration that the system meets requirements for coverage and accuracy, the present section will describe the remaining aspects of system performance as determined during the OPEVAL. These aspects fall into the categories of ease of use, reliability, and maintainability. Discussion of these categories will be preceded by a brief description of typical cases the system has been used on.

5.1 OVERVIEW OF OPERATIONAL USE

The system was used on several types of cases, such as, boat lost, injured seaman, sinking, and hoax.

On several occasions, the system was used to determine the position of a lost vessel. As an example, a pleasure vessel became lost in heavy fog in Salem Harbor. The approximate position was determined by the DF system and a Coast Guard vessel was directed to the vessel without a search.

A seaman was seriously injured on a fishing vessel off Cape Ann. The vessel's radio operator did not speak English but was able to convey the seriousness of the problem. The vessel's approximate position was determined on the initial transmission and a Medical Evacuation was carried out. In this case the DF position was backed up by a LORAN-C position from an assisting fishing vessel.

A fishing vessel off Cape Ann reported it was sinking and the crew was being rescued by another vessel which then left the scene. A utility boat was dispatched from Station Gloucester to the scene but could not locate the vessel due to poor visibility and the fact that the vessel was low in the water. The Staff Duty Officer was able to vector the utility boat to the sinking vessel by using the DF in a differential mode. In this mode the vector difference in DF positions of the distress and rescuing vessel is derived and used to direct the rescuing vessel.

transmissions can occur, making it very difficult to identify the correct position calculation when it eventually is presented.

To resolve the above problem a third mode of operation, the "MODIFIED MANUAL" mode will be incorporated which is similar to the present manual mode except that calls occurring up to 15 seconds before the "MANUAL" button is pressed will also be displayed. With this feature a call will not be lost with the system in manual mode as long as the "MANUAL" button is pressed within 15 seconds after the transmission ended. It is recommended, based on operator's comments, that future systems be operated in the "MODIFIED MANUAL" mode.

5.2.3 Control Convenience

In the original configuration, the method of changing channels, which required calling the menu, selecting the channel and deselecting the menu, is time consuming in comparison to conventional channel selection methods. As a solution to this problem, a software modification will be incorporated which will allow the operator to change DF receiving channels without having to leave the DF mode.

5.2.4 Vector Calculation

Since the predominant error source in most position calculations is a repeatable site induced bearing error, and since these errors have been shown to be fairly constant in 5-10° bearing sectors, positions calculated on targets located within 2-3 nm of each other tend to have the same repeatable error segment. The vector difference becomes more accurate as the targets approach each other. A software routine will be incorporated allowing automatic calculation of this vector.

5.2.5 Graphical Display

A software routine will be incorporated to allow the LAT/LONG and error ellipse of a selected transmission to be presented on

5.3.1.2 <u>Communication Link Reliability</u> - <u>UHF Link to Thacher</u>
<u>Island</u>: Intermittent outages were experienced on several occasions in July and September, possibly due to interference. This problem has not recurred in the last several months, and link reliability is considered excellent. <u>Phone Lines</u>: The dedicated voice-grade phone lines to Marshfield and Highland Light suffered three outages, all of which were repaired within 24 hours. This performance was better than anticipated.

5.3.2 <u>System Maintainability</u>

Early indications are that the system will be quite reliable with the major maintenance problem being the DF processors, due to their remote location and specialized circuitry. Due to the small number of these units at the group or district level it does not appear cost effective to train personnel to repair them locally. However, the alternative, returning them to the factory, results in approximately one week down time per site per failure. A spare processor could be obtained for approximately $30,000 but would not be efficiently utilized with only three field units installed. However, if more than one system were installed in a district the provision of a spare processor would probably be cost effective, eliminating the need to return to the site with the repaired unit and reducing down time.

6. COST/BENEFIT ANALYSIS

One measure of the desirability of the VHF-DF System is the difference between the cost of installing, operating and maintaining the system and the value of the benefits derived from the system. The cost/benefit analysis is a vehicle for looking at these quantities. A cost benefit analysis was performed for the system as installed as well as for theoretical systems which could be installed in the Nantucket Island-Block Island-Woods Hole Area and the Chesapeake Bay Area.

6.1 BENEFIT ANALYSIS

The most difficult of the two quantities to determine is the economic value of the benefits which might be derived from the system. The benefits can be split into two groups. The first group contains benefits to the Coast Guard in the form of resources saved as a result of reduced search requirements. The second group consists of benefits to society in the form of additional property and lives which might be saved. Because of the small amount of time available to collect Search and Rescue (SAR) data while the VHF-DF System was operational, it was decided to use the SAR Data Base for fiscal years 1979, 1980, and 1981, which is maintained at Coast Guard Headquarters, as the data base for this analysis. There was insufficient reliable data for fiscal years 1977 and 1978 to justify including this data in the analysis. The benefit of the system can be determined by analyzing each case in the file to determine the extent to which the use of the VHF-DF system would have impacted on resources expended, lives lost, or property lost.

It is recommended that the procedures described in this document be utilized to determine the cost effectiveness of potential sites for VHF-DF Triangulation Systems throughout the Coast Guard. Initial identification of areas of possible interest can be accomplished using a special computer program written by LT. J. Lentz (G-DST-3). This program, utilizing FY 1982 SAR data, identifies

Once the applicable cases were identified, they were analyzed to determine the potential savings to the Coast Guard in resources which might have been realized if a VHF-DF Triangulation System had been available and used. For cases involving a loss of life or property, the individual case files were examined to determine if the use of a triangulation system might have prevented the loss. A detailed description of the benefit analysis methodology is contained in Appendix A.

6.1.2 Results

The preceding methodology was applied to three geographical areas of interest to the Coast Guard. The first area was the coverage area of the existing VHF-DF Triangulation System, which includes Cape Cod Bay and Massachusetts Bay. The specified lattitude boundaries used were 41 degrees 43 minutes North to 42 degrees 41 minutes North; and the longitude boundaries were 70 degrees West to 71 degrees West. The data for fiscal years 1979 through 1981 was analyzed. Table B-1 of Appendix B summarizes the expected savings to the Coast Guard in resources spent grouped by resource type and year. Table B-1 also summarizes the total benefit to the Coast Guard and to society for all three years. There were no cases in which it was determined that additional lives or property might have been saved if the VHF-DF system had been available and used.

The second area analyzed is covered by a theoretical five site VHF-DF system. The system covers the Nantucket Island, Block Island and Woods Hole areas. The latitude and longitude boundaries used were 41 degrees 05 minutes North to 41 degrees 40 minutes North and 69 degrees 40 minutes West to 71 degrees 30 minutes West. Table B-2 of Appendix B summarizes the benefits which might be derived from the theoretical system. There was one case in which it was determined that the use of a VHF-DF system might have enabled the Coast Guard to save two lives which were lost. The total benefit to society if those two lives had been saved would have been $560,000. The case in question took place in fiscal

The cost of Coast Guard manpower for routine system maintenance plus a service contract is estimated to be approximately $10,000 per year. There is an additional estimated cost of $1000 per year to maintain each required UHF data link.

Table C-1 of Appendix C summarizes the costs for each of the three systems which were analyzed. These costs assume that no UHF data links will be required for either of the two theoretical systems.

If a large number of complete systems were purchased at one time (on the order of twenty to twenty-five systems) the price for each receiver site would drop to approximately $33,000. A further overall cost reduction can be realized if UHF data links rather than telephone lines are used for all communications. However, this requires line of site communications capability between the central computer and each DF receiver site. Table C-2 of Appendix C shows the resultant system costs if these cost reductions are incorporated.

6.3 OTHER CONSIDERATIONS

Several assumptions of note were made in determining the benefits which could be derived from using the VHF-DF System. The first assumption is that the system will be used to fix the position of the distressed vessel at the outset of all cases where there is VHF-FM communications with the distressed vessel. This insures that an accurate distress vessel position will be known so that the assisting vessel will not be sent to an erroneous position, and that hoax cases will be spotted quickly rather than after several hours of fruitless search. If the system operators wait until the assisting unit has discovered that the position given by the distress vessel is in error before they use the system to fix the distress vessel's position, part of the value of the system will be lost.

The second assumption made is that the system will be used on all cases which occur in its coverage area. This requires that the personnel at the unit possessing the system be aggressive in

5. The ASSISTING RESOURCE TYPE (field C04) field contains
    data codes not listed in the SAR Data System Manual.

As can be seen from the fiscal year 1979 results for the Woods
Hole area, the occurrence of a single case involving a loss of life
or property or a large expenditure of resources can severely affect
the results of the analysis. In general, these cases occur quite
infrequently. The authors feel that the three years of data avail-
able in the SAR data base is inadequate to statistically reflect
the value of a VHF-DF system in prosecuting these major cases.
The occurrence of one or two of these cases during the life of the
system would be more than enough to justify the cost of the system.

As the use of EPIRBs becomes more widespread among the boat-
ing public, the possible benefit to be derived from a VHF-DF sys-
tem will increase. There are several reasons for this. First,
the number of cases reported via VHF-FM will increase. Second,
the system will be able to locate more people in the water and in
life rafts. Finally, the number of false alarms and hoaxes is
likely to increase as the use of EPIRBs increases, which will
make a VHF-DF system more valuable in detecting these cases.

The analysis as it was done does not take into account the
fact that the system coverage area is smaller when trying to detect
an EPIRB than it is when trying to detect a transmission from a
vessel. This was done because of the extremely small number of
cases analyzed involving the use of EPIRBs. If an analysis was
done involving larger numbers of EPIRBs, this difference would have
to be considered.

The VHF-DF system has been analyzed strictly from the point
of view of the Coast Guard's Search and Rescue mission. If the
system were modified by adding channel synthesis and scanning
capability, it could also be used to increase the Coast Guard's
capabilities in carrying out its Law Enforcement Mission. This
would increase both the cost of and the benefits derived from the
system. The magnitude of the changes have not been analyzed.

7. CONCLUSIONS AND RECOMMENDATIONS

1. The Direction Finding Triangulation System satisfied all program objectives.

2. Accuracy of position location on the order of 1-2 nautical miles was typically obtained and was considered very useful by operational personnel. Somewhat greater accuracy could be obtained through reduction of site reflection errors. All DF equipment should include capability for programmed bearing corrections.

3. Coverage requirement for the Class-C EPIRB should be limited to single line-of-position only because its power output is significantly lower than standard transceivers. Failure to do this would result in significantly higher system costs due to requirements for higher antenna heights and/or closer spacing of remote sites.

4. Cost effectiveness of the triangulation system depends on geography and SAR density. Based on the analysis presented in Section 6, it is concluded that properly sited and operationally integrated systems will prove cost effective. The procedures defined in Section 6 and Appendix A should be utilized to analyze candidate sites.

5. To assure cost-effective utilization of any DF system with centralized control, operational procedures should be developed to assure its use in each applicable case. Particular attention should be given to installations crossing group boundaries.

6. Based on Lentz's study (ref 4), cost-effectiveness of bearing-only single DF remoted to high site should be considered for high SAR density regions with little overlap on high site coverage.

7. The use of UHF radio links should be considered on links that would result in phone line costs of $2000/yr or more, or where the reliability of phone service is questionable.

8. DF control and display units should be designed to be incorporated into existing radio consoles at group communication centers.

APPENDIX A

BENEFIT ANALYSIS METHODOLOGY

The following is the methodology used to determine the bene-
fits derived from the VHF-DF system. By changing the latitude
and longitude boundaries of the coverage area, this same method-
ology can be used to determine the potential benefits which could
be derived from a system in any given area of interest.

The Information Systems Staff of the Search and Rescue Divi-
sion of the Office of Operations (G-OSR-3) maintains the SAR Data
Base. Mrs. Elly Paulos (FTS 426-1951) should be contacted in
order to receive data from the SAR Data Base. The Search and
Rescue Data System Manual (COMDTINST M5230.10 dtd 17 FEB 1982)
contains a description of the organization and meaning of the
information contained in the SAR Data Base and must be consulted
in order to complete the analysis.

The SAR Data Base contains many pieces of information on all
SAR cases handled by the Coast Guard. The information is organ-
ized into records with a separate record for each sortie. The
information in each record is broken into fields, and is entered
using alphanumeric codes. By specifying the desired codes of a
few selected fields, the data on sorties which meet the case
selection criteria can be retrieved.

The first fields of interest are those which specify the loca-
tion of the particular SAR case in question. Field B06 contains
the latitude of the case and field B07 contains the longitude.
By specifying minimum and maximum values for both fields which
correspond to the boundaries of the coverage area of the system,
cases which fall outside the coverage area are eliminated from
consideration. If the coverage area of the system cannot be
closely approximated by such a rectangle, specify boundaries which
loosely approximate the coverage area and eliminate by hand the
cases which fall outside of the coverage area.

order for the listing to be of use, the information desired on each sortie must be specified. The following fields of information were requested.

FIELD	DESCRIPTION
A01	OPFAC NUMBER
A02	UNIT CASE NUMBER
A03	MULTI-UNIT CASE NUMBER
B03	METHOD OF NOTIFICATION
B04	NATURE OF INCIDENT
B06	CASE LOCATION-LATITUDE
B07	CASE LOCATION-LONGITUDE
B08	METHOD OF LOCATING
B17	LIVES LOST AFTER C.G. NOTIFICATION
B20	PROPERTY LOST (THOUSANDS OF DOLLARS)
C03	SORTIE NUMBER
C04	ASSISTING RESOURCE TYPE
C08	TIME SPENT SEARCHING (TENTHS OF HOURS)
C11	TIME ON SORTIE (TENTHS OF HOURS)
C15a	ASSISTANCE RENDERED-TYPE OF SORTIE

When specifying field B17, it must be specified that LIVES LOST AFTER COAST GUARD NOTIFICATION is the data desired. The reason is that field B17 lists both LIVES LOST BEFORE COAST GUARD NOTIFICATION as well as LIVES LOST AFTER COAST GUARD NOTIFICATION.

Once a sortie-by-sortie listing of the above information on the desired sorties is obtained, it is necessary to eliminate sorties which for any reason are not applicable to the analysis. First, as mentioned earlier, it is necessary to eliminate sorties involving distressed vessels which are included in the boundaries specified for latitude and longitude but which fall outside of the actual coverage area of the VHF-DF system.

The second step is to eliminate sorties based on the nature of the incident (field B04). With current SAR conditions, there are several types of incidents whose outcome could not be affected by the use of the VHF-DF system. Among these are personnel in the

party before the life or property were lost then the system might have enabled the Coast Guard to save the lives or property which were lost. This determination relies on the judgement of the individuals performing the analysis.

The total benefit to society is computed by multiplying $280,000 by the number of lives which might have been saved (the $280,000 figure was taken from the Operating Program Plan for the Search and Rescue Program FY 1983-1992), to which was added the total value of the property which might have been saved.

If on examining the individual case files, it is evident that the use of the VHF-DF system would not have affected the expenditure of resources in prosecuting the case (the collision involving the USCGC Cuyahoga is one such case), then that case should be eliminated from consideration before proceeding with the resource savings analysis.

The final measure of the benefit of the system is the value of the resources which would not have been expended if the VHF-DF system were in use. This savings in resources is a benefit directly to the Coast Guard. In determining the amount of resources which could be saved, the assumption made is that if the system were in operation and used in the differential mode, no search time would be required by the assisting vessel in order to locate the distress vessel and the system operator would be able to spot a case as a hoax prior to large amounts of resources being committed to a search. It is also assumed that an assisting vessel would have to respond to all cases whether or not the system were in use; therefore, on single sortie cases, the system could eliminate only the TIME SPENT SEARCHING (field C08) by the assisting unit. On multiple sortie cases, the entire TIME ON SORTIE (field C11) can be saved for all units with the exception of one of the assisting units. This unit must respond to the case, but will still be able to save the amount of time equal to the TIME SPENT SEARCHING. The decision as to which assisting unit would be required to respond is left to the judgement of the individuals performing the analysis.

CAPE COD BAY/MASSACHUSETTS BAY

Fiscal Year 1979   Table B-1

Resource Type	# of Sorties	Hours Saved	Cost/Hour	Dollars Saved
HH52A	1	0.1	$ 794.55	$ 79.46
HH3F	1	0.2	$1,552.01	$ 310.40
UTB	159	164.5	$ 83.10	$13,669.96
UTL	2	1.9	$ 36.36	$ 69.08
MLB	16	15.7	$ 92.48	$ 1,451.94
Skiff	2	1.0	$ 14.54	$ 14.54
WPB	2	1.5	$ 199.75	$ 299.63
WLB	1	0.1	$ 564.42	$ 56.44
Misc. Boats	2	1.2	$ 14.54	$ 17.45
Personnel	1	0.3	$ 8.26	$ 2.48
Auxiliary	16	11.0		
Total				$15,971.38

Fiscal Year 1980

Resource Type	# of Sorties	Hours Saved	Cost/Hour	Dollars Saved
HU16	1	0.1	$1,356.24	$ 135.62
HH52A	1	0.1	$ 794.55	$ 79.46
HH3F	5	6.0	$1,552.01	$ 9,312.06
UTB	88	64.7	$ 83.10	$ 5,376.57
UTL	5	2.9	$ 36.36	$ 105.44
MLB	7	8.6	$ 92.48	$ 795.33
Skiff	2	1.9	$ 14.54	$ 27.63
Misc. Boats	1	0.5	$ 14.54	$ 7.27
WHEC	1	2.3	$1,969.68	$ 4,530.26
WPB	3	3.6	$ 199.75	$ 719.10
Personnel	1	1.2	$ 8.26	$ 9.91
Auxiliary	19	13.5		
Total				$20,098.65

Fiscal Year 1981

Resource Type	# of Sorties	Hours Saved	Cost/Hour	Dollars Saved
HH52A	3	2.8	$ 794.55	$ 2,224.74
UTB	60	67.1	$ 83.10	$ 5,576.01
UTL	4	5.8	$ 36.36	$ 210.89
MLB	5	7.7	$ 92.48	$ 712.10
Skiff	1	0.1	$ 14.54	$ 1.46
WHEC	1	2.0	$1,969.68	$ 3,939.36
Auxiliary	16	9.6		
Total				$12,664.56

Total Benefits From System

Type of Benefit	Total Benefits	Benefits/Year
Resources Saved	$48,734.59	$16,244.86
Auxiliary Hours Saved	34.1 Hours	11.4 Hours
Benefit to Society	none	none

Fiscal Year 1979

TABLE B-3

Resource Type	# of Sorties	Hours Saved	Cost/Hour	Dollars Saved
HH3F	10	9.4	$1,552.01	$14,588.89
UTB	45	31.4	$ 83.10	$ 2,609.34
UTM	16	14.0	$ 58.40	$ 817.60
UTL	5	1.5	$ 36.36	$ 54.54
MLB	4	5.2	$ 92.48	$ 480.90
TICWAN/TANB	1	1.0	$ 54.61	$ 54.61
Skiff	4	3.1	$ 14.54	$ 45.07
Misc. Boats	1	0.1	$ 14.54	$ 1.45
WPB	8	18.3	$ 199.75	$ 3,688.42
WYTM	1	4.7	$ 324.03	$ 1,522.94
Auxiliary	108	66.6		
Total				$23,697.69

Fiscal Year 1980

Resource Type	# of Sorties	Hours Saved	Cost/Hour	Dollars Saved
HH3F	1	1.7	$1,552.01	$ 2,638.42
UTB	20	22.5	$ 83.10	$ 1,869.75
UTM	14	4.1	$ 58.40	$ 239.44
UTL	3	3.5	$ 36.36	$ 127.26
MLB	4	24.1	$ 92.48	$ 2,228.77
Skiff	1	0.5	$ 14.54	$ 7.27
Misc. Boats	1	0.2	$ 14.54	$ 2.91
WPB	3	1.3	$ 199.75	$ 259.68
WLB	1	2.6	$ 564.42	$ 1,467.49
Auxiliary	96	52.1		
Total				$ 8,840.99

Fiscal Year 1981

Resource Type	# of Sorties	Hours Saved	Cost/Hour	Dollars Saved
HH3F	7	8.1	$1,552.01	$12,571.28
UTB	37	23.4	$ 83.10	$ 1,944.54
UTM	6	3.4	$ 58.40	$ 198.56
MLB	3	0.7	$ 92.48	$ 67.74
Skiff	2	1.1	$ 14.54	$ 15.99
ANB	4	6.3	$ 104.06	$ 655.58
Misc. Boats	2	7.5	$ 14.54	$ 109.05
WMEC	1	5.1	$ 789.03	$ 4,024.05
WPB	2	2.3	$ 199.75	$ 459.43
Auxiliary	3	1.3		
Total				$20,043.22

Total Benefits From System

Type of Benefit	Total Benefits	Benefits/Year
Resources Saved	$52,581.90	$17,527.30
Auxiliary Hours Saved	120.0 Hours	40.0 Hours
Benefit to Society	none	none

APPENDIX C

SYSTEM COSTS ASSUMING PURCHASE OF A SINGLE SYSTEM AND THE USE OF PHONE LINKS

Table C-1

CAPE COD BAY/MASSACHUSETTS BAY

System Costs

Type of Cost	Total Cost *	Cost/Year
Initial Acquisition and Installation	$150,000	$10,000
Operation		$ 7,200
Maintenance		$11,000
Total		$28.200

NANTUCKET ISLAND/BLOCK ISLAND/WOODS HOLE

System Costs

Type of Cost	Total Cost	Cost/Year
Initial Acquisition and Installation	$225,000	$15,000
Maintenance		$18,000
Total		$10,000
		$43,000

CHESAPEAKE BAY

System Costs

Type of Cost	Total Cost	Cost/Year
Initial Acquisition and Installation	$180,000	$12,000
Operation		$14,400
Maintenance		$10,000
Total		$36,400

*Includes one UHF Link

REFERENCES

1. A Proposal for a VHF Radio Direction Finding and Radiolocation System; Southwest Research Institute, San Antonio, Texas, 22 October 1981.

2. United States Coast Guard Massachusetts Bay Direction Finding Triangulation Test Results; Jaycor, Inc., Woburn, MA, 10 September 1982.

3. United States Coast Guard Direction Finding Triangulation Test and Evaluation Plan; Charles J. Murphy, Transportation Systems Center, Cambridge, MA, 19 April 1982.

4. Study of Direction Finding Sites (unpublished), LT Jerry Lentz, U.S. Coast Guard Headquarters, Washington, DC, Sept. 1982.

5. Operation and Maintenance Manual for Model 6896 VHF Radio Direction Finding and Radiolocation System, Southwest Research Institute, San Antonio, TX, 1 June 1982.

6. "Statistical Theory of DF Fixing," R.G. Stansfield, Proc. IEE Vol. 94, pp. 111a, 762-770, 1947.