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STUDY OF ALERTING AND LOCATING TECHNIQUES AND THEIR IMPACT (SAL--ETC(U)
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(6) # STUDY OF ALERTING AND LOCATING TECHNIQUES AND THEIR IMPACT (SALTTI).

HIGH SEAS COST-BENEFIT ANALYSES VOLUME 1 MAIN REPORT.

Prepared for

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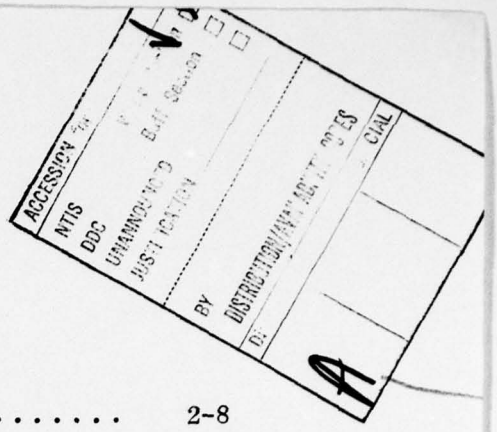

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SECTION 1 - INTRODUCTION AND SUMMARY

1.1 PURPOSE

This report provides an analysis of candidate electronic alerting and locating techniques applicable to the Coast Guard search and rescue (SAR) mission on the high seas. Candidate techniques involve user resources on ships, fishing vessels, and aircraft; Coast Guard equipment and facilities; and Government-owned or leased satellites. The capabilities of these techniques are identified, discussed, and rank-ordered based on their cost-effectiveness and benefits for support of the SAR mission. In addition, the applicability of selected techniques for coastal and inland SAR use is examined. Comparisons are made of system rank order based on total cost and benefit data as well as alerting and locating functions and equipment used.

1.2 STUDY ORGANIZATION

1.2.1 Coast Guard Staff

The Telecommunications Management Division of the Coast Guard Staff provided valuable consultation, assistance, and guidance for the conduct of this High Seas study. This included furnishing information and data on Coast Guard high seas operations and resources, shipping and fishing vessel operations, and costs. Reports of the SALTTI studies conducted by the Coast Guard Staff identified candidate alerting and locating techniques. In addition, information was furnished regarding inland SAR activities and resources.

1.2.2 Contract Support

Support in this study was provided by Contract DOT-CG-61555A dated 17 January 1976. Essential information and data was progressively assembled and analyzed regarding the candidate alerting and locating techniques, maritime shipping operations, AMVER reports, and air carrier operations. The development of analytical models was initiated early in the study effort, including

computer assistance to verify the methodology for determining the effectiveness of alerting and locating techniques. A computational model was prepared and used in the analysis of system and geographical parameters, and provided the basis for rank-ordering of candidate techniques.

1.3 METHODOLOGY

1.3.1 General

This study is an extension of the Coastal Area study and is concerned with the Maritime Regions that extend more than 20 nautical miles offshore It evaluates candidate electronics alerting and locating systems included in the Coastal Area study plus several that are applicable on the high seas. These additional types of systems include primarily satellite L-band systems, installed high frequency (HF) radio,and survival type radio equipment (8364 kHz). The total list of candidate systems is shown in Appendix A.

The use of candidate systems is examined from the standpoint of the geographic and system parameters involved. A standard geographical grid cell is used as the origin for emergency transmissions. Depending on their specific location, these cells contain a variable population of ships and platforms of opportunity for the receipt of alert messages and location of the distress area. The capabilities of emergency transmissions to reach shore stations or platforms of opportunity and which result in locating of the emergency site are analyzed as effectiveness parameters.

System parameter data includes costs of candidate systems to the Government and users. This data is essentially the same as used in the Coastal Area study except that additional information has been assembled for the added candidate systems. The scope of the information and its format facilitates its use in the benefit:cost analysis which requires four major groupings of input data and four different analytical models. The two derived figures

of merit by which alternative candidate systems are rank-ordered are the benefit:cost ratio and benefits minus cost. The details and procedures used are described in Appendix B. Insofar as practicable, the data and methodology developed in the Coastal Area study are used as the basis for the current analyses and provide values for comparison of results from the two efforts. A pictorial representation of the methodology used for benefit:cost analysis is shown in Figure 1-1. The discussion that follows describes this process and the relationship of the various steps.

1.3.2 System Parameters and Effectiveness Factors

The alerting and locating techniques, or systems, are analyzed with regard to their effectiveness for alerting only (AO), locating only (LO),and alerting and locating (AL). These are the system groupings used in Appendix A. Within these groups, systems are listed with regard to characteristics that include types of equipment (e.g., installed, EPIRB, survival, satellite), frequency of operation, and methods used for AO, LO,and AL. The system parameters required as an input for the computation process are fully described in Appendix B, together with a listing of applicable values. This data includes the following items.

1.3.2.1 Cost Data

Cost data includes the Government's initial acquisition cost and annual operating expenses. It also includes the unit price of the equipment and the data needed for adjustment of this price on an annual basis to account for expected increases in production quantities.

1.3.2.2 Population and Usage Data

Data in this category identifies the number of commercial ships and fishing vessels that may be expected to have the system equipment, and the factor that describes system watch when the ship or vessel is on the high seas. In addition, a factor is included to indicate whether the system can alert aircraft overflights.

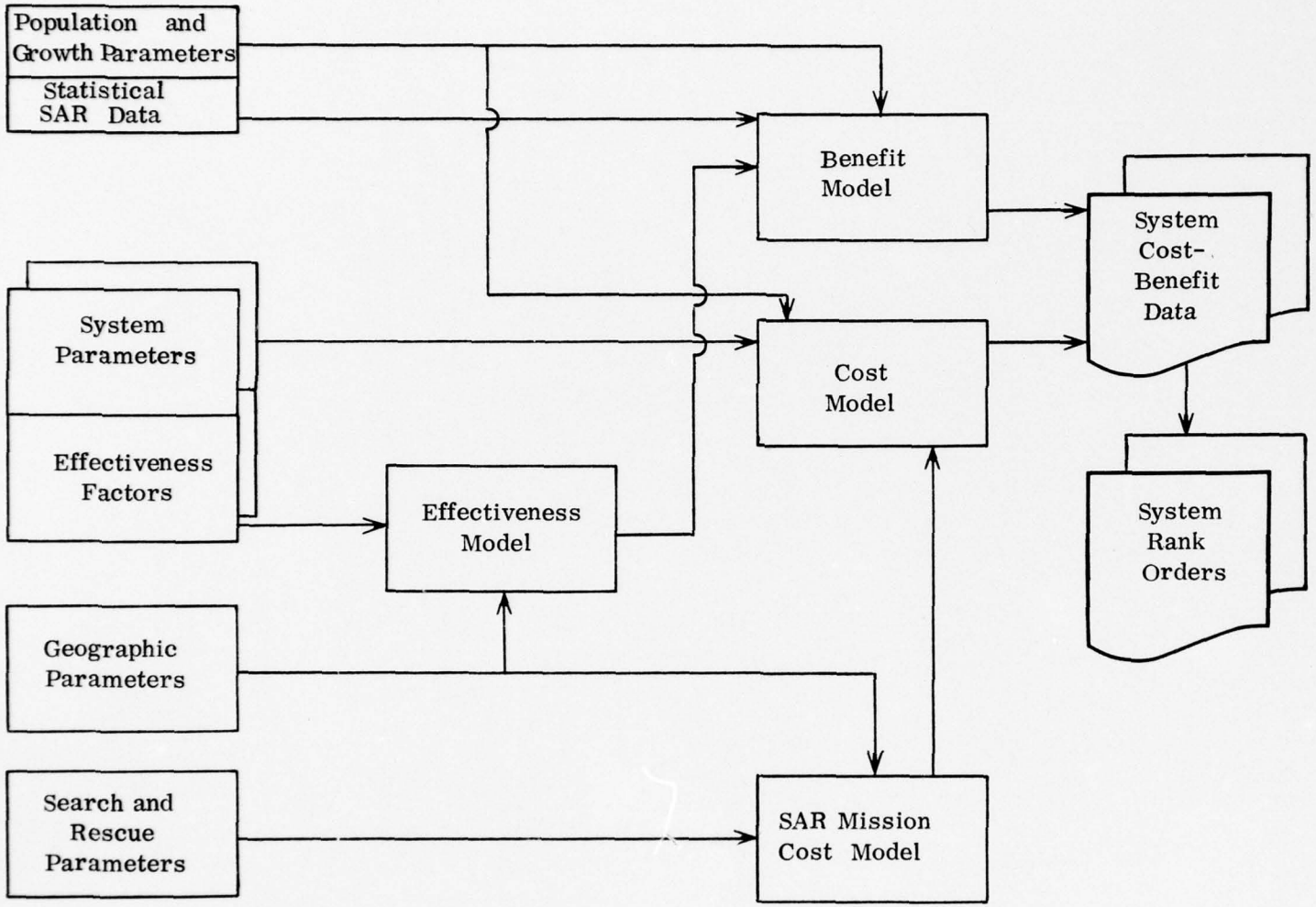

Figure 1-1. Methodology for Cost:Benefit Analysis

1.3.2.3 Alerting and Locating Range

This is the expected transmitting range at which the system may alert and/or be located by passing ships or vessels.

1.3.2.4 Effectiveness Factors

The effectiveness factors applied to the candidate alerting and locating systems are the same types used in the Coastal Area study and are summarized in Table 1-1.

- Signal Propagation (EP) describes the capability to provide an adequate signal throughout the geographical zone. It is dependent on the distance between the originating point for an alerting message and the receiving station.
- Operator Availability (ET) describes the daily time during which a system operator would be available for detecting an alerting and/or locating signal. "Operator" also includes the use of automatic alarm equipment and satellites.
- Equipment Availability (EA) describes the availability of system equipment in the detecting station or platform of opportunity and is 0.995 for all systems.
- Signal Environment (ES) describes the probability of successfully alerting a receiving station, considering traffic congestion on the frequency used.
- Signal Location (EL) describes the probability of successfully determining the location of an emergency transmitter suitable for SAR.

1.3.3 Population and Growth Parameters and Statistical SAR Data

The two classes of users in this analysis are commercial ships and fishing vessels, both of which will incur a cost of ownership for, and derive benefits from, candidate alerting and locating devices. The types of information required are:

Table 1-1. Summary of System Parameter Scoring Guides

PARAMETERS	500 kHz Installed	500 kHz Survival	2182 kHz Installed	2182 kHz Survival	2182 kHz EPIRB	8364 kHz Survival	① Combination Survival	High Frequency Installed	121.5 243 MHz EPIRB/ELT	156.8 MHz Installed	406 MHz EPIRB	② Combination EPIRB	VHF-FM EPIRB	VHF-AM EPIRB	UHF-AM EPIRB	L-BAND SATCOM
EP Propagation Coverage																
Shore	③		③			③	④	③								
Ship/Vessel	1.000	.850	1.000	.910	.500	.600	④	.950								
Aircraft Overflight									1.000							
Orbiting Satellites									.940			.940				
Geosynchronous Satellites									1.000		1.000	1.000				1.000
ET Time Availability																
Terrestrial	.996	.996	.996	.996	.996	.996	.996	.996								
Aircraft Overflights									.996							
Satellites									1.000		1.000	1.000				1.000
ES Signal Environment																
Terrestrial	.990	.980	.907	.880	.944	.968	④	.968								
Aircraft Overflight									.980	.980		.980				
Orbiting Satellite									.996		.996	.996				
Geosynchronous Satellites									.900		.900	.900				1.000
EL Location Effective																
Self-Determined	.990		.880			.650		.990								
Shore LOP and Signal Judgement or DF Fix	.980	.950						.985								
Shipboard DF & Homing	.950	.940	.800	.700	.200	.860		.960	.620	.620		.620	.620	.620		
Aircraft DF & Homing	.950	.900	.900	.850	.280	.940		.975	.500	.950		.950	.950	.950		
Doppler Satellite								.990			.995	.995				
NAVAID Retransmission											.999	.999				

① Combination 500, 2182 and 8364 kHz
② Combination 121.5, 243 and 406 MHz
③ Geographical parameter
④ Use factor for individual frequency

- Population data identifies the total number of ships and vessles in the Maritime Region which, in turn, defines the maximum number of potential users and user costs. The total number of ships and vessels is the sum of these platforms in specific geographic areas. The number of ships in each geographic area is used to generate the benefits and cost of SAR missions for that area.

- Growth parameters describe the expected annual rate of increase in the population of ships and vessels. This information is essential for projecting user population into the 1980 time frame.

- Statistical SAR data includes the expected number of SAR incidents and rate of increase by type of user, as well as the expected rate of fatalities and property damage. This data was derived from the SAR report data base and was used in the Coastal Area study.

1.3.4 Geographic Factors

In the evaluation of the High Seas systems, the geography of the SAR region impacts the system effectiveness as well as the expected costs and benefits. The basic model area for the benefit:cost methodology is the 15-by-15 degree geographical grid square. The factors that must be considered in the benefit:cost models include:

- Ocean Area of the 15-by-15 degree grid or portion thereof in square nautical miles.

- Great circle distance in nautical miles to nearest SAR facility.

- Expected number of commercial ships in grid square.

- Expected number of fishing vessels in grid square.

- Number of designated aircraft tracks across grid square.

- The expected propagational capability for RF signals from installed 500-kHz equipment, installed 2182-kHz equipment, installed HF equipment, and 8364-kHz survival equipment in the designated grid square to the nearest shore station.

1.3.5 Search and Rescue Unit Factors

The estimation of annual costs for the primary SAR units (SRUs) is based on speed, range, and fuel consumption. The primary SRUs considered are the HU-16, HH52, HH3, HC130, WPB, WMEC, and WHEC.

The speed of the SRU is given in knots and is the expected speed for transit to and from the search area as well as during the search. The range in hours is the effective time that the SRU can operate - the combined transit and search time - and does not include enroute reserve, approach and landing reserve, alternate reserve, holding reserve, or false sighting reserve. For air SRUs the range is given in hours by the speed. For surface SRUs, the range is given in nautical miles and the endurance time derived by dividing the given range by the speed. The fuel consumption is given. The operating cost per hour is derived by multiplying the fuel consumption in gallons per hour by fuel costs, $0.40 for surface SRUs and $0.42 for air SRUs.

1.4 MATHEMATICAL MODELS

1.4.1 Cost Models

The cost model computes the present value of system acquisition and operating costs for ten years for both the Government and the commercial and fishing categories. The present value of the cost estimates for acquisition, annual operation, and total are further broken out by the Atlantic and Pacific SAR Regions.

The Government initial acquisition and installation costs data for the terrestrial systems include:

- Type and number of installed electronic units
- Unit and installation costs
- Spare equipment, modules and parts costs
- One time costs for test equipment, documentation and training.

The initial acquisition and installation cost data for the satellite systems include:

- Number of satellites and on-orbit spares required
- Expected life of satellites
- Satellite costs; unit, launch, RDT&E
- Ground stations; number required, unit cost, RDT&E cost.

The Government annual recurring O&M costs include:

- Annual Maintenance Cost (10% of unit cost)
- Number of personnel at $10,200 per annum
- Recurring training cost
- Cost of landlines
- Ground station O&E.

The SAR cost includes only the cost of fuel for aircraft and cutters/boats deployed on an SAR. It does not include the "SAR Impact Cost" that represents the acquisition and operation of additional SAR resources due to the impact of recreational boats on SAR resources which was included in the costs for the Coastal Area study. The computation of SAR cost depends on the location effectiveness of the system, the SRUs deployed, the search time required, and the expected number of SAR missions. The search time considers the area of uncertainty, the expected value of the detection range and the coverage factor. A coverage factor of 1.6 was selected as the value which gives a 0.95 probability of detection on the first search (Ref: Figure 8-65, National SAR Manual, CG308).

The location effectiveness of the system determines the area of uncertainty. To be eligible for deployment, an SRU must be able to reach the search area and still provide a minimum search time of 2 hours for air SRUs and 24 hours for surface SRUs.

The user initial AC&I costs (number of units acquired annually times current unit cost (UC(i)) are computed on an annual basis and the total user initial cost is the sum of the present values of the annual initial AC&I cost. Each year, additional units are purchased because of the population growth and the unit cost changes because of the learning curve effect. The number of AL devices acquired each year is based on the potential market and the rate of growth. The unit annual O&M cost is estimated to be 10 percent of the unit acquisition cost and therefore the total annual O&M cost is 10 percent of the cumulative investment cost.

1.4.2 Benefits Model

The system benefits are the savings that accrue from the prevention of fatalities and property damage to commercial ships and fishing vessels due to the use of the AL device. The benefits are computed for each year in each grid of the model and consider the expected saving per SAR incident, the rate of SAR incidents, the annual concentration of high seas traffic, the fraction of losses that could be saved, the percent of total traffic expected to carry the AL device, and the effectiveness of the AL device. The benefit data presentation for each system lists the expected benefits in terms of fatalities and property damage prevented for each category, commercial or fishing, in both the Atlantic and Pacific SAR Regions.

1.4.3 Effectiveness Model

The system-effectiveness describes the probability of accomplishing the system objective, AO, LO, or AL, in terms of the probability of the EP, ET,

EA, ES, and EL. There are two major differences between the methodology for the Coastal Area and the High Seas. In the procedure for the High Seas:

- The values of EP are dependent on the geography - the distance between the area where the signal originates and the station at which the signal is received. For the several different types of systems there are different values of EP for each designated grid area. It therefore follows that there will be a different value of EV for each grid area, which is designated EV(m).
- One of the major means of requesting assistance due to the occurrence of an event requiring SAR is the alerting of appropriate platforms of opportunity, passing ships or aircraft overflights. Therefore, the probability of accomplishing the system objective, AO, LO, or AL, must consider communications with passing ships and aircraft overflights as well as communication with shore SAR stations.

1.5 APPLICABILITY OF HIGH SEAS SYSTEMS TO COASTAL AREA INLAND REGION

1.5.1 General

The analyses results for High Seas systems were examined with regard to their applicability for use in the Coastal Area and Inland Region. One reason for this examination was to identify the potential for greater use among the SAR Regions, and to identify associated increased cost-benefits that may accrue. Although differences in system usage, user population, and SAR forces do not permit a direct application of High Seas data to these other areas, an assessment can be made based on the characteristics and utility of the selected systems. For the Coastal Area, the systems selected were the top ten of High Seas rank ordering effectiveness (e.g. EP, ET, ES, EL) costs and benefits. High Seas systems considered for Inland Region use were selected primarily on the basis of their estimated utility and effectiveness for alerting and locating.

1.5.2 Coastal Area Applicability

Systems considered to have high applicability for Coastal Area use are primarily the EPIRB, for LO or AL. Most selected systems involve aircraft DF/homing, followed by the use of satellites. From a total cost standpoint, systems using EPIRBs have a relatively lower cost and involve only one type of user equipment in the alerting and locating processes. The top ten ranked systems from a total benefit standpoint are for both alerting and locating, rather than AO or LO. Only five systems have a positive total benefit minus cost, and all involve EPIRBs. The highest ranking systems, based on total benefit:cost ratio, use an EPIRB for alerting an orbiting satellite, which also provides Doppler location. The foregoing considerations showed that all of the selected systems were applicable and suitable for Coastal use. However, widespread use of EPIRBs on 121.5 MHz by recreational boaters could contribute to an existing high false alarm rate on this frequency from ELTs used in the Inland Region and along the coast. In addition, multiple orbiting satellites are desirable for the Coastal Area to provide continuity of radio coverage in the high density user population.

1.5.3 Inland Area Applicability

High Seas systems applicable for the Inland Region are capable of alerting SAR forces and provide the capability of locating the emergency site anywhere within the region. An analysis of the 97 High Seas systems showed that only eight meet this criteria. The applicability of all High Seas systems were examined as to the frequency used, probability of equipment carriage, transmission range and type of alerting and locating platform used. As a result, only eight of the 97 High Seas systems were selected for examination. These systems involved the use of EPIRBs and aircraft or satellites

in the alerting and/or locating processes. The utility of the selected systems was examined on the basis of environmental effects, emergency frequency occupancy, and system usage. All systems selected are applicable in the Inland Region. However, only systems using satellites will provide assurance of emergency frequency watch as well as complete radio coverage of the Inland Region. The alerting of aircraft and their locating capability may be affected by the environment at the emergency site (e.g. terrain, overgrowth, snow, fog). In addition, use of 121.5/243 MHz as an emergency frequency involves a high false alram rate which can reduce responsiveness to emergencies by SAR forces.

1.6 HIGH SEAS ANALYSIS RESULTS

The results of the High Seas Analysis are provided by the data in the appendices to this report. Appendix B, *contains the Systems Parameters* (Attachment 1), Geographic Parameters (Attachment 2), and System Parameter Data Sheets (Attachment 3). The data in Appendix B is presented in a consolidated form by Appendix C, System Data Summaries and Cost-Benefit Results. Information in Appendix C is provided for each system in terms of costs, system effectiveness, system coverage and watch, benefits and measures of effectiveness expressed by benefit:cost ratio and benefit minus cost. Subdivisions of data are made for commercial ships and fishing vessels as well as for the Atlantic and Pacific SAR Maritime Regions. Appendix D provides 24 categories of rank order for each High Seas system based on the information contained in Appendix C.

The scope and depth of information in the appendices provide a broad data base for a variety of analyses ranging from comparisons of rank order among systems to more detailed examinations for specific purposes. Representative rank order comparisons are made in Section 9, using total cost and benefit information. In addition, comparisons are made of rank order for systems based in alerting and locating functions and the type equipment

being used. These comparisons showed that there are ranges of rank order values based on the type of transmission equipment used for alerting and/or locating; within some rank order ranges, distinct subdivisions are apparent for systems using dedicated versus shared satellites and for alerting/locating systems versus those capable of alerting or locating. Several systems showed prevalent high rank order in all comparisons. These included some systems using EPIRBs, four systems capable of LO, systems in which aircraft DF/homing is used for locating, and systems using shared satellites. In all these top rank order systems, a single user equipment is involved in the alerting and locating processes. Almost all systems in top rank order for total cost are capable of LO, while all systems in the highest rank order for benefit have an AL capability. Expansion of this type of analysis can be made using other available rank order data involving cost and benefit with and without SAR, for commercial and fishing vessels, and for the Atlantic and Pacific SAR Maritime Regions.

SECTION 2 - GEOGRAPHICAL CONSIDERATIONS

2.1 OVERVIEW

In analyzing the effectiveness, costs, and benefits of the candidate alerting and locating systems, the geographical locations of the alerting transmitter and alerted receiver are highly significant factors that influence successful receipt of an alert signal and finding its source. Technical considerations involved include the communications path and its quality, transmitter power, and the types and locations of receiving equipment. Receiving equipment may be ashore, on a satellite, or in a passing ship, vessel, or aircraft. The success of alerting is related to the population of receiving stations ashore, satellites in orbit, and the density of afloat and aircraft platforms. Computations for each of the candidate systems, therefore, must include the numerous variables arising from geographical considerations. The discussions that follow describe the geographic factors considered in the computational process involving ships and fishing vessels. Geographic consideration for air routes is discussed in Section 5, and for satellites in Section 6.

2.2 SAR MARITIME REGIONS

2.2.1 Geographical Designations

The United States, in a world cooperative plan coordinated through international aeronautical and maritime organizations, has accepted responsibility in defined oceanic areas for SAR incidents of ships and survival craft of all nations. The total oceanic areas included in these responsibilities cover approximately 24.6 million square miles in the Atlantic and Pacific regions. The Atlantic region is approximately 5.9 million square miles in area and the Pacific region approximately 18.7 million square miles.

To delineate locations within these immense areas, the Atlantic and Pacific regions have been subdivided into 15-degree grids of latitude and longitude.

Each of these grids is identified by two letters that correspond to its latitude and longitude designators. A further subdivision is made of these 15 degree grids into 5-degree cells in the Automated Mutual Assistance Vessel Rescue (AMVER) system described in Paragraph 2.3.2

2.2.2 Atlantic SAR Maritime Region

The Atlantic SAR Maritime Region is shown in Figure 2-1 and is comprised of the oceanic area between the dashed lines and the coastline to the west. The 15-degree grids and their designators also are shown. Transit paths of ships in this region incorporate numerous random tracks between parts of the East Coast, Europe and South America. Some canalization of traffic results from the Gulf Stream, the passages through the Bahamas and Antilles, and routes to the Panama Canal. Aircraft routes are well defined, the North Atlantic route having the highest density of any in the Atlantic or Pacific regions. Fishing areas are highly populated off Massachusetts, Newfoundland, Venezuela, Guyana, Surinam, and Guiana. The Rescue Coordination Center (RCC) for the Atlantic Region is at Governors Island, N. Y. Coast Guard Radio Stations for the region are in Boston, Portsmouth, Miami, San Juan, and New Orleans. Figure 2-2 shows the magnitude of distances involved among radio station locations and the farthest outlying locations in the region. Radio propagation conditions are generally normal for this area except for higher electrical noises in the Gulf of Mexico.

2.2.3 Pacific SAR Maritime Region

The Pacific SAR Maritime Region is shown in Figure 2-3 and is comprised of the oceanic areas between the dashed lines and the coastline to the east. The 15-degree grids and their designators also are shown. Both maritime and aeronautical tracks in the Pacific region are more clearly defined than in the Atlantic. Seasonal shipping with the Orient shifts to more

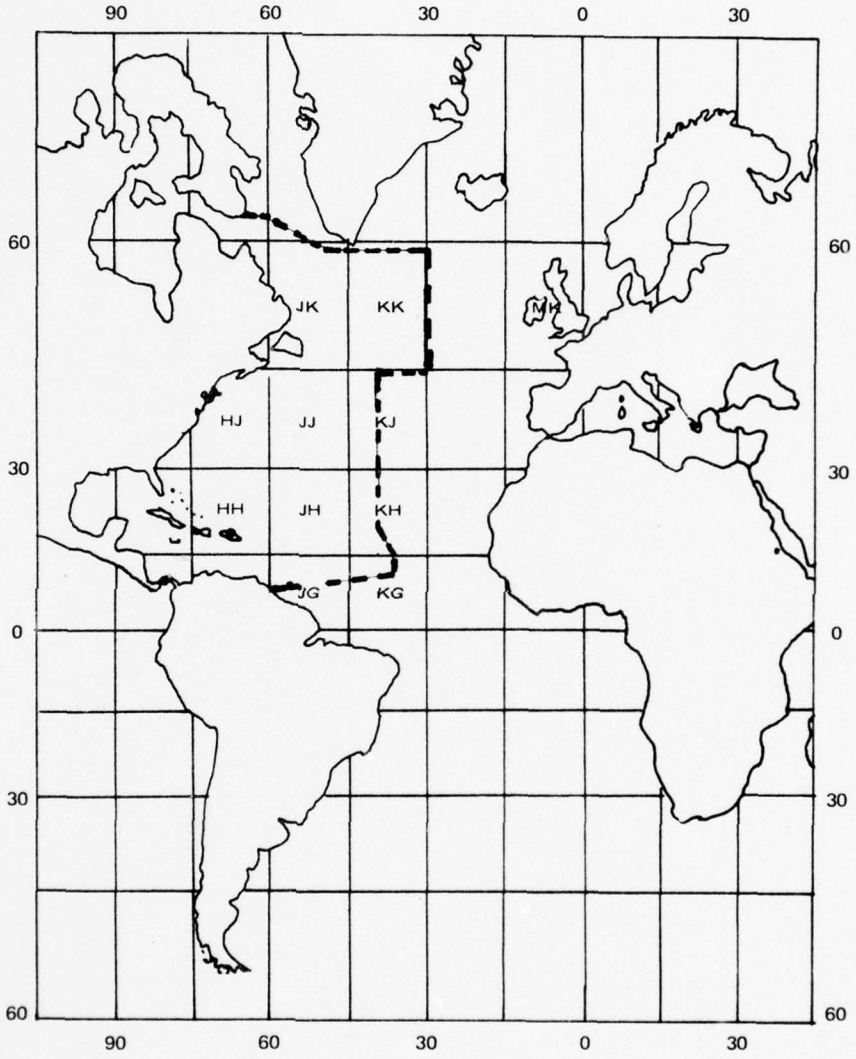

Figure 2-1. Atlantic SAR Region

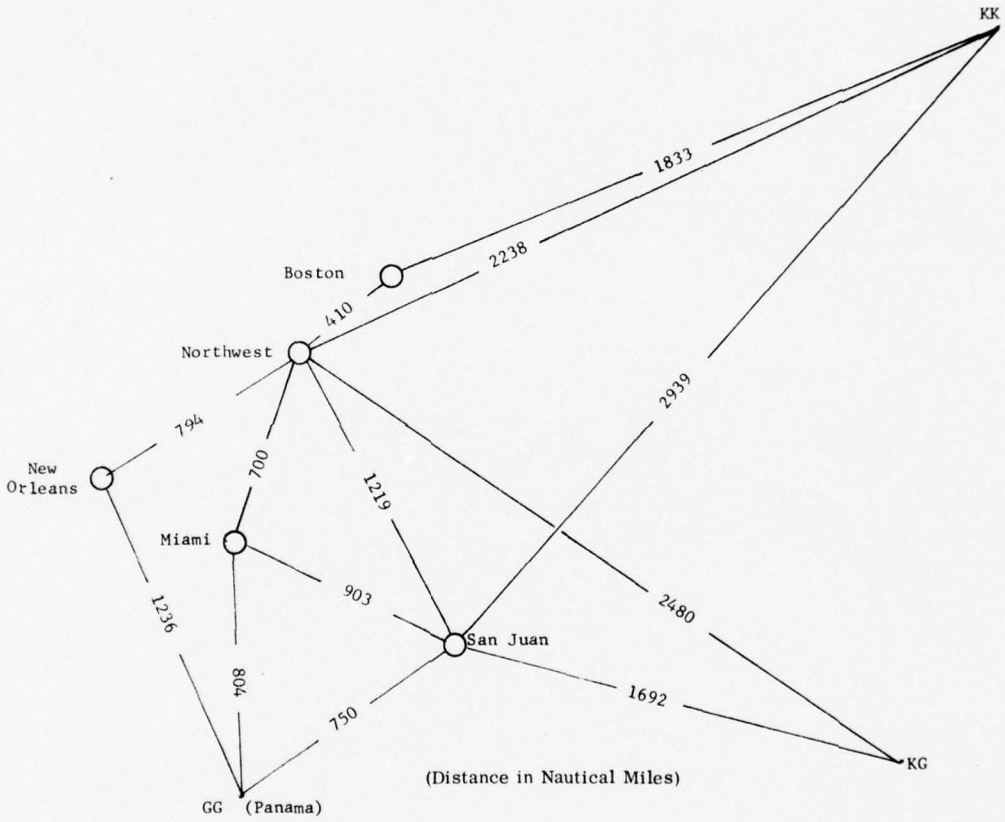

Figure 2-2. Magnitude of Distances in Atlantic Region

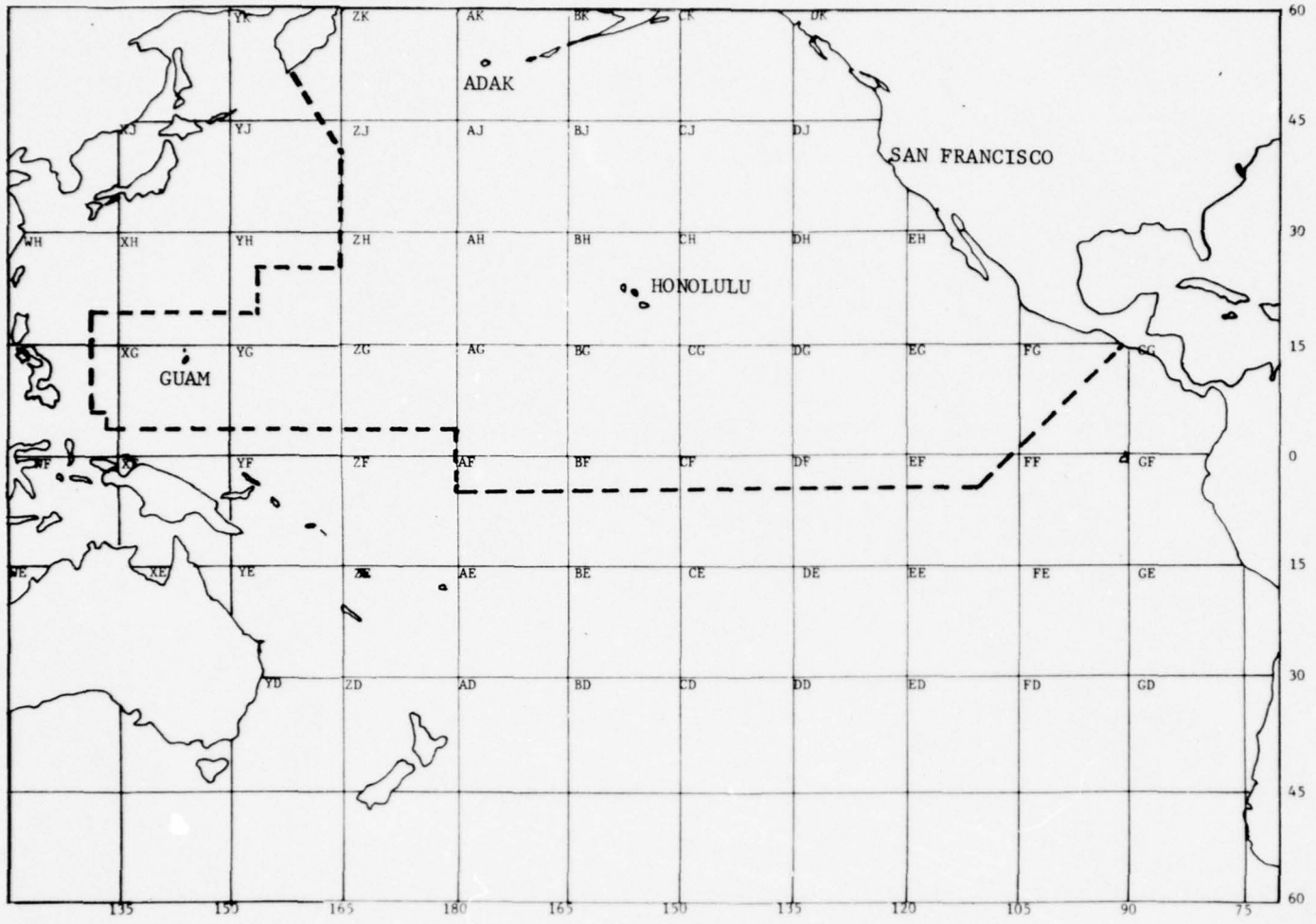

Figure 2-3. Pacific SAR Region

southerly limits in latitude but otherwise follows great circle paths. Fishing areas are highly populated off the Aleutians, in a vicinity about 600 nautical miles west of Mexico, and in the area between Japan and the Carolina Islands. The RCCs for this region are at Long Beach, San Francisco, Seattle, Juneau, and Honolulu. Coast Guard Radio Stations are at San Francisco, Adak, Honolulu, and Guam. Figure 2-4 shows the magnitude of distances among radio stations and to perimeter locations of the region. Radio propagation is similar to that in the Atlantic region except that higher frequencies are feasible over long paths as a result of increased electron densities and equatorial enhancement.

2.3 SHIP AND VESSEL POPULATION AND DISTRIBUTION

2.3.1 General

Data on ship and vessel[1] population and distribution for an average day is required to determine costs and potential benefits of electronic alerting and locating systems. Population data is needed as the basis for user costs while geographical distribution in each SAR Maritime Region is required to estimate benefits. In connection with benefits, data on geographical distribution is needed for determining the probability of alerting passing ships when the candidate system is beyond the normal receiving range of shore stations. In the absence of comprehensive daily records of ship tracks, similar to the kind of information available through oceanic air traffic control and coordination sources, the data must be estimated by analysis of available source material. This material includes Lloyds reports, daily arrival and departure notices, tonnage moved or fish caught, aircraft sightings, and computer models. Each of these sources has its limitations and judgement must be exercised in their application or extrapolation.

[1] Vessels in this report are defined as fishing boats greater than 5 tons.

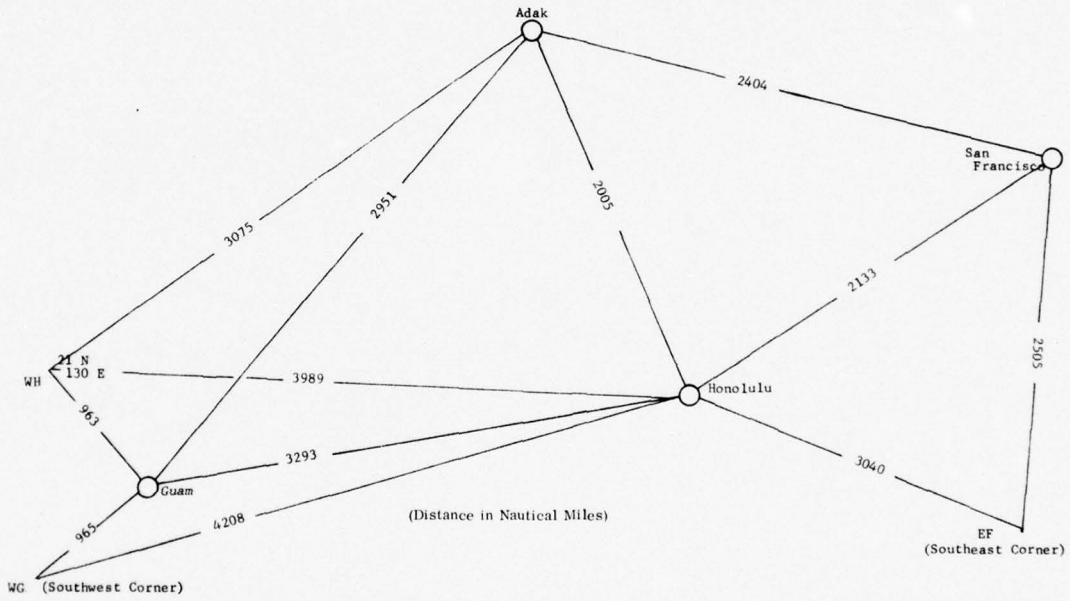

Figure 2-4. Magnitude of Distances in Pacific Region

2.3.2 Ships

A basic factor in determining costs for candidate systems is the total ship population at sea in each region. Only ships that ply routes in the SAR Maritime Regions and visit ports in areas adjacent to these regions will be counted in an installation base. A determination of this population data involves the use of available information on shipping in the region and development of the total ship population at sea for ocean areas.

The primary data source on ship population and distribution in the SAR Maritime Regions is the Automated Mutual Assistance Vessel Rescue (AMVER) System that is sponsored by the Coast Guard. This is a voluntary system in which ships may report their locations, course and speed as the basis for assistance in an emergency. AMVER reports from ships are entered into the system for twice daily updates. Location data uses the grid designator system referred to in Paragraph 2.2.1. A deployment picture can be obtained at any time showing participating ships that should be in the immediate vicinity of an emergency, based on data in their most recent AMVER report. The system also furnishes a monthly statistical summary for each SAR Maritime Region.

In developing the required data for ship population, consideration must be given to the fact that AMVER reports are voluntary inputs and probably do not show actual totals at sea. To compensate for this, the total at sea ship population is first estimated and then used as a factor in determining at sea population in the SAR Maritime Regions. Estimates resulting from the study report "Government Maritime Communications" [2] and "at sea" percentages compiled by "A Study of Maritime Mobile Satellites," [3] provide a basic

[2] Contract DOT-CG-13020A, Computer Sciences Corporation

[3] Contract DOT-CG-00505A, Automated Marine International

estimate of ships at sea in the Western Atlantic and Pacific Ocean areas. These estimates have been compared with various reports of a sampling nature and are considered reasonable. The average daily ships at sea in the Atlantic and Pacific Ocean basins are estimated to be:

Atlantic Area	7,800
Pacific Area	5,300
Total	13,100

The installation base for equipment costs pertinent to this study is the total ships at sea and in port that are assumed to be routine users of the Atlantic and Pacific Oceans. The average at-sea time for tank and bulk carriers is 74 percent, and the average at-sea time for container cargo ships is 61 percent. The overall average for all ships, excluding low utilization freighters, is 69 percent[4]. The total installation base for this analysis is derived by dividing the at-sea fleet by .69, which is:

Atlantic Installation Base	11,304
Pacific Installation Base	7,681
Total Installations	18,985

Selection of AMVER data that was considered most representative of ship population and distribution required assessment of reports covering a two-year period. By covering such a broad time span, a reasonably complete data source was assured. A relatively sound distribution pattern emerged for both seasonal and total distributions. The AMVER tracks for October 1975 are the most representative of total movement within the geographic cells throughout the Atlantic and Pacific.

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[4] Mathematical reduction of data in Table I, Summary Volume, Study of Maritime Satellite Service Requirements, Contract DOT-CG-00505A, Automated Marine International, 1970.

The data was averaged to a daily basis and is shown in Figures 2-5 and 2-6. By dividing the total population at sea by the AMVER daily tracks, a participation factor results for each ocean area. Using the historical record of AMVER reports from within the Atlantic and Pacific SAR Maritime Regions, an estimated ship population distribution for each region was extracted and totaled. The at-sea totals within these regions for an average day are:

Atlantic SAR Maritime Region	3,876
Pacific SAR Maritime Region	2,764
Total	6,640

2.3.3 Fishing Vessels

Fishing vessels operating in the oceanic and off-shore areas are significant users of voice-operated medium and high frequency radio equipment. Their operating areas fluctuate widely as a result of market demands, agreements, and movement of species as reported by radio or followed by experience. Their intercommunications by groups, fleets, and fishing interest provide close mutual support and activity on common, company or high seas telephone nets. All vessels in this analysis are considered 50-ton gross tonnage or more.

Data sources utilized in reporting fishing vessels are extracted from "Fishery Statistics of the U.S."; telephone discussions with representatives of the National Marine Fisheries Service at Washington, Glouchester, Beaufort, Miami, La Jolla, and San Diego; fish landings in tons related to ocean areas and vessel capacities; and interviews with representatives of major commercial fishing associations. Foreign fishing vessels in the U.S. SAR Maritime Regions were scaled from Coast Guard visual counts, and fishing statistics. Data for fishing vessel population in the extreme Western portion of the Pacific SAR Region also considered estimates in the study by Automated

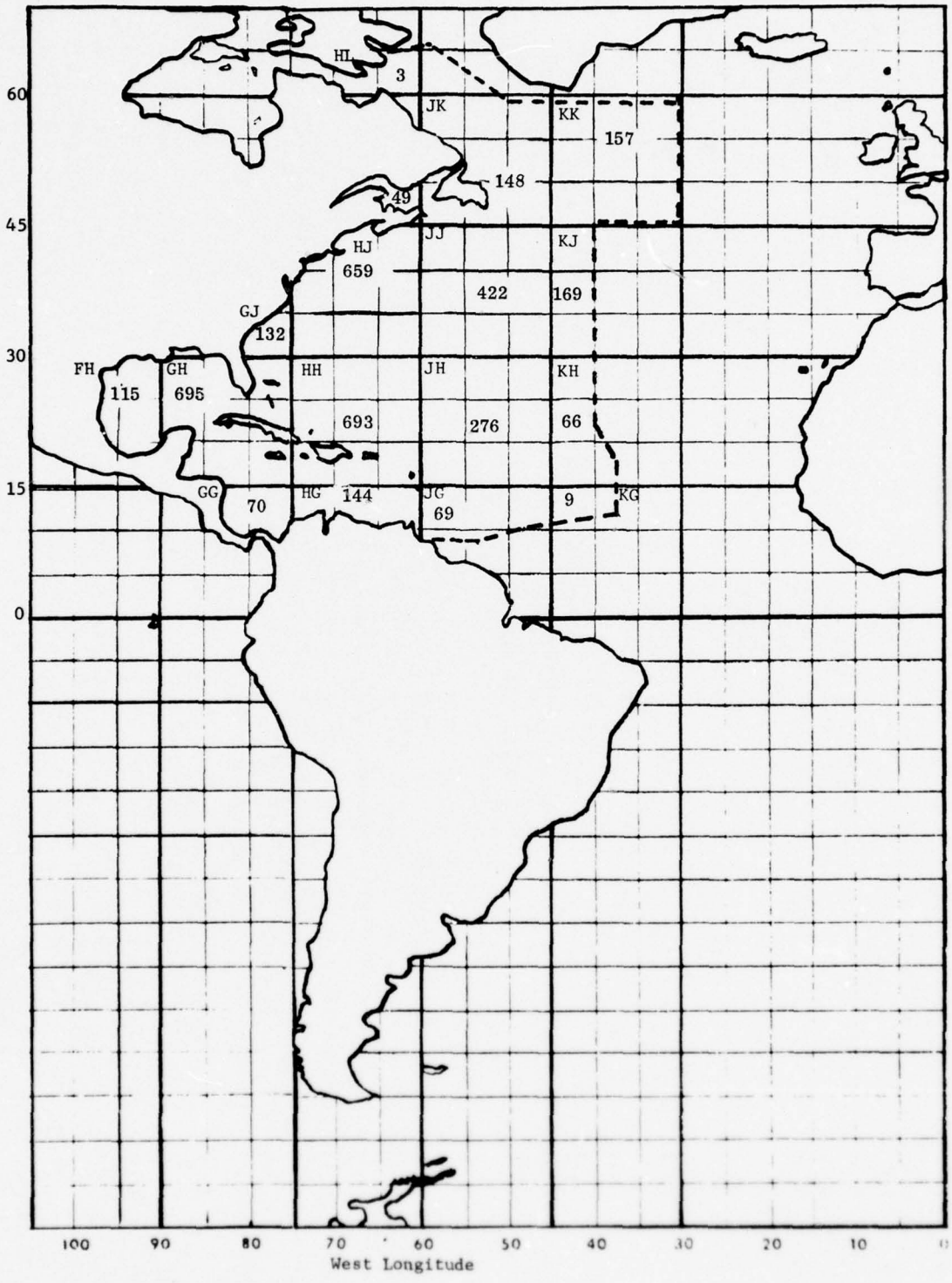

Figure 2-5. Commercial Ship Distribution in Atlantic SAR Region

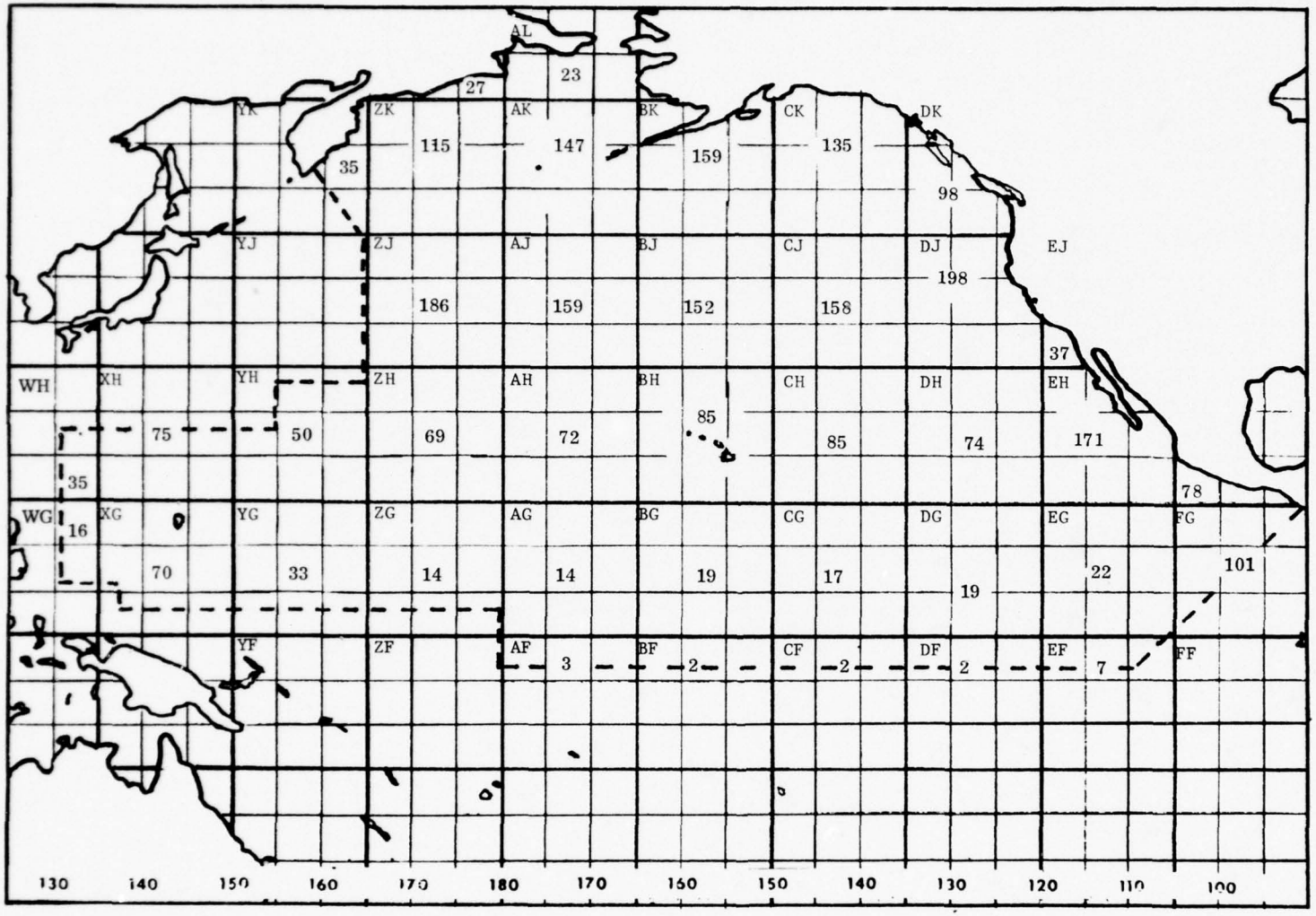

Figure 2-6. Commercial Ship Distribution in Pacific SAR Region

Marine International. These total population estimates for fishing vessels at sea in the SAR Maritime Regions for an average day are:

Atlantic SAR Maritime Region	4,779
Pacific SAR Maritime Region	3,021
Total	7,800

The distribution model by geographical grid is shown in Figures 2-7 and 2-8.

The total installation base costs per user for this category of vessel is derived by dividing the population at sea within the SAR Maritime Regions by a percentage believed to represent typical operating patterns. The overall average is estimated as 78 percent at sea. The installation base is:

Atlantic Fishing Vessels	6,127
Pacific Fishing Vessels	3,873
Total	10,000

The equipment installed is assumed to be fabricated by approximately 15 manufacturers.

In considering candidate communication systems for fishing vessels, it is assumed that a uniform pattern is applicable throughout the SAR Maritime Region. It is recognized that some specific subdivisions may depart from this pattern, but the impact is considered of minor statistical variation. For example, fishing vessels in Alaska are influenced by shore facilities and distances. Those west of Kodiak primarily use HF SSB, whereas those east of Kodiak use 2182-kHz or 2-MHz working frequencies.

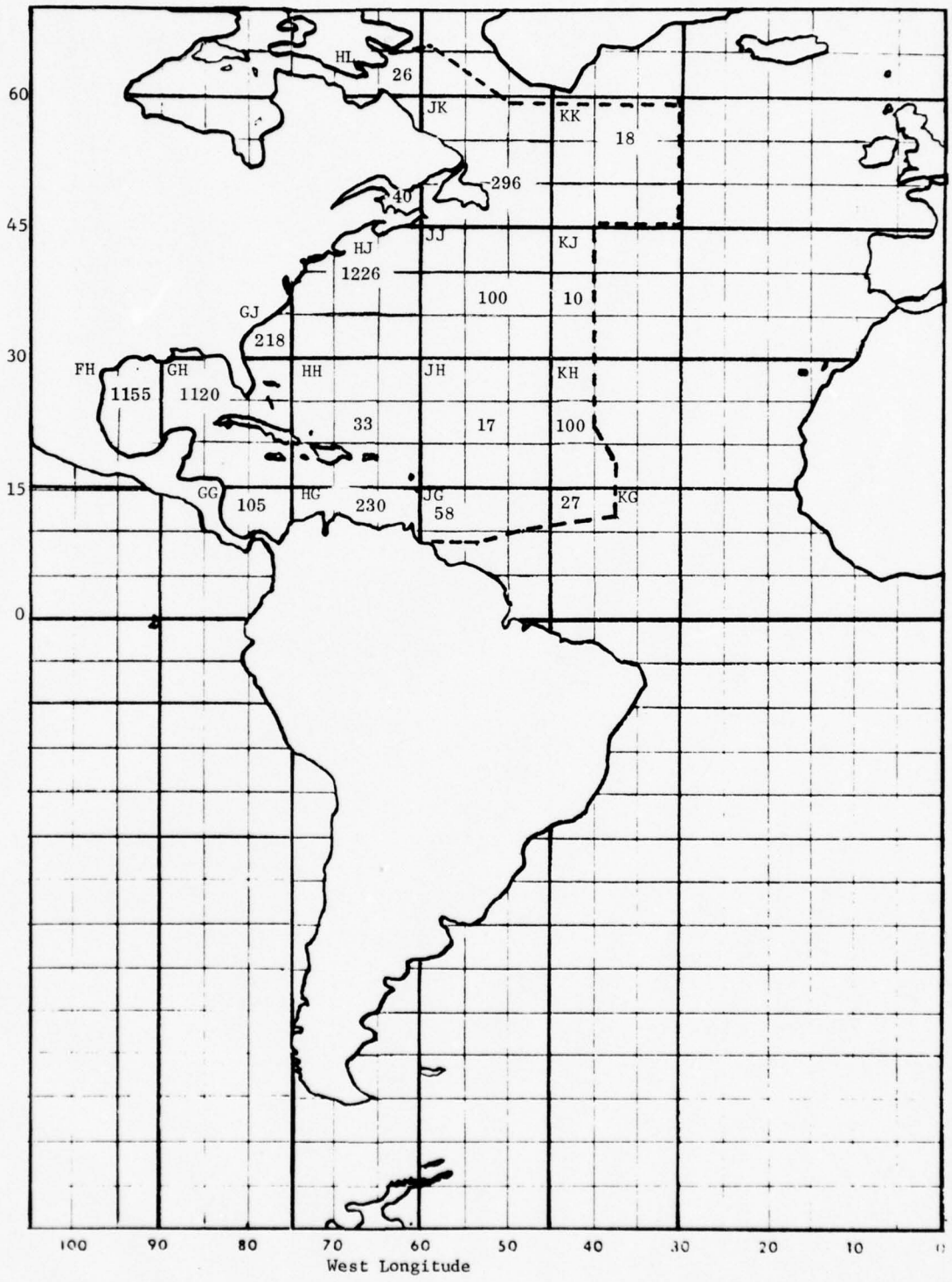

Figure 2-7. Commercial Fishing Vessels in Atlantic SAR Region

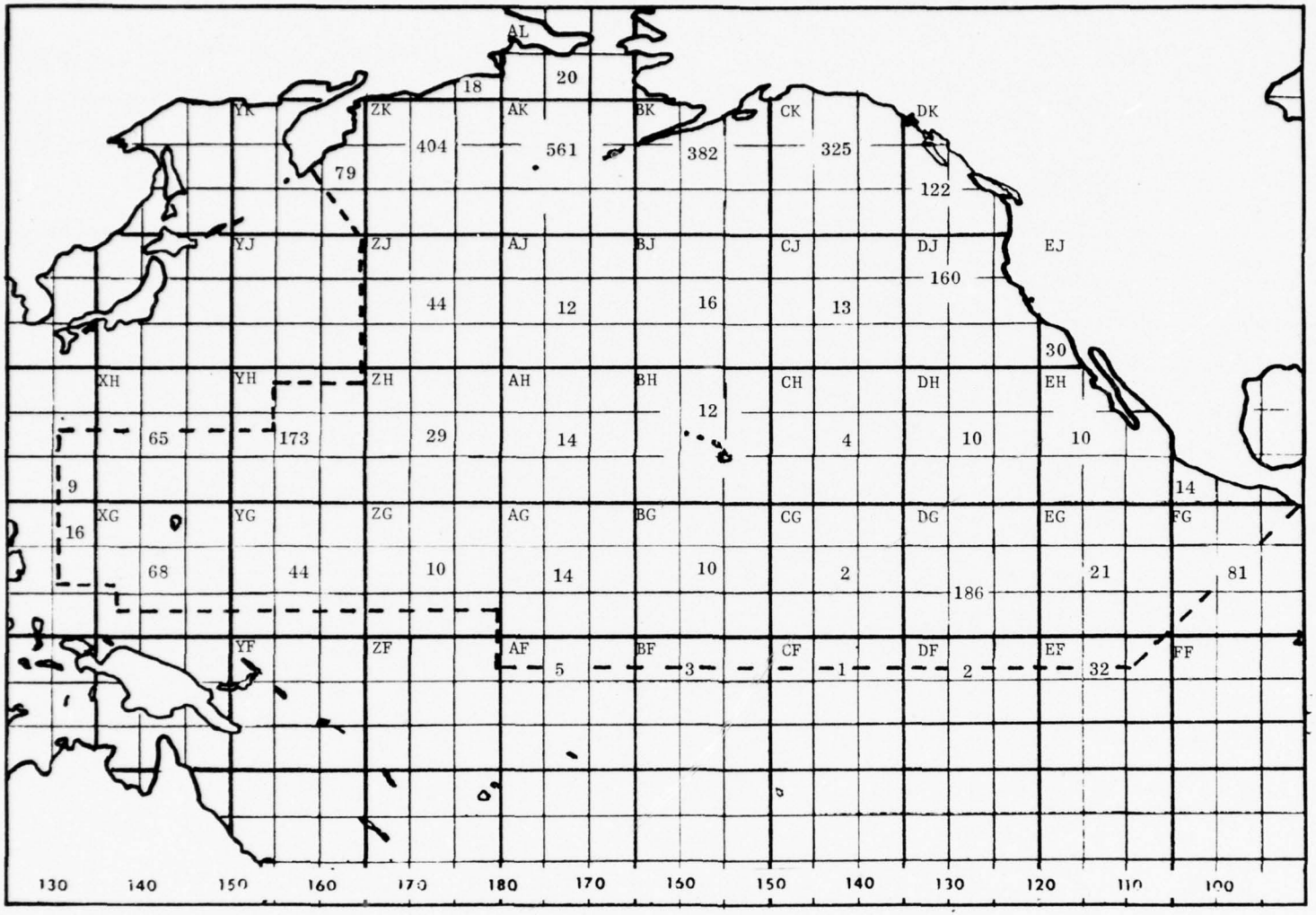

Figure 2-8. Commercial Fishing Vessels in Pacific SAR Region

SECTION 3 - EFFECTIVENESS FOR SHORE ALERTING

3.1 OVERVIEW

Potential benefits to be derived from any alerting system stem from the inherent capabilities to contact the SAR organization. The most preferable alert is made direct to shore. Obviously, the effective alerting range of each candidate electronic system decreases with increasing distance from shore. Lacking a capability to reach shore, the candidate system must rely on the probabilities of being within range of passing ships, which are classified as platforms-of-opportunity. The computed effectiveness for alerting is the probability of alerting either shore stations or passing platforms-of-opportunity. This Section addresses the rationale in determining effectiveness for shore alerting while Section 4 discusses effectiveness of alerting passing platforms of opportunity.

The candidate systems considered in this Section are those utilizing terrestrial groundwave or skywave modes of transmission and moderate to long-range capabilities for alerting. These include installed 500-kHz and 2182-kHz equipment and the 8364-kHz survival transmitter. The technical characteristics of these candidate systems are related to system parameters, but their effectiveness in propagation (EP) varies with location as stated previously. Therefore, the EP values are used as inputs of grid parameters in the computational processes.

3.2 HIGH FREQUENCY RADIO COVERAGE OF OCEANIC AREAS

3.2.1 General Methodology

The probability that a distress signal is sufficiently above the atmospheric noise threshold for reception at any specific station may be expressed as a path reliability, or EP. Given the receiving station location, signal characteristics, and radio propagation data, analytical techniques are

available to establish EP values for any geographical path. Computations are based on a worst-case analysis using a summer month and minimum sunspot activity (June, Sunspot Number 15). Propagation data, including noise, was obtained in magnetic tape form from the Institute of Telecommunication Services (ITS), Boulder, Colorado.

To obtain the required data for each of the ocean areas, the use of a representative model was examined. However, variations,primarily in HF radio path reliability, indicated that the best method of deriving this information would be to base calculations on each grid as a model and to aggregate the results. Such a course also would provide flexibility and a sound basis for further sensitivity investigations. However, the computational process required to determine path reliabilities from each geographical grid to all Radio Stations would involve lengthy and complex calculations. In addition, for calculations of this magnitude,computer costs may be disproportionate to the analytical needs of this study. Instead, 12 oceanic locations were selected at varying distances from each Coast Guard Radio Station as the basis for computing path reliabilities. Additional data were selected where available from Coast Guard HF coverage reports. Because computer solution of a spherical triangle is simple and inexpensive, distances were computed to ocean grids from each Radio Station and translated to a reliability factor. Those stations having the best reliabilities were used. The HF analysis then found the combined probability among the best two or three, and discarded any station whose contribution was too minor to influence the result. These reliabilities were then plotted by distance from the station to permit a reliability estimate for any given distance.

3.2.2 High Frequency Installed Telegraphy Systems

The use of installed high frequency telegraphy equipment aboard ship for distress calls also assumes the availability of a Radio Officer. In these

instances, an awareness of an optimum frequency to shore for time of day and location exists, and the highest reliability for each hour can be selected regardless of the frequency band. Accordingly, the average daily reliability will be an average of the 24 highest hourly reliabilities. These averages are plotted against distance as shown in Figures 3-1 and 3-2, and can be used to find the EP. In using these curves, the distance is computed from each grid examined to Radio Stations expected to provide alert coverage for the SAR Region involved. Through the graph, the distance is translated to EP. These EP values are used to analyze all systems with HF installed configurations. Of course, minor differences exist among stations and directions, but these are considered within statistical bounds when examined only for the SAR operating areas of interest.

3.2.3 Survival Radios

The high frequency survival radio is a manually-cranked transmitter operated by any crew member. Internal cams cause the transmitter to alternate frequencies between 500 kHz (70 seconds) and 8364 kHz (122 seconds). The transmitted power is 2 watts and the emission is slow-speed manual Morse using a 700-Hz tone-modulated carrier. The radiating antenna is a 20-foot jointed, tubular whip.

Path reliabilities for the 8364-kHz survival craft transmitter were computed for a series of points extending to 2100 nautical miles and are plotted against distance in Figure 3-3. The survival craft-to-shore EP for a grid is determined on the basis of the distance to each of the two nearest Coast Guard Radio Stations. The results are inputs to the grid parameter data base.

The HF survival radio was particularly sensitive to relatively short distance reliability because its fixed frequency exhibits a skywave skip at certain hours. At 350 nautical miles, there were 8 hours during which no propagation link exists. However, for 4 hours each day a path reliability of .99 occurs over the 350-nautical mile path.

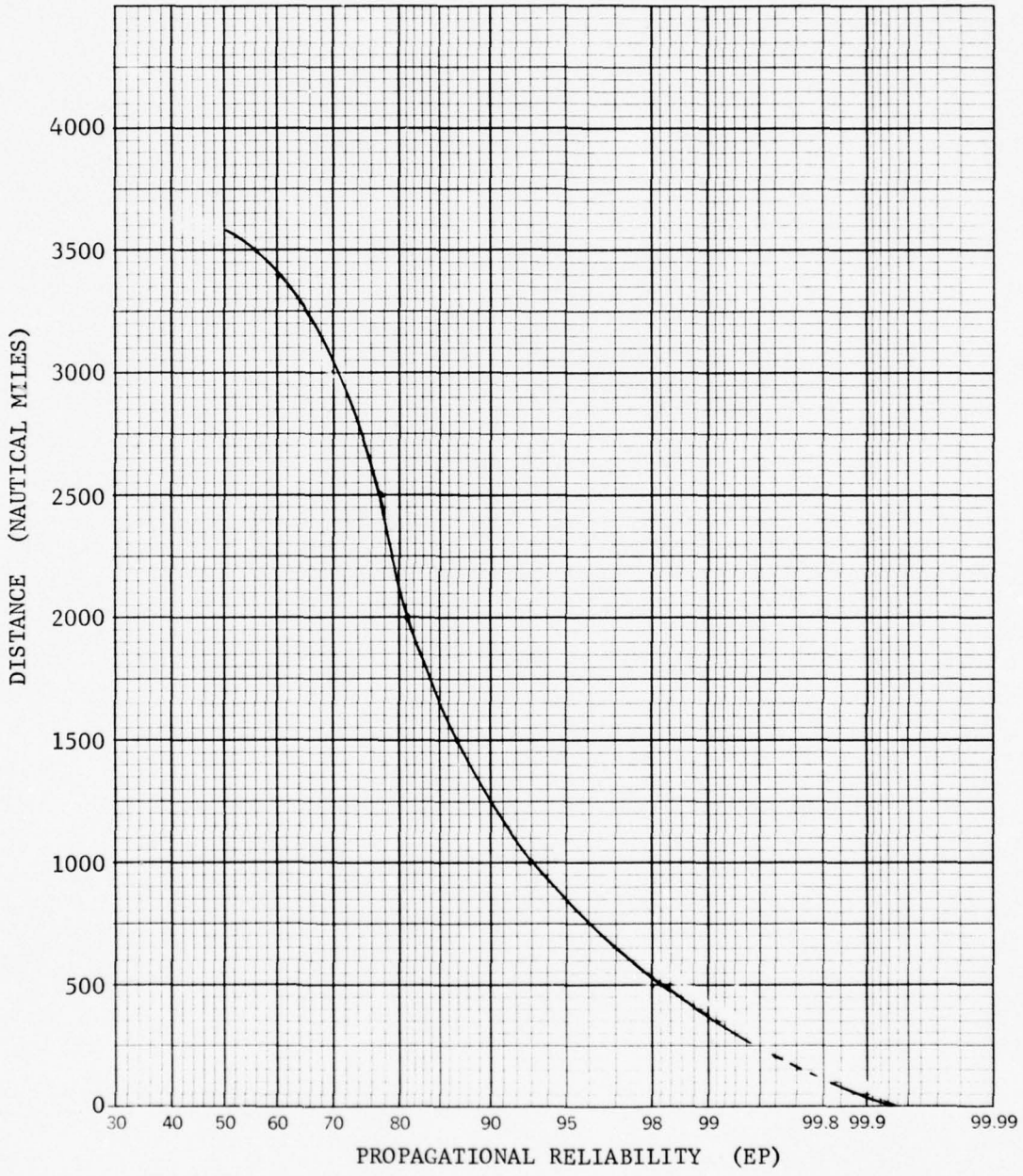

Figure 3-1. Radio Propagation Reliability with Distance for Atlantic SAR Region (Installed HF)

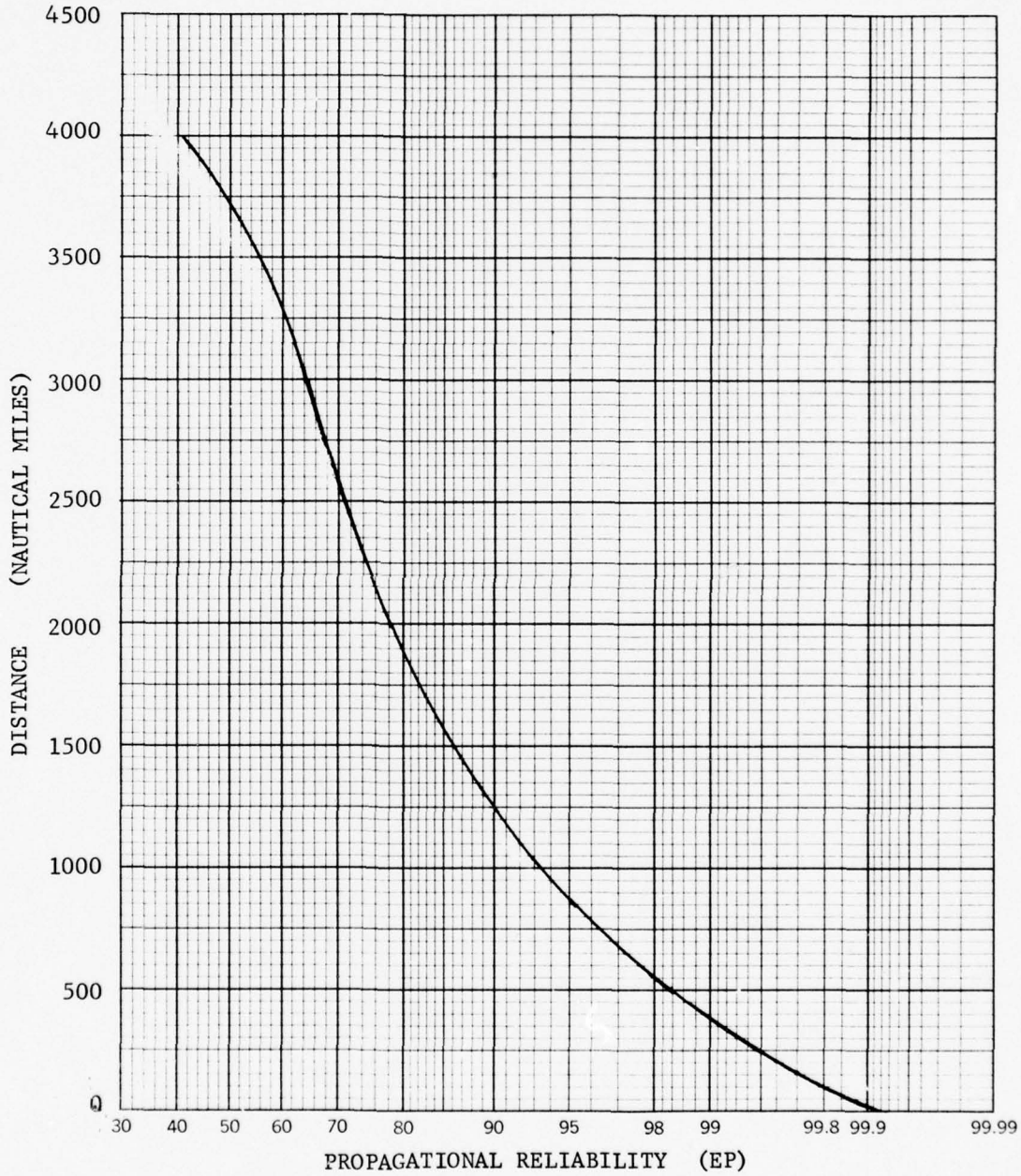

Figure 3-2. Radio Propagation Reliability with Distance for Pacific SAR Region (Installed HF)

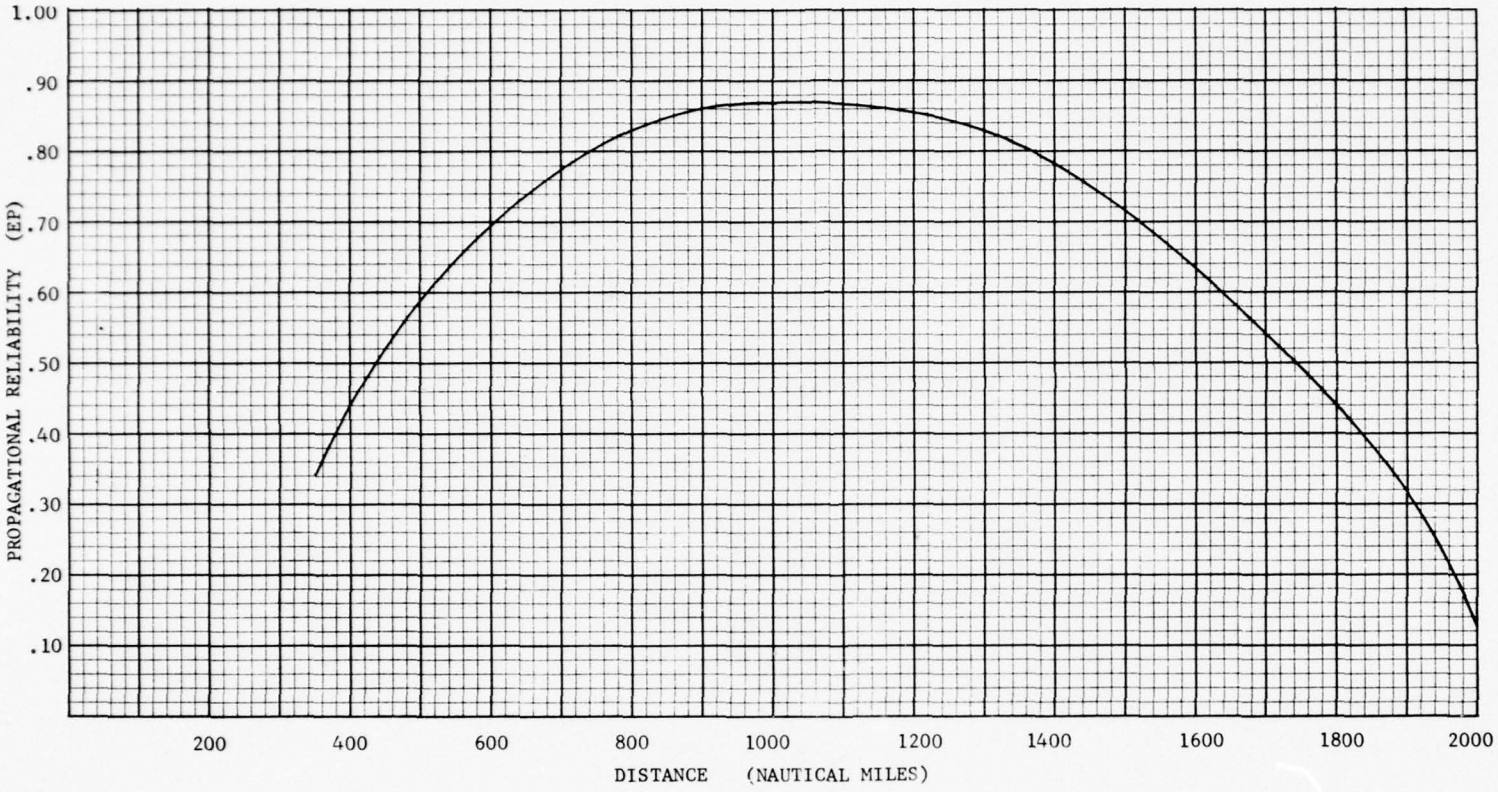

Figure 3-3. Radio Propagation Reliability with Distance for HF Survival Units (8364 kHz, 2 watts)

3.2.4 2182-kHz Voice

The predominant mode of propagation at 2182 kHz is by groundwave and, therefore, its use to shore stations is limited to coastal or immediate offshore areas. Long-range alerting using 2182 kHz is unpredictable because the existence of skywave propagation does not follow convenient diurnal, seasonal, or sunspot cycles. Additionally, local receiving conditions are affected by electrical noise and interference from other stations in the groundwave coverage area. Therefore, long-range alerting using 2182-kHz skywave propagation is not included.

The radio transmission range of 2182-kHz voice signals for a given transmitter power and performance are limited primarily by noise. The typical transmitter is rated at 100 watts peak envelope power, or approximately 25 watts average power. Noise levels contained in CCIR Report 322, World Distribution and Characteristics of Atmospheric Radio Noise, show representative values in the SAR Maritime Region between 64 and 78. Signal-to-noise power density ratio (in 1-Hz) is 49 dB. The computed range at the lower noise level is 130 nautical miles. The effectiveness of 2182 kHz in reaching Coast Guard or commercial facilities ashore is accordingly limited to 130 nautical miles offshore. This value is included in appropriate grid parameters.

3.3 MEDIUM FREQUENCY RADIO COVERAGE OF OCEANIC AREAS

The long established use of 500 kHz for distress alerting has resulted in procedures and an operating discipline that enhances its effectiveness. Transmission of the distress message commences with 4-second dashes that will provide a distinctive distress signal. In addition to shore alert, these signals can activate a shipborne auto alarm and relayed by Radio Officers through congested signal conditions if shore acknowledgement is not observed. The mandatory requirement for 500-kHz installations on ships of

1600 tons and over, and the provision of battery-operated emergency 500-kHz transmitters provides a reliable distress alerting means for these ships. Under FCC regulation, coastal stations operating as common carriers in the maritime mobile service are required to guard 500 kHz. Due to the importance attached to safety guard, the usual practice in multiple operator stations is to assign a senior operator to the 500-kHz position. Because messages on medium frequencies account for approximately 10 percent of the total medium and HF traffic, guard on 500 kHz may be interrupted briefly to receive traffic.

The average ship transmitter and associated antenna radiates approximately 50 watts.[1] During the noisiest time block (0000-0400 local, summer), the transmission range to shore is 380 nautical miles. During low noise periods (i.e., winter, evening), ranges up to 700 nautical miles may occur but are too susceptible to interference to be considered reliable. Grid parameter inputs for 500-kHz capabilities to shore are evaluated on the basis of 400 nautical miles as a representative value for the overall region.

3.4 HIGH FREQUENCY VOICE COMMUNICATION SYSTEMS

The Coast Guard has recently increased facilities for HF voice communications with high seas vessels. Users of this type service are primarily commercial ships of less than 1600 tons. Although fishing vessels have increased their HF voice installations, they are usually used on limited coastal station frequencies for contacts with fishing cooperatives or owners ashore. These company-assigned frequencies may be used for emergency reporting in the temporary absence of a primary alerting means or usable distress frequencies, but would require relay to the Coast Guard.

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[1] "East Coast Communications Coverage at 500 kHz", Leslie Berry, ITS, Boulder.

Because of its current status and limited data base, HF voice communications are not examined. The expected performance and coverage of HF voice has been investigated by ITS for the Coast Guard.

3.5 HIGH FREQUENCY WATCHKEEPING AT SHORE STATIONS (TELEGRAPHY)

3.5.1 General

The connectivity effectiveness (ET) is the probability that a shore operator will successfully receive a telegraphic emergency transmission at the time it is sent. ET is a function of the listening time provided by shore operators which, in turn, is affected by traffic handling conditions involving the number of frequencies used and amounts of traffic being received. There are six high frequency bands available on which emergency messages can be sent, each having as many as nine calling frequencies. These bands are jointly shared by commercial stations and Coast Guard Radio Stations. Operators will scan calling frequencies until diverted to working frequencies for message reception. The scanning of calling frequencies is accomplished automatically at Coast Guard and most commercial stations. Each information transfer, however, interrupts the complete scan of all calling frequencies until the coastal station has concluded each contact. The number of messages and number of queries from ships accordingly tend to increase the time required to accomplish a complete search of each calling frequency. If the alerting message is from a survival craft, a further reduction in ET may result from congestion or violations that deteriorate this designated (8364 kHz) emergency frequency.

3.5.2 Commercial Radio Stations

Commercial stations operating on maritime high frequencies are primarily oriented to traffic exchange with ships on the high seas. The communications plant is installed to enhance this capability. These stations also

maintain a manned watch on 500 kHz. However, 90 percent of the traffic handled is on high frequencies. Of the six bands, three bands (8, 12 and 16 MHz) account for 30 percent each of the total HF traffic. The magnitude of HF traffic through U. S. commercial stations averages 631,000 messages annually on the East and Gulf Coast. Pacific coastal stations average 314,000 messages annually. The average loading for a commercial station is approximately ten messages per hour. However, a few major gateway stations peak as high as 60 messages in a busy hour and, in these instances, the queuing time may reach a 2-hour wait for ships. In an automatic scan mode, a typical commercial station requires 4.5 minutes to scan all calling frequencies in an HF band if uninterrupted by calls.

3.5.3 Coast Guard Radio Stations

Watchkeeping at Coast Guard Radio Stations is primarily oriented to distress and emergency calls. However, each station handles medical, weather observation reports, bathylogical reports, and position and track reports (AMVER). This traffic and distress watch is conducted on the same calling frequencies utilized by commercial ships and coast stations. The magnitude of traffic through Coast Guard Radio Stations operating in HF bands is approximately 35,000 messages annually for East and Gulf Coast coverage. The Pacific average is approximately 39,000 messages annually. Coast Guard Radio Stations utilize automated scanning of calling frequencies which may be adjusted by the operator. Typical settings provide for 20-second dwell on each calling frequency with 3 minutes to complete a cycle. Message calls to the Coast Guard Radio Station will halt temporarily the automatic sequences. The Station achieves a higher probability of recognizing a distress call because of its mission orientation and moderate message loading in comparison to commercial radiotelegraph stations. However, during the busy hours for commercial communications and the resulting congestion on common calling frequencies, the Coast Guard radio operator may be forced to make slight changes in scanning rates.

3.5.4 Success Probabilities in HF Telegraphy

Currently, calling is conducted on as many as nine available maritime mobile HF frequencies. Improved procedures to reduce this to three calling frequencies with separate receivers on each frequency is expected to be implemented in the future. Examination of access delays in reaching shore stations considered both concepts.

Probability of successfully establishing operator contact ashore was determined by computer simulation. Shore station scanning by commercial stations was modeled on the basis of practices followed at Chatham Radio (WCC) and Mobile Radio (WMO). Information on Coast Guard scanning practices was obtained by interview with an experienced Coast Guard operator. The simulation program applied a Monte Carlo technique in examining each simulated second for 16 hours. During this time, 100 distress calls were entered at random. The distress message was assumed as one minute in duration. Six coast stations were assumed to be in technical transmission range. The signal strength differed as a typical condition among stations and the assumed coast station reception reliabilities with a ship 1500 nautical miles off shore are:

1 station - .850
1 station - .800
2 stations - .600
2 stations - .200

The simulation analysis was applied to Coast Guard and commercial stations, using both a three- and nine-frequency calling concept. The results are shown in Figures 3-4 and 3-5, respectively. Because low traffic levels permit high scan rates in Coast Guard Radio Stations, the difference between three- and nine-frequency calling concepts is negligible provided additional operators are assigned to monitor as an exclusive function. However, alerting

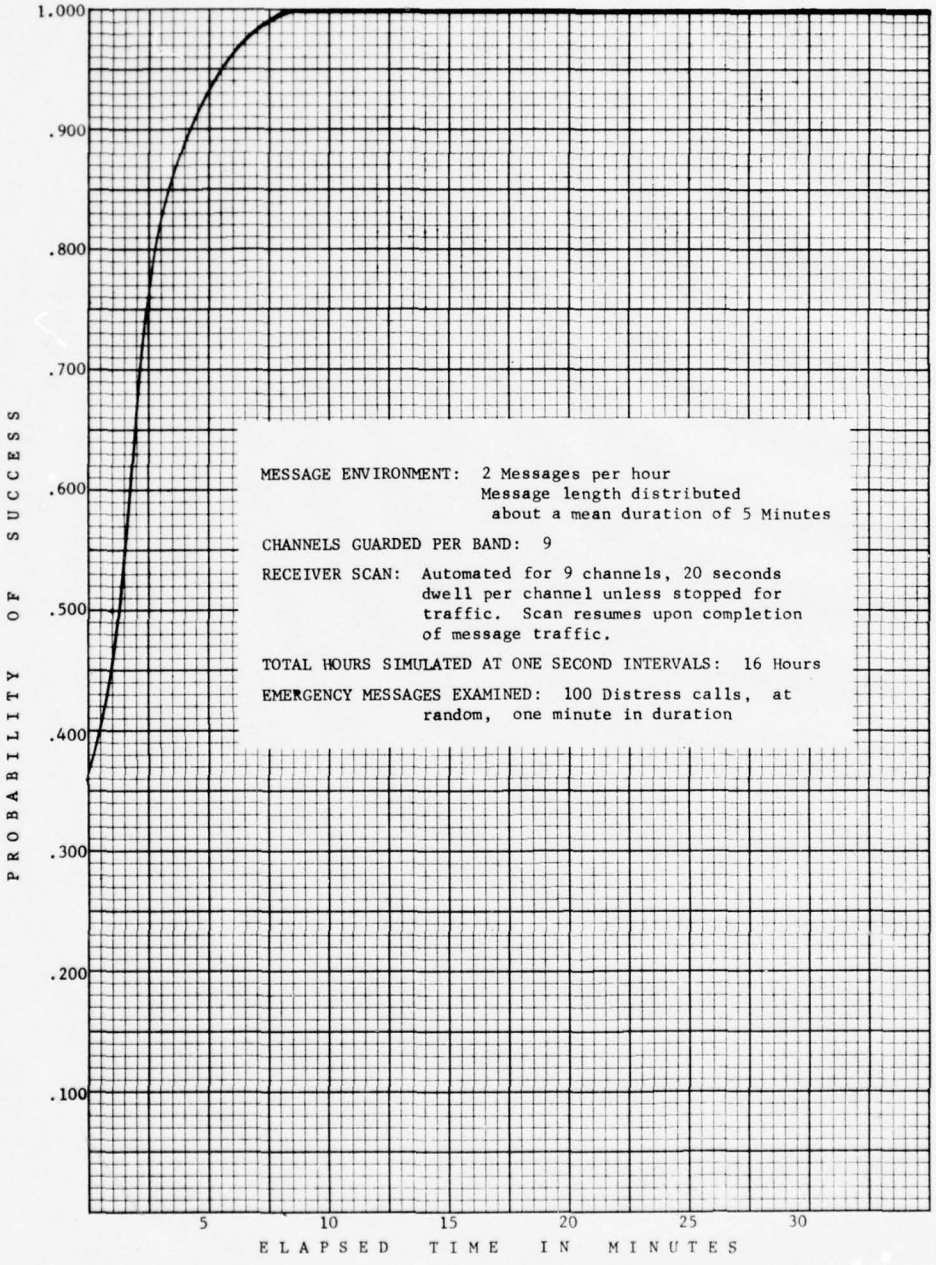

Figure 3-4. Alerting Probability for Coast Guard High Frequency Guard (Simulation)

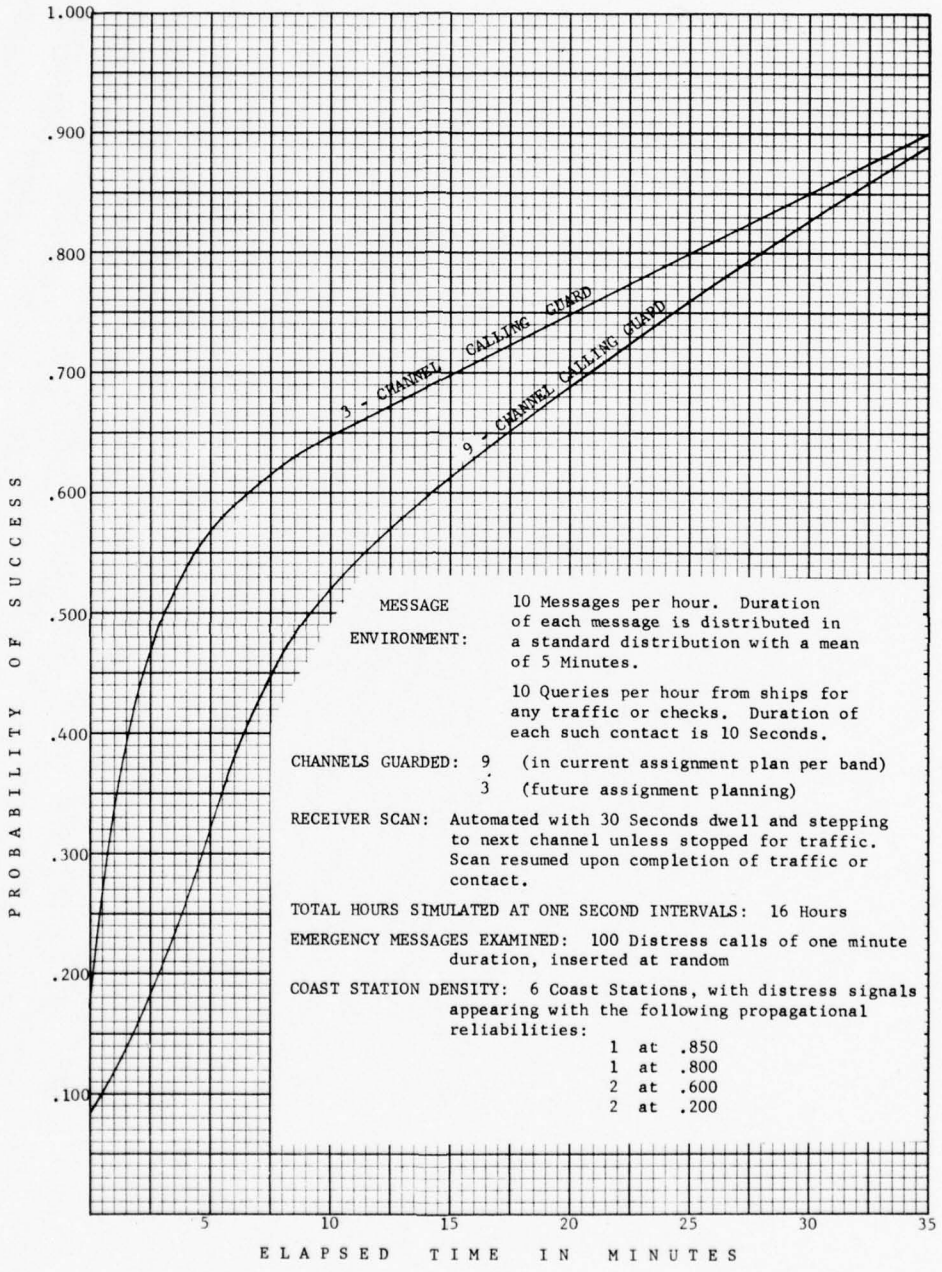

Figure 3-5. Alerting Probability for Commercial Coast Stations, High Frequency (Simulation)

a commercial station to an emergency call is improved by the three-frequency concept as shown in Figure 3-5.

If a 5-minute delay is the maximum acceptable, the ES of the Coast Guard Radio Station is 0.930 (Figure 3-4). The commercial station, with its higher traffic and additional operator duties, provides an alerting effectiveness of 0.320 in the nine-frequency concept and 0.570 in the three-frequency concept (Figure 3-5). If the Coast Guard Radio Station is assumed to be supplemented by the watch of two commercial stations, the consolidated effectiveness for a 5-minute alerting is:

$$ES_{\text{consolidated}} = E_1 + E_2 + E_3 - E_1E_2 - E_2E_3 - E_1E_3 + E_1E_2E_3$$

$$\text{If } E_1 = .930$$
$$E_2 = .320$$
$$E_3 = .320$$

$$= .9676$$

SECTION 4 - ALERTING PLATFORMS OF OPPORTUNITY WHEN BEYOND COAST STATION RANGE

4.1 OVERVIEW

At distances beyond normal communications range to shore radio facilities, some of the candidate electronic systems may be used to alert platforms-of-opportunity that are within range. These platforms-of-opportunity include passing ships, fishing vessels, and overflying aircraft. Platforms-of-opportunity can serve as relays for the alerting message and assist SAR forces. This section addresses the alerting of ships and vessels; Section 5 is concerned with alerting aircraft overflights. The primary considerations in the discussion that follows include platform population, transmission ranges of applicable electronic alerting systems, and the probabilities that an alerting message will be received.

4.2 METHODOLOGY

The effectiveness of alerting passing platforms-of-opportunity is related to the number of platforms in a geographical area, the transmission range capabilities of the alerting radio system, and availability of an on-duty operator or an auto-alarm device. Where the range of the alerting system is particularly limited compared to distances within the grid area examined, effectiveness is related to probabilities of random tracks passing within radio range. The analytical techniques are used to define these probabilities, and provide inputs to the computational process. Because ship density is geographically related, populations of ships and fishing vessels are included in the grid parameters data base. The transmission range of candidate systems is a system characteristic, and is included in the system parameters data base.

4.3 APPLICABLE TRANSMISSION RANGES

4.3.1 General

Candidate electronic systems considered could be expected to be on passing ships and vessels and operating on frequencies normally used for emergency alerting. This includes installed radio equipment operating at 500- and 2182-kHz. Receipt by platforms-of-opportunity of alerting messages sent from other candidate systems is considered highly unlikely. This latter equipment category includes high frequency radio used for scheduled Fleet nets and call/traffic transmissions and beacons operating on aeronautical emergency frequencies (121.5/243-MHz).

Characteristics of the candidate electronic system considered in the analysis for platforms-of-opportunity are discussed in Section 3 in connection with their effectiveness for alerting shore stations. However, operating ranges for this equipment in alerting platforms-of-opportunity can be expected to be less than for shore stations, due to lower efficiency of onboard antennas and higher onboard electrical noise levels.

4.3.2 Installed 500-kHz Equipment

The computed range of a typical ship transmitter operating on 500-kHz is 270 nautical miles in average atmospheric noise and considering the signal level required to ensure activation of the autoalarm. This is in contrast to the minimum 150-nautical mile range recommended by IMCO. Activation of the 500-kHz auto-alarm receiver requires 100 uv/m; a typical operator may copy traffic at a receive level of 83 uv/m.

4.3.3 Survival Radio

This equipment is the hand-cranked transmitter that automatically transmits alternately on 500- and 8364-kHz. Only the 500-kHz operating frequency was considered in this analysis due to the limited probability of alerting at the higher frequency, as stated above. For this analysis, a range of 27 nautical miles is used. Although the transmitter power is 2 watts, radiated

power is approximately 0.05 watt because of low antenna efficiency. This radiated power is confirmed by manufacturer and Coast Guard measurements. If the receiver/antenna sensitivity is 25 uv/m, the transmission range is 27 nautical miles 90 percent of the time. During 10 percent of the time, a range of 7.5 nautical miles may occur in areas of high noise. The IMCO requirement is for a receiver/antenna sensitivity of 50 uv/m.

4.3.4 2182-kHz Installed Transmitter

An average installed transmitter operating on 2182-kHz is rated at 100 watts PEP, which is approximately 25 watts continuous power. With this power, the ship-to-ship alerting range will be normally between 60 and 70 nautical miles. A range of 70 nautical miles was used in this analysis.

4.3.5 2182-kHz Survival Transmitter

In this analysis, the maximum range for the 2182-kHz survival transmitter is 37 nautical miles for an onboard receiver sensitivity of 25 uv/m. This range is the controlling parameter for all atmospheric noise levels of 75 or less. The transmitter is rated at 2 watts, but, because of antenna inefficiencies, the rated power is assumed as 100 milliwatts. The bandwidth is assumed as 4000 Hz and the required signal-to-noise ratio as 3:1.

4.3.6 2182-kHz Emergency Position Indicating Radio Beacon (EPIRB)

A performance specification has not been established for this equipment but a number of models are available commercially or in prototype form. The transmission capability of a 2182-kHz EPIRB is severely limited in radiation efficiency by feasible antenna configurations, transmitter power as balanced against battery life and package size, and atmospheric noise.

In Coast Guard tests of available EPIRBs[1], radiated power and maximum detection range were measured using surface craft. The data reported illustrates the range of some typical units in field tests:

Radiated Power (Milliwatts)	Detection Range, Surface (N. Miles)
0.42	9
0.73	13
0.83	16

The conditions of atmospheric noise existing at the time of these field tests are not indicated but apparently are low in view of the season and ranges.

The system range is computed to obtain distances based upon similar conditions used for other systems in the analysis. For this purpose, it is assumed that antenna designs are available to achieve a radiated power of 2 milliwatts. The bandwidth is assumed as 4400 Hz and the required signal-to-noise is 3:1. The ship receiver sensitivity is assumed as 25 uv/m as recommended by IMCO. The system capability as governed by receiver sensitivity and 2 milliwatts power is 5.2 nautical miles.

The difference between ranges in the Coast Guard field test and the range computed for the 25-uv/m receiver represents the receiver sensitivity differences. The receiver used in the Coast Guard field test had a sensitivity of at least 6 uv/m. If this receiver is representative of those aboard High Endurance Cutters, the detection range of the 2-milliwatt EPIRB is 22 nautical miles as a system limit. However, this would not be achieved in expected levels of atmospheric noise. Noise would limit the range of the 2-milliwatt EPIRB to 6.3 nautical miles at noise levels of 74 dB, and to 12 nautical miles at a noise level of 68 dB.

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[1] EPIRB Field Tests, 11th Coast Guard District, 2 December 1975

Examination of noise levels for 2182 kHz in the SAR Maritime Region suggests a noise level of 68 dB as representative of most times and areas. Accordingly, a range of 12 nautical miles is used in the analysis for ship reception of the 2182-kHz EPIRB.

4.4 WATCHKEEPING ABOARD SHIP

4.4.1 General

Watchkeeping affects the probability that a recognition system exists on a platform-of-opportunity that is within range. In the absence of recognition capabilities for an emergency or distress signal, the alerting process is ineffective. The extent that automated alarms are installed in passing ships is a key consideration. The effectiveness in watchkeeping (ET), whether operator or automatic, is a system characteristic unrelated to population or geography and is a system parameter.

4.4.2 500-kHz Watch

Ships with 500-kHz compulsory installations are not required to guard 2182-kHz on the high seas; however, IMCO recommends this practice. Discussion with major ship operators indicates that unless some situation or report suggests a 2182-kHz guard, such monitoring is sporadic. In the absence of regulatory requirements for full participation, it is assumed that 10 percent of the ships are guarding 2182-kHz in addition to 500-kHz.

Fishing vessels primarily operate on 2-MHz frequencies including 2182 kHz in the fishing areas and enroute, and maintain 2182-kHz guard when not exchanging traffic on other frequencies. Although reliable data is unavailable to confirm the percentage of fishing vessels on 2182-kHz, comments of fishing association representatives suggest that approximately 90 percent are either operating or guarding 2182 kHz in the oceanic areas. An estimated 5 percent are temporarily on high frequency limited coast station frequencies or 2-MHz working channels.

4.4.3 High Frequency Guard

The probability of ship guard on the HF calling bands is non-existent because of normal working procedures. In using HF, the ship operators either meet scheduled fleet nets or listen to call/traffic list transmissions of specific coast stations on the frequency assigned to the coast station.

4.4.4 121.5/243 MHz Emergency Beacons

Ships and fishing vessels are not equipped to guard the aeronautical emergency frequencies, 121.5 and 243 MHz.

4.5 EFFECTIVENESS AS A FUNCTION OF SHIP POPULATION

The probability of alerting platforms of opportunity in oceanic areas is directly related to ship population in the sample grid, the range of the radio device, and availability of an on-duty operator or automatic recognition device. Of the effectiveness parameters applicable to this situation, the probability of a propagation path (EP) and availability of recognition (ET) are dependent functions and both must be satisfied for success. The estimated ship and fishing vessel population as described in Section 2 are used as grid parameter inputs. The probability model for alerting platforms-of-opportunity is based on a 900 by 900 nautical mile grid corresponding to a 15-degree grid at the equator. The probability for random intercepts during a 24-hour period is expressed by the following relationship:

$$P_{24} = 1 - \left(1 - EA * ES * \frac{\pi R^2 + (2R)(24)(V)}{S^2}\right)^N$$

where:

P_{24} = Detection Probability in 24 Hours

R = Transmission Range of Candidate System

S = Side of Sample Grid at 900 nautical miles

N = Number of Platforms in Grid

V = Velocity of platform through Sample Grid

EA = Equipment availability, 0.996 for all systems

ES = Signal environment factor

The sample results for the probability of alerting passing platforms of opportunity are shown in Figure 4-1. Several curves are shown for the different transmission ranges and the velocity of the passing platform.

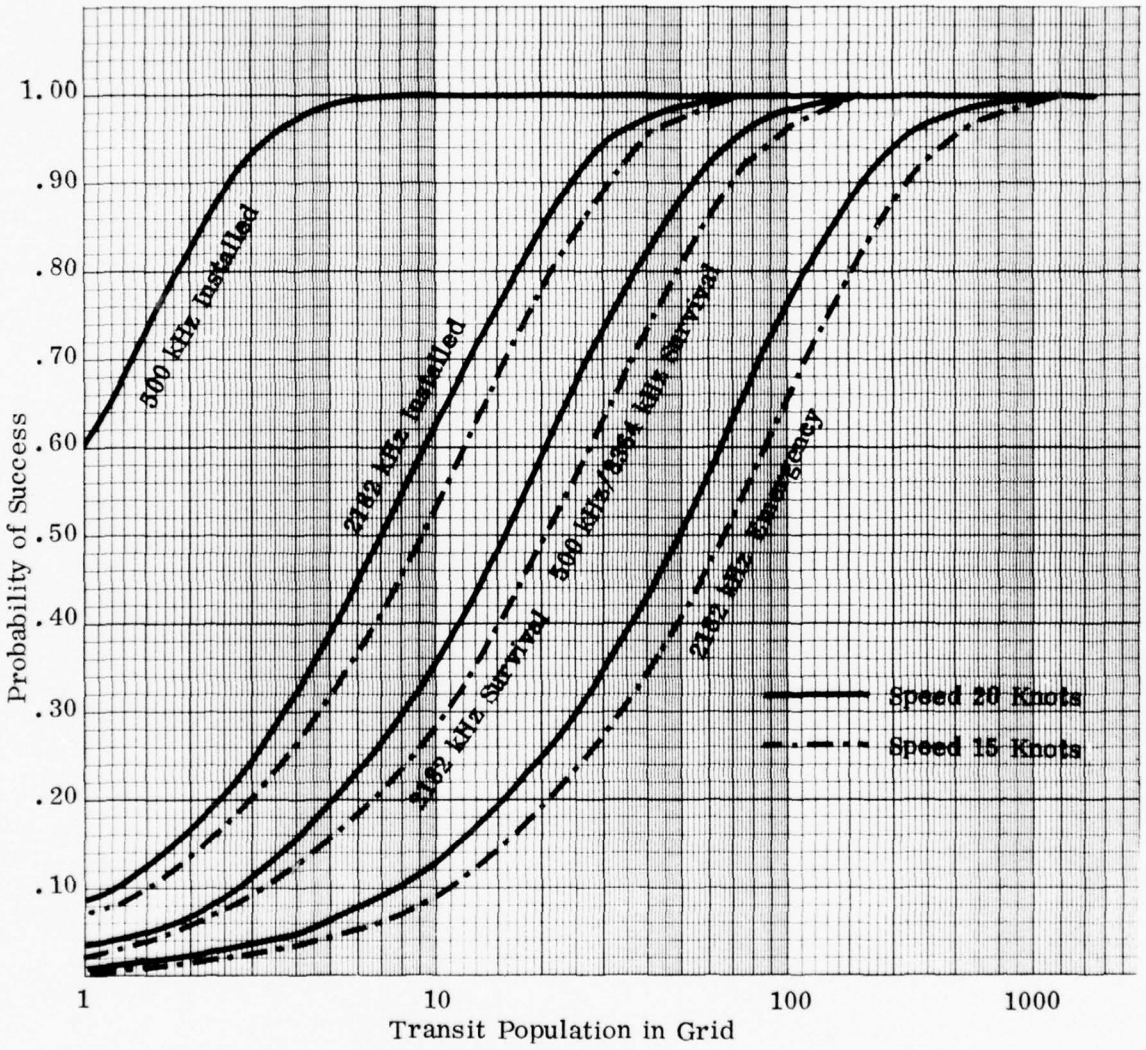

Figure 4-1. Probability of Alerting Platforms-of-Opportunity

SECTION 5 - ALERTING AERONAUTICAL OVERFLIGHTS

5.1 OVERVIEW

5.1.1 Regulatory Background

To ensure that downed aircraft and aircraft survival rafts have capabilities for alerting and location, Public Law 91-596, enacted 29 October 1970, required most civil aircraft to be equipped with an approved Emergency Location Transmitter (ELT) after 30 December 1973. Specifications for three categories of ELT were prepared by the Radio Technical Commission for Aeronautics (RTCA). Through international coordination and carrier implementation, aircraft on oceanic routes carry ELT units which may be activated manually or automatically by impact or by immersion in water. These units transmit a distinctive signal on the aeronautical emergency frequencies of 121.5/243 MHz. Oceanic aircraft monitor 121.5 MHz on these routes.

Installation and carriage of electronically similar equipment is compulsory for certain inspected U.S. ships and onboard survival craft. Some foreign ships also carry this type equipment. The U.S. carriage requirement is in accordance with U.S. Notice 71-7, dated 13 March 1971, published in the Federal Register and is responsive to international recommendations,[1] and FCC. Report and Order of Docket 19693[2] for ship, survival craft, or EPIRB. Boats normally operating within range of coastal or inland VHF-FM coverage are purposely excluded since their use of the aeronautical emergency frequencies would create severe degradation to aeronautical communications. Ships and fishing vessels are neither required nor expected to carry radio receivers for the aeronautical emergency frequencies.

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[1] Recommendation 48 of the 1960 Safety of Life at Sea Conference and subsequent Assembly Resolutions of the Inter-Governmental Maritime Consultive Organization (IMCO).

[2] Amendment of Parts 2 and 83, stations on shipboard in the Maritime Services.

Currently, not all types of ships are required to carry this radio emergency beacon, but there has been increasing interest for all ships and fishing vessels in the oceanic area to carry such devices. Accordingly, the user base examined in this study assumes mandatory carriage.

5.1.2 Concept

The alerting and locating concept for this type ELT or beacon involves two elements. The first element is the small transmitter automatically capable of transmitting a recognizable distress signal, and in which a moderate transmission range and line-of-sight frequency transmission characteristics are exploited against feasible physical and battery constraints. The second element critical to the system is an operating receiver tuned to the emergency frequencies as a standing requirement of aircraft in transit of oceanic routes. Enhanced by the wide radio horizon of high-altitude aircraft and the line-of-sight ranges feasible with very low powers at these frequencies, the concept provides a relatively simple and durable technique in areas of aircraft operation.

Location of the distress transmitter by enroute civil aircraft is intended to establish a probable area without altering the aircraft's track. The initial location is based upon time and position of first detection and final loss of signal along the aircraft track. This information is reported immediately through aeronautical communications to an oceanic center which notifies the Coast Guard. SAR aircraft and High Endurance Cutters have direction finding and homing equipment for these frequencies.

5.2 EFFECTIVENESS METHODOLOGY AND PARAMETERS

Oceanic aircraft routes are well-defined, generally by international route and telecommunication facilities. However, their routes may overfly only portions of the large number of steamer tracks that exist in the SAR Maritime Regions. Therefore, a probability of success (i.e., aircraft within radio range of the ELT/beacon) must be evaluated for particular ocean grids. This

probability is a function of geographical location and aircraft density similar to that of surface platforms-of-opportunity, and the radio propagational area swept by the moving aircraft. The probability of being detected within a period of 24 hours depends on the range of transmission and the number of aircraft overflights during the 24-hour period. The range of transmission, in turn, depends on the coverage by an individual aircraft as determined by its altitude and speed. These factors are developed by examination of the areas swept and ocean grids, and are used as grid parameter inputs to the computational program.

5.3 INDIVIDUAL AIRCRAFT COVERAGE

5.3.1 Beacon Transmission Characteristics

The transmitter power of units required in transoceanic aircraft is specified as 225 milliwatts. Amplitude modulation is used with an audio frequencysweep downward of not less than 700 Hz within the range 1600 to 300 Hz, and a sweep rate between two and four times per second. These characteristics are in accordance with RTCA Documents DO-145 and DO-146. The analysis assumes that receivers, including future automated guard receivers, are designed to function at maximum possible line-of-sight ranges.

5.3.2 Individual Aircraft Coverage Profile

Determination of aircraft coverage is based on the line-of-sight range to the horizon at typical flight levels and the distance traversed by the aircraft through the SAR region of interest. The line-of-sight range (R) in nautical miles is determined by:

$$R = \sqrt{113.69 * FL}$$

where FL is the flight level in hundreds of feet and 113.69 is the earth radius factor for optical line-of-sight. A requirement that the recognition system

have at least 5 minutes exposure time to react to the signal will not effectively reduce the computed line-of-sight range. The deviation of exposure time is related geometrically to the offset distance and aircraft speed but the reduction in the computed range is negligible. The effective path width (W_p) is considered equal to the instantaneous diameter of coverage (D), which is essentially twice R, as illustrated in Figure 5-1.

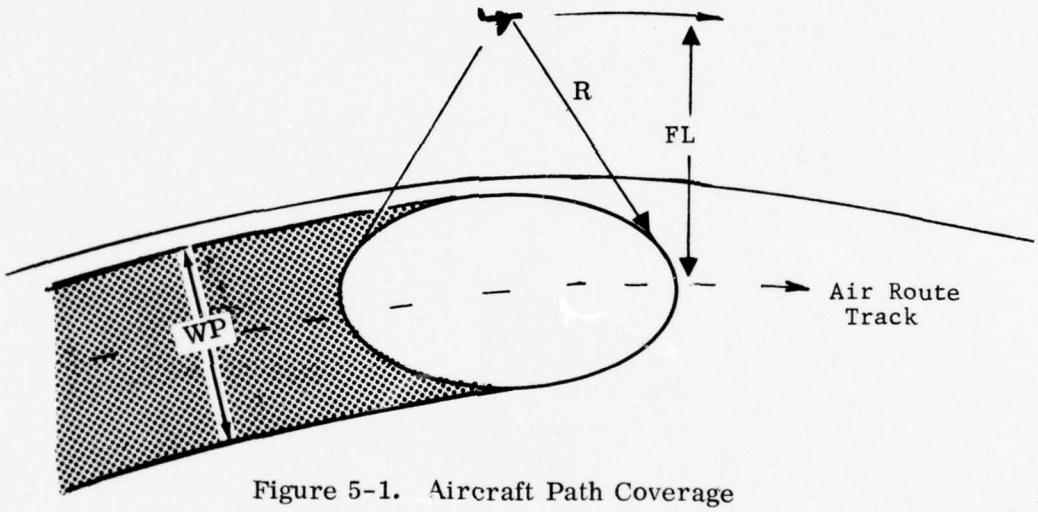


Figure 5-1. Aircraft Path Coverage

Altitudes along designated transoceanic routes are assigned to the individual subsonic aircraft by the air traffic control organization with consideration of aircraft performance characteristics, density, and winds. Cruise altitudes range up to 45,000 feet with a large number of aircraft operating between 30,000 and 45,000 feet.

The area (A) covered by a single aircraft is:

$$A = L_p * W_p$$

where L_p is the expected path length in the grid. The value of L_p for the unit square has been determined to be 0.75 and represents the average length of a random track across the unit square.

The probability (P) of a 122.5/243 MHz emergency transmitter being detected by an individual aircraft overflight within a 900 nautical mile square

during a 24-hour period is determined by dividing the area (A) by the number of square miles in the grid.

$$P = 900 \times 0.75 * Wp/900^2$$
$$= 8.333 \times 10^{-4} * W_p$$
$$= 8.333 * 10^{-4} * 2 * \sqrt{113.69 * FL}$$

Values of the line-of-sight radius, effective path width (W_p) and probability of being detected (P) are illustrated as follows for several different altitudes (FL).

FL (feet)	R (n. mi.)	W_p (n. mi.)	P
45,000	226	452	0.3767
40,000	213	426	0.3550
35,000	199	398	0.3317
30,000	185	370	0.3083

5.4 AIR ROUTES EXAMINED

5.4.1 North Atlantic SAR Maritime Region

The U.S. Atlantic SAR Maritime Region lies within the boundaries of the Gander Oceanic, New York Oceanic,and portions of the San Juan Flight Information Regions (FIRs). The principal U.S/Canada/Mexico-Europe traffic is through a paralleled track system implemented in the Gander Oceanic FIR. Fixed routes are employed in the New York and San Juan sectors.

The spacing of aircraft along a route is coordinated by oceanic air traffic control to ensure that distant landfalls are separated by at least 15 minutes. Because of the highly standardized aircraft types in operation, it may be assumed that 600-knot aircraft would maintain separations over the route. An increase in density in excess of that over four aircraft per hour per 600 miles of track results in activation of a parallel track.

Table 5-1. Data Utilized for Aircraft Coverage of Atlantic SAR Region

Route	End Points		Daily Aircraft	In SAR Region			Coverage (adjusted for overlap) (sq. miles, n)
				Track Length (N. Miles)	Transit Time (Hours)	Coverage Area (sq. miles, n)	
	US/Canada/Mex	Shanwick	414	836	1.39		
two						406,045	406,045 (min)
three						506,362	
four						606,685	
five	Tracks					707,005	
six						807,325	
seven						907,645	
eight						1,007,965	1,007,965 (max)
Great Circle	Vic. Nantucket (Cod)	Santa Maria	2	1265	2.1	462,610	462,610
Q Route	Bermuda	Lisbon	appr. 8	1248	2.08	456,393	527,868
N Route	Bermuda	Santa Maria	25	1240	2.06	453,468	
B22	Bermuda	Vic. Nantucket (Haddock)	7	500	0.83	182,850	1,240,817
B23	Bermuda	Vic. New York (Tuna)	14	534	0.89	195,283	
B24	Bermuda	Vic. Philadelphia (Shad)	3	521	0.87	190,529	
R12	Bermuda	Vic. Washington (Bass)	2	477	0.80	174,438	
R13	Bermuda	Vic. Charleston (Smelt)	4	634	1.05	231,853	
R14	Bermuda	Vic. Jacksonville (Trout)	4	727	1.21	265,864	
G1	Bermuda	Nassau	2	805	1.34	294,389	294,389
A15	Nassau	Vic. New York (Tuna)	7	885	1.48	323,645	291,280
B12	San Juan	Vic. Charleston (Smelt)	4	1002	1.67	366,431	567,395
A24	San Juan	Vic. Washington (Bass)	6	1045	1.74	382,156	
A20	San Juan	Vic. New York (Tuna)	139	1298	2.16	474,679	
A23	San Juan	Vic. New York (Tuna)	52	1362	2.27	498,083	
A17	San Juan	Miami	12.8	850	1.4	310,845	
A13, A14, A15	Panama and South	Miami	17	1002	1.67	366,431	329,787
A17, A18	Caracas, South	Miami	29	1226	2.04	448,348	175,536
R1	Mexico City	Miami	2	886	1.47	316,696	196,192
A4, A5	Mexico City	Gulf Coast	15.7	626	1.04	245,240	

Table 5-2. North Atlantic Hourly Flight Density

Time GMT	Fractional[1] N.Y.-London Departures	Fractional[1] London-N.Y. Departures	Fractional[2] Total A/C Entering SAR Region	Total A/C Entering SAR Region	Total[3] A/C in SAR Region	Tracks[4] in Use
0000-0100	.0621	.0035	.0246	10.2	21.9	4
0100-0200	.0825	.0033	.0470	19.5	38.2	8
0200-0300	.0675	.0023	.0656	27.2	54.7	8
0300-0400	.0613	.0041	.0858	35.5	63.6	8
0400-0500	.0424	.0064	.0698	28.9	60.2	8
0500-0600	.0222	.0056	.0654	27.0	51.6	8
0600-0700	.0157	.0043	.0488	20.2	39.5	8
0700-0800	.0099	.0026	.0278	11.5	25.8	5
0800-0900	.0083	.0034	.0200	8.3	16.7	3
0900-1000	.0035	.0152	.0125	5.2	11.8	2
1000-1100	.0035	.0350	.0117	4.8	11.3	2
1100-1200	.0034	.0516	.0187	7.7	18.1	3
1200-1300	.0029	.0613	.0385	15.9	31.2	6
1300-1400	.0036	.0680	.0550	22.8	44.1	7
1400-1500	.0126	.0651	.0642	26.6	52.8	8
1500-1600	.0155	.0535	.0716	29.6	59.1	8
1600-1700	.0041	.0415	.0777	32.2	61.3	8
1700-1800	.0017	.0303	.0690	28.6	54.1	8
1800-1900	.0030	.0193	.0456	18.9	39.9	7
1900-2000	.0020	.0083	.0320	13.3	27.4	5
2000-2100	.0017	.0040	.0223	9.2	18.2	4
2100-2200	.0052	.0042	.0111	4.6	10.4	2
2300-2400	.0204	.0042	.0057	2.4	6.7	2
2400-0000	.0440	.0030	.0094	3.9	10.6	2
Σ	0.5	0.5	1.0	414[5]		

Notes:

[1] It is assumed that daily eastbound and westbound traffic each account for 50% of the total daily traffic.

[2] (a) SAR region is coincident with boundaries of GANDER FIR.
(b) Assumed flight time London to eastern FIR boundary and N. Y. to west boundary is two hours after departure.

[3] Assuming uniform entry over the hourly period.

[4] Assuming nomimal 15 minute intervals between aircraft on each track, with 6 aircraft per track.

[5] Does not include traffic to Reyjkavik.

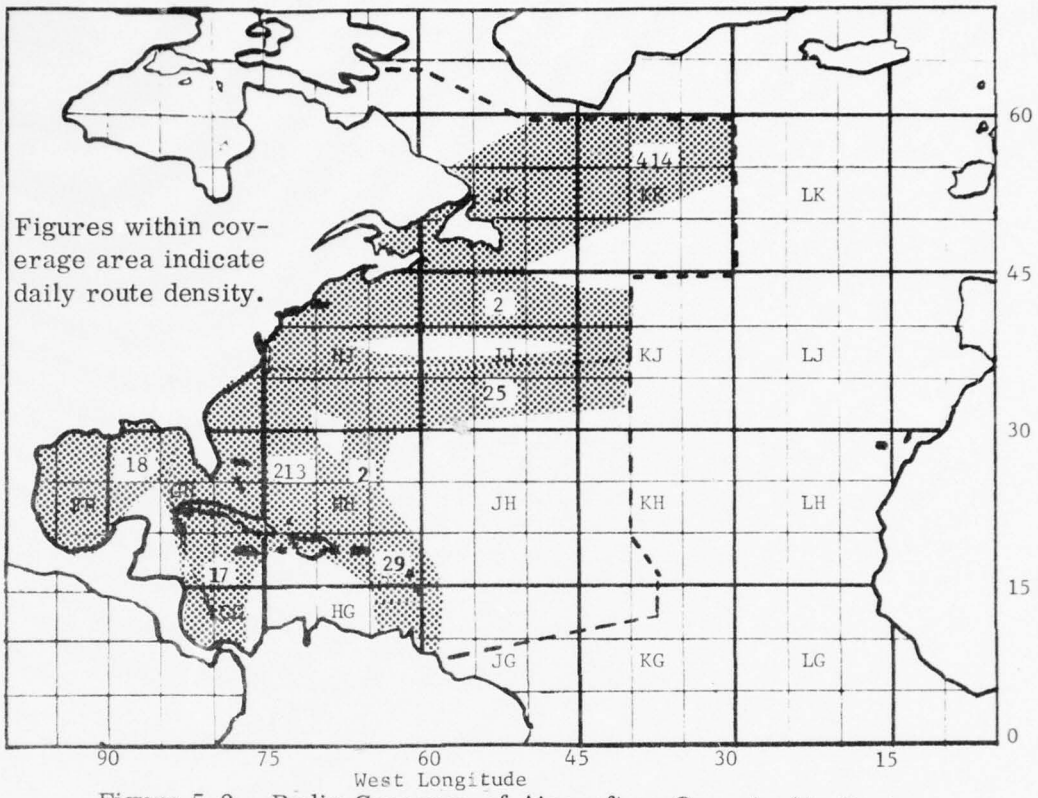


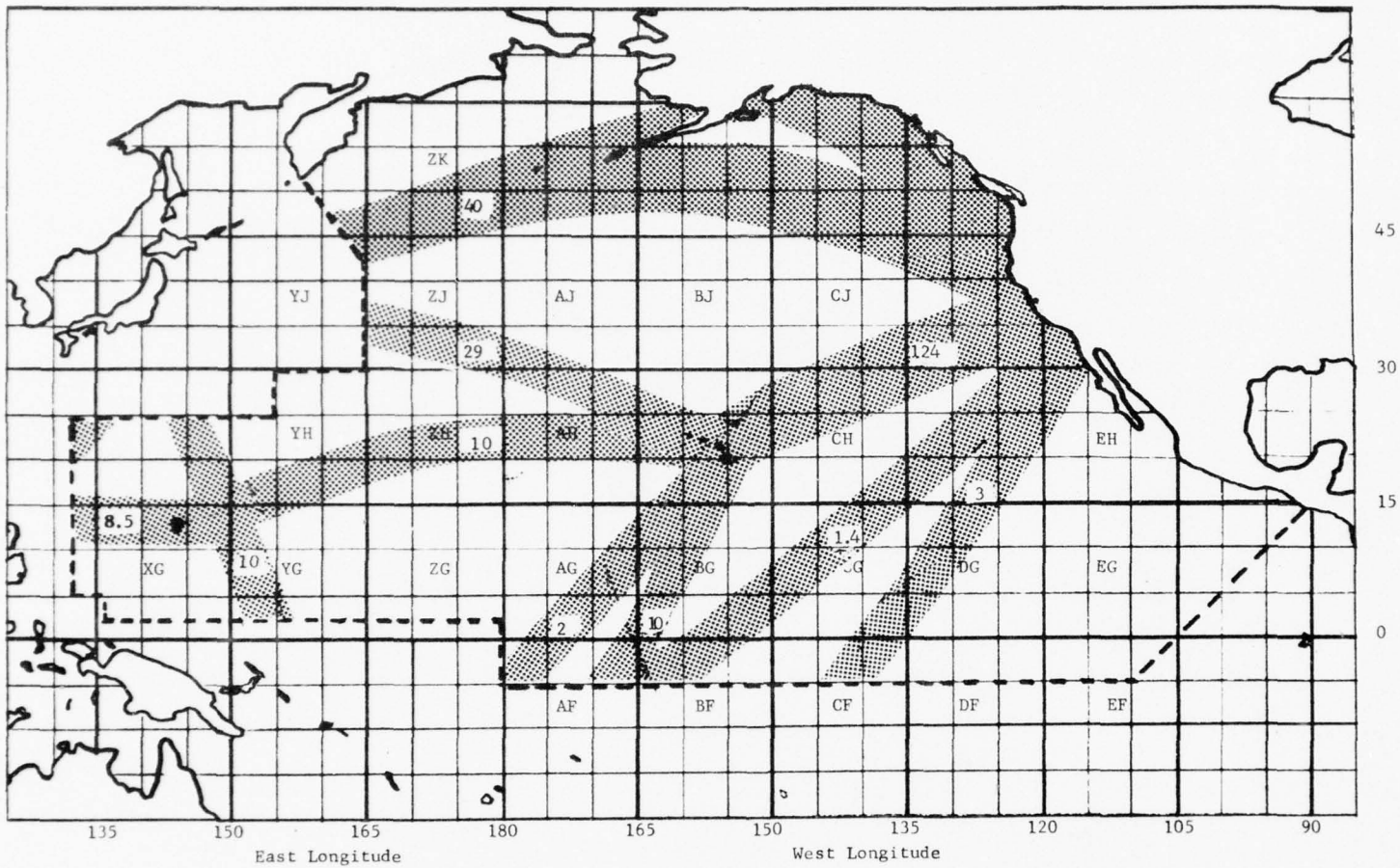
Figure 5-2. Radio Coverage of Aircraft on Oceanic Air Routes within Atlantic SAR Region

5.4.2 Pacific SAR Maritime Region

The U.S. Pacific Maritime SAR Region coincides with the aeronautical FIRs of Oakland Oceanic, Honolulu, Guam, and part of the Anchorage Oceanic FIR. Routes in this region include fixed international routes and some great circle paths. The heaviest concentration of aircraft traffic is on four fixed parallel tracks (B1, B2, B3 and B4) between the U.S. west coast and Honolulu. The routes are shown in Figure 5-3 and listed in Table 5-3.

5.4.3 Flight Data Sources

Information on the preceding air routes and loadings is from ICAO publication, airline schedules, and FAA reports for aircraft carrier and cargo aircraft operating regularly over oceanic routes. Although military aircraft guard 243 MHz, their coverage was considered too inconsistent to be included. However, military aircraft generally fly established air routes when beyond coastal areas.



Figures within coverage areas indicate daily route density.

Figure 5-3. Radio Coverage of Aircraft on Oceanic Air Routes Within Pacific SAR Region

Table 5-3. Data Utilized for Aircraft Coverage of Pacific SAR Region

Route	End Points		Daily Aircraft	In SAR Region			Coverage as adjusted for exclusive, convergence, or overlaps in SAR Region
				Track Length (N. Miles)	Transit Time (Hours)	Coverage Area (sq. miles, n)	
Great Circle	Tokyo	Seattle	12.1	2594	4.3	948,626	3,804 809
Great Circle	Tokyo	San Francisco	11.4	3024	5.0	1,105,877	
Great Circle	Tokyo	Los Angeles	16.4	3268	5.4	1,195,108	
B1	Honolulu	California	124.5	1960	3.2	716,772	1,464,463
B2				2007	3.3	733,960	
B3				2033	3.3	743,468	
B4				2072	3.4	757,730	
B77	Pago Pago	Los Angeles	1.4	3183	5.3	1,164,023	931,218
G75	Tahiti	Los Angeles	3.5	2538	4.2	928,147	928,147
Great Circle	Guam	Honolulu	10.0	3316	5.5	1,212,661	1,030,761
B80	Noumea	Honolulu	2.1	1978	3.3	723,355	687,187
A79	Nandi	Honolulu	7.1	1832	3.0	669,962	636,463
B75	Pago Pago	Honolulu	2.8	1965	3.2	718,610	431,166
B96	Rarotonga	Honolulu	1	1592	2.6	582,194	11,250
B95	Tahiti	Honolulu	1.4	1617	2.7	591,336	101,259
Great Circle	Tokyo	Honolulu	29.3	2060	3.4	753,342	602,673
R84	Okinawa	Guam	2.1	726	1.2	235,498	440,498
R97	Philippines	Guam	3.6	867	1.4	317,062	
R96	Hong Kong	Guam	2.8	905	1.5	330,959	

5.5 EFFECTIVENESS OF AIR TRAFFIC ON OCEANIC ROUTES

Capabilities for aeronautical overflight detection of 121.5/243 MHz EPIRB are based upon geographical coverage for a minimum of one scheduled aircraft per day. If more than one aircraft per day is scheduled over the route, the probability of detection is increased. In the coastal area, the effectiveness (ET) scoring for aircraft platforms-of-opportunity was related to the proportion of time that coverage is available compared to the total time per day. This approach was used because of the many recreational boats being used, the possibility of inexperienced individuals, and the significant impact of time delay in SAR operations. In the oceanic areas, however, the training and survival equipment carried reduce the impact of time delay as does the transit time to the scene by SAR aircraft. The average time between all oceanic grids and the nearest Coast Guard facility is 3.88 hours for the Atlantic and 4.27 hours for the Pacific.

The probability of an emergency transmitter alerting at least one out of N aircraft overflights is determined in the same manner as for ship platforms-of-opportunity and is computed by:

$$P_{24A} = 1 - (1 - EA*ES*P)^N$$

where EA is the equipment availability (0.996 for all systems), ES is the signal environment factor, and N is the expected number of aircraft overflights of the grid during a 24-hour period. P is the probability of a single aircraft overflight event. Figure 5-4 shows the probability of alerting with aircraft at different altitudes.

Overflight by even one aircraft a day assures successful alerting. Fortunately, a low density of aircraft movement occurs only on a few routes. The radio coverage area of aircraft is large compared to ships, as described in

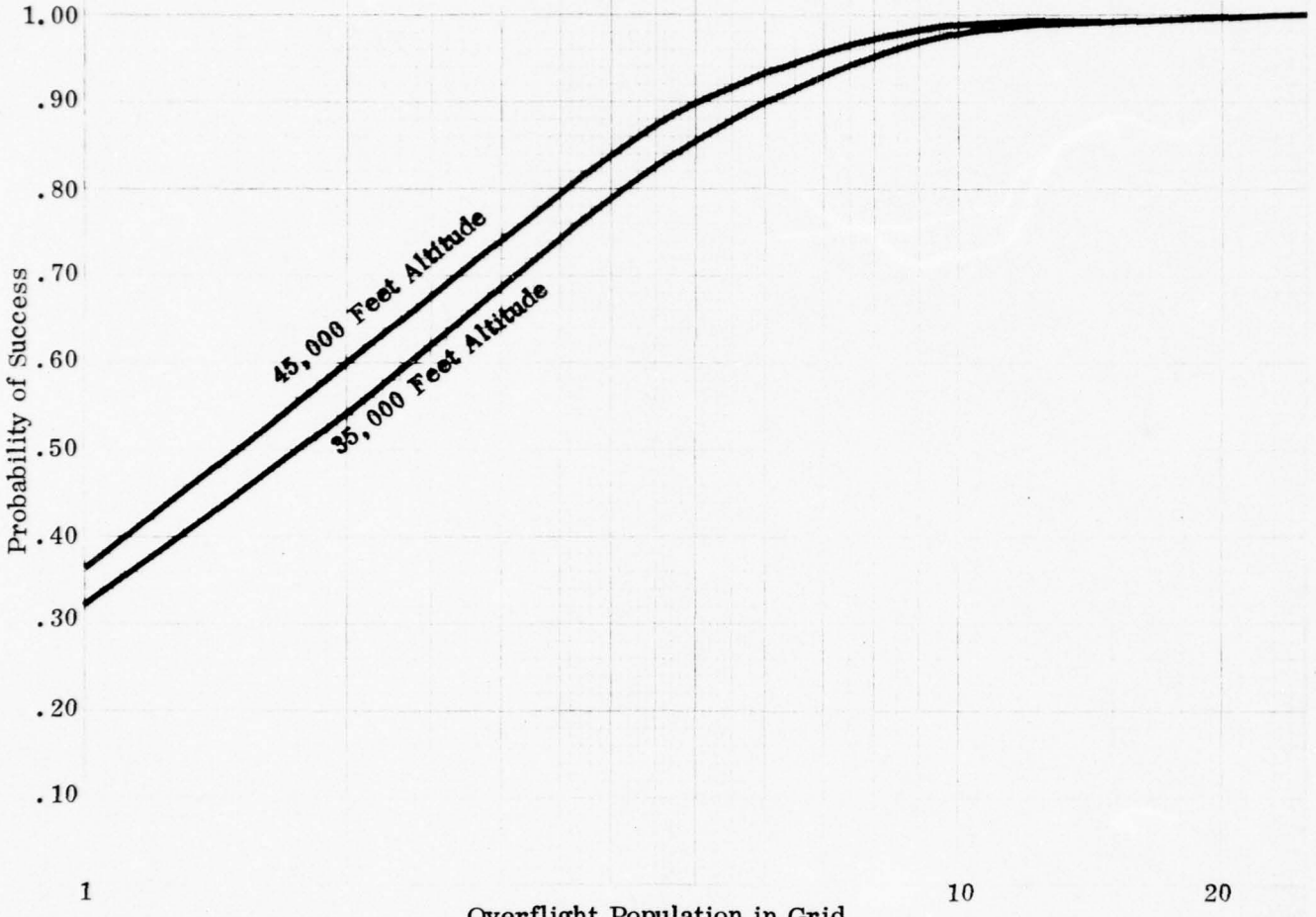


Figure 5-4. Probability of Alerting Aeronautical Overflights

Paragraph 5.3.2. The significance of available time (ET) for radio coverage by aircraft overflights in high seas areas depends on the occurrence of an *event rather than span of time for this coverage.* The ET for an 121.5/243 MHz EPIRB/ELT with aircraft overflights is considered at least equivalent (.996) to ships and shore stations operating on other frequencies.

SECTION 6 - SATELLITE ALERTING AND LOCATING CANDIDATE SYSTEMS

6.1 OVERVIEW

Although an operational SAR system using satellite techniques is unavailable in 1976, the potential advantages and interest in development requires consideration of potential candidate systems. The feasibility of small packages and battery configurations for survival units operating at line-of-sight (LOS) frequencies already has been demonstrated in terrestrial applications. However, range limitation is an operational disadvantage of terrestrial LOS systems. The use of satellites will permit alerting signals from such equipment to be received and relayed from very large areas of coverage. Because of this large area of coverage, the alerting signal must also indicate the location of the terrestrial transmitter. This location data can come from either user inputs or be provided by automated location sensing features in the system.

The United States is actively pursuing conceptual development of a future satellite-supported SAR system that will provide alerting and locating of maritime and aeronautical emergencies. Several experimental programs have evaluated or demonstrated possible techniques,including interferometer, range measurement, Doppler location, navigational aid retransmissions, and low-power access of satellites. Current United States efforts in this area are coordinated in the Interagency Committee on Search and Rescue (ICSAR) which includes representatives of NASA, Coast Guard, FAA, MARAD, and FCC. In addition to U.S. efforts, the Canadian Department of National Defense is investigating feasible satellite systems for SAR in Canada. Further, the Inter-Governmental Maritime Consultative Organization (IMCO) is considering various solutions recommended by participants, including United States proposals.

An optimum design study of a satellite-supported SAR system is beyond the scope of this study, and documents of the referenced organizations provide technical

and operational details. Pertinent approaches are discussed herein only as they affect the relative evaluation of proposed systems, recognizing that concepts are not finalized.

6.2 BASIC CANDIDATE ALTERNATIVES

Pending selection of an accepted satellite SAR system design, certain configurations may be postulated and examined as to their benefits and estimated costs. Alerting capabilities vary with availability of satellite visibility, but locating capabilities vary with technique and sophistication of electronic equipment.

Satellite relay alternatives are represented by two approaches: a geosynchronous satellite covering the SAR Maritime Region continuously, or by a low-orbiting Polar satellite that covers a relatively large swath of the oceanic area in each passage. Geosynchronous satellites provide continuous coverage but are more complex and expensive because of station-keeping requirements. Orbiting satellite systems for SAR require either a real-time relay from emergency beacons to an earth terminal, or, satellite storage and relay when within range of an earth station. Orbiting satellites are less expensive individually but coverage is intermittent, depending upon the number in orbit. For example, one orbiting satellite would provide coverage of any selected point in the SAR Maritime Region at least once in 12 hours. The use of five orbiting satellites properly spaced could cover the same point each two hours. Because of orbital characteristics related to inclination angle, a polar orbiting satellite covers the higher latitudes more often per day than the lower latitudes.

The principal techniques for providing location information in the alerting signal transmission are the use of manually inserted inputs or an automated location sensing means that is integral to the alerting system. Manual inputs may be based on data from inertial navigation devices or by locally computed fixes using Omega, Loran C, Transit, the future Global Positioning System, or sight reductions through sextant readings.

Automated inputs may be by one of the following means used in conjunction with the type satellite indicated:

Location Technique	Satellite Required
Retransmission of Navigational Aids (probably OMEGA)	Geosynchronous
Range Measurement (range measurement from pairs of satellites)	Geosynchronous
Angle Measurement (interferometer measurement at satellite)	Geosynchronous
Range Rate Measurement (Doppler, 13-minute minimum signal at swath edge)	Orbiting, Low Polar (single or multiple constellation)

All candidate satellite systems require a capability for terrestrial DF homing to the emergency site. Radio frequencies for user terminals include 121.5/243 MHz and 406.1 MHz. The 406.1-MHz signal in the three-frequency system is particularly designated for the satellite uplink with the 121.5/243 MHz utilized for homing.

6.3 EARTH TERMINAL IMPACTS OF ALTERNATIVE SATELLITE CANDIDATES

Geosynchronous satellites for SAR require earth terminal sites commensurate with satellite positioning, a power budget, and communications with SAR resources. Low earth orbiting satellites require a series of earth station locations to maintain satellite-earth link connectivity. For continuous coverage by orbiting satellite, ICSAR recommends ten stations in the Pacific SAR Maritime Region and three stations in the Atlantic.

A Canadian study[1] estimates the cost of an earth terminal installation as $996,000 with an additional $100,000 required for development and installation

[1] Technical Report for Feasibility Study of Orbiting Satellites for Search and Rescue, Dept. of National Defense Contract SQ. 67120-3-810-614, Leigh Instruments, 14 June 1974.

of phase-locked loops. Building construction or modification costs are estimated to be $100,000. Annual operating costs per station are estimated as follows:

Personnel:

Manager (1)	$ 20,000	
Technicians (10 @ $15,000)	150,000	
Admin. Support	7,000	
Misc. Benefits & Support	50,000	
		$227,000
Expendable Supplies		25,000
Power, heat, telecommunications		17,000
		$269,000

6.4 PRINCIPAL SYSTEM CANDIDATES

Investigations of optimum performance and costs by the ICSAR Working Group in the United States and the Department of National Defense in Canada indicate tentatively that an orbiting satellite is preferred on the basis of performance and cost tradeoffs. Whereas a synchronous satellite system provides immediate alerting capabilities, locating functions favor an orbiting satellite using Doppler location techniques. In addition, satellite costs will depend on use of a stored or dedicated electronics platform. The preferred candidates are summarized in the following paragraphs.

6.4.1 Canadian Feasibility Study[2]

System Concept: Orbiting with an optimum altitude of 600 nautical miles, and an inclination of 90 degrees (Polar). A single satellite is proposed initially with options for additions. Beyond 1980, a system similar to GRAN (See Paragraph 6.7) and using 406 MHz appears of interest.

[2] Feasibility Study of Orbiting Satellites for Search and Rescue (Technical Report TR-951099), Leigh Instruments Limited, 14 June 1974.

System Cost Data: Satellite and two earth stations are estimated as $23.6 million for a satellite life of five years. This would serve Canada, but the two earth stations are inadequate to cover the SAR Maritime Area.

6.4.2 United States Principal Candidates (1976)[3]

6.4.2.1 Orbiting Satellite Using Real-Time Relay Between Emergency Beacon and Earth Station

Satellite: Single satellite, 482 nautical miles in altitude, inclination = 90 degrees, Latitude extent = 0 to 90°N, Longitude extent = 60°W to 165°W.

Spacecraft Costs (incl launch): $55 million.

Earth Stations: Eight, total of $20 million.

Coverage Interval, all areas: At least once in 12 hours.

6.4.2.2 Orbiting Satellite Using Storage/Processing in Satellite, Accessed by Command of Earth Station

Satellite: Single satellite, 482 nautical miles in altitude, inclination = 90 degrees, Latitude extent = 0 to 90°N, Longitude extent = 60°W to 165°W.

Satellite Cost (incl launch): $66.5 million.

Earth Stations: Three, total of $3 million.

Coverage Interval, all areas: At least once in 12 hours.

6.5 EFFECTIVENESS FOR ALERTING

6.5.1 Geosynchronous Satellite

The highest effectiveness for alerting will result from geosynchronous satellites positioned to cover the SAR regions of interest. A single geosynchronous satellite can have a radio visibility over 150 degrees of longitude[4].

[3] ICSAR Working Group, Briefing of 10 May 1976. Also Satellite-Aided Search and Rescue Panel Report, Goddard Space Flight Center, NASA, May 1975.

[4] To limits of 3 degree elevation.

Because the SAR Maritime Region extends over 200 degrees (30^{o}W to 130^{o}E), two geosynchronous satellites would be required for complete coverage. Within the high seas swath of each satellite, the connectivity or availability (ET) would be 1.00.

6.5.2 Orbiting Satellite

6.5.2.1 Real-Time Relay

One of the candidate systems for real-time relay will employ a satellite at an altitude of 482 nautical miles. This will result in a radio coverage swath of 3,448 nautical miles for each passage. This system would have a coverage interval between 5 and 12 hours for a single satellite. By increasing the number to a five-satellite constellation, the average coverage could be reduced to one hour[5].

A real-time satellite relay system requires an earth station within radio visibility at all times when over the SAR Maritime Regions. For an altitude of 482 nautical miles, this requires a satellite earth station within 1724 nautical miles of all areas of interest. In the Atlantic Maritime Region, two stations sited at Boston and San Juan would nearly cover the area shown in Figure 6-1. The deficit area (shaded) in the Atlantic would not be reached using these two stations. The effectiveness of coverage (EP) provided by two stations is estimated as 0.96. Coverage in the Pacific Maritime Area is shown in Figure 6-2. The deficit area is more serious in terms of uncovered area and the availability of sites for earth terminals. The effectiveness of coverage for four stations[6] is estimated as 0.84. These effectiveness factors are based on maximum possible ranges and would be less if minimum satellite elevation angles are considered.

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[5] A Satellite Aided Search and Rescue Program, Goddard Space Flight Center, December 1975.

[6] San Francisco, Honolulu, Adak, Guam.

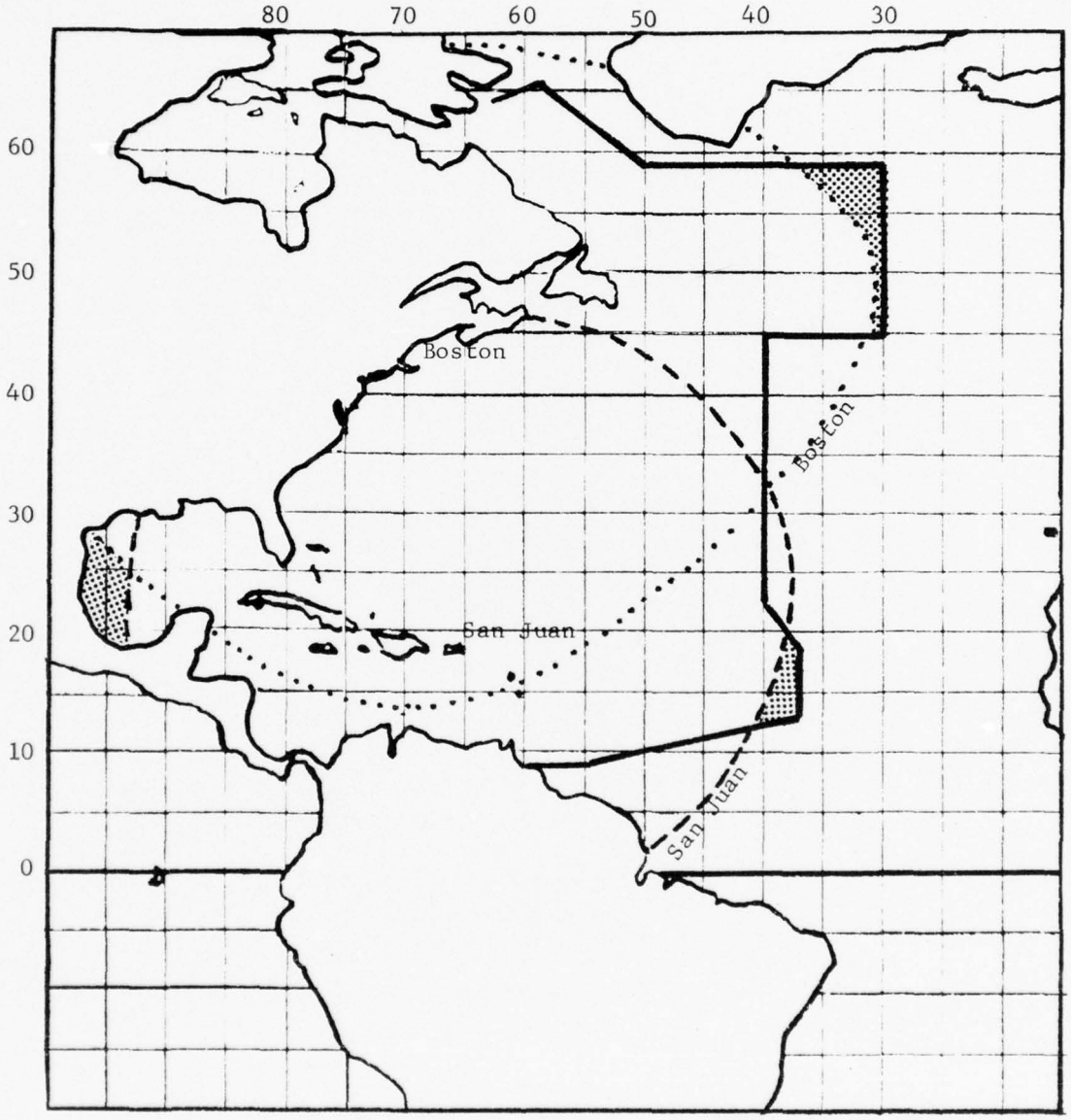

Figure 6-1. Maximum Ranges of Mutual Visibility with an Orbiting Satellite (482 n. miles) from Boston and San Juan

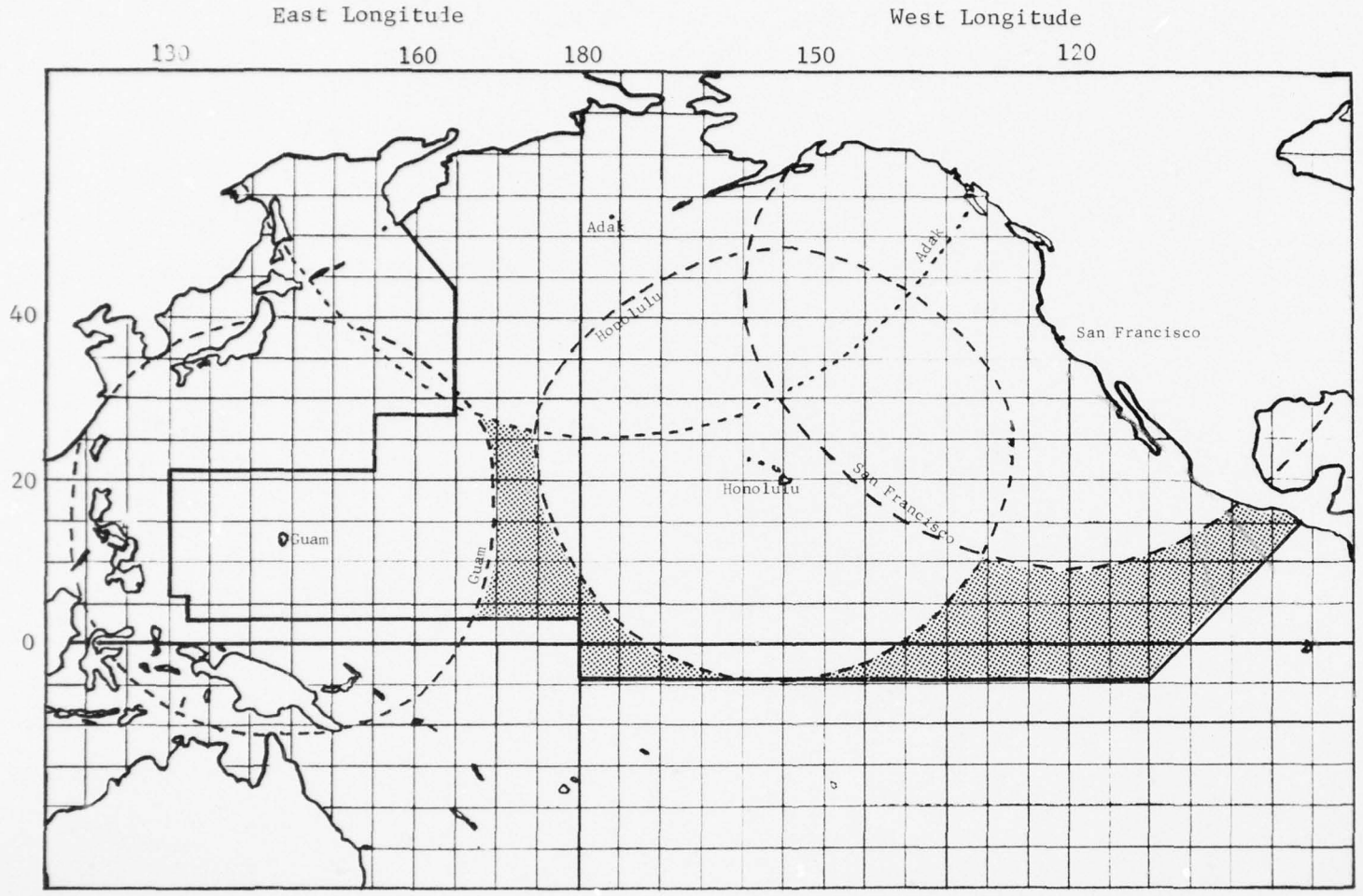

Figure 6-2. Maximum Ranges of Mutual Visibility with an Orbiting Satellite (482 n. miles) from San Francisco, Adak, Honolulu and Guam

The deficit areas of satellite coverage in the Atlantic and Pacific SAR Maritime Regions could be eliminated with additional earth stations. This solution is dependent on the availability of suitable earth station sites. On the other hand, the increased cost benefits of additional coverage must be weighed against reliance on alternative SAR capabilities for these areas. Comparison of the satellite coverage areas shown in Figures 6-1 and 6-2 with ship distributions (Figures 2-4 through 2-6) shows relative densities of ship population in deficit areas. The predominant fleet population is above 10 degree latitude. The gap of approximately 400 nautical miles in the Honolulu-Guam path (Figure 6-2) is significant but an earth station at Wake Island would correct this deficiency. Similarly, a supplemental station at San Diego would increase coverage in the eastern low latitude area within the SAR Maritime Region. For this reason, an additional candidate configuration was analyzed based upon a six-station concept in the Pacific. The small areas beyond mutual visibility in the Atlantic (Figure 6-1) are beyond range of U.S.-based sites in a 482 nautical mile system. The small portion of the Western Gulf outside of Atlantic coverage is within mutual visibility of San Francisco.

6.5.2.2 Signal Storage

Provision of memory storage in the low orbiting satellite corrects the mutual visibility constraints in the previous paragraph, and the coverage effectiveness (EP) is 1.00. However, the availability time (ET) for the distress message involves waiting for a satellite to pass within alerting range and its movement to an accessing earth station. Increasing the satellite population and the earth sites that query the satellite improves the effectiveness in time.

6.5.2.3 Increased Altitude

Increasing the altitude of circular near-polar satellites above 482 nautical miles also will reduce the uncovered areas in the SAR Maritime Regions. Analysis of mutual visibility areas as the altitude is increased shows that the

total SAR Maritime Region will be covered with a satellite altitude of approximately 800 nautical miles[7]. Although the increased satellite altitude will improve mutual visibility coverage effectiveness for alerting, location accuracy by Doppler frequency measurement will be penalized (See Paragraph 6.6).

6.5.3 Alerting Effectiveness

Satellite systems have a relatively high effectiveness for alerting in comparison to other systems that were evaluated. The primary effectiveness considerations involved are the radio coverage of the satellite (ET), radio coverage of earth stations (EP), and usage of the alerting frequency (ES). For geosynchronous satellites, EP is 1.00, and for orbiting satellites .94 because of gaps in radio coverage. A comparison of EP for geosynchronous and orbiting satellites is given in Table 6-1.

ET for satellite systems is 1.00, based on the consistent geosynchronous satellite radio coverage and the occurrence of a satellite orbit over an emergency area during some part of a day. This coverage, plus training and use of available EPIRB/ELT equipment, will assure successful alerting.

Within satellite coverage areas, the signal environment (ES) may include simultaneous alerts. Resolution of multiple signals can be made if a coding technique is used in EPIRB/ELT transmissions, or by manual analysis of emergency transmissions, including use of location information provided by the system. This resolution process should be relatively easier in an orbiting satellite system with its moving radio coverage than for a geostationary satellite system. Based on these considerations, the estimated ES is .996 for orbiting satellites and .900 for geosynchronous satellites.

[7] Computer analysis with varying altitudes (Program COVSIM).

Table 6-1. Propagation Coverage (EP) for Geosynchronous and Orbiting Satellite Systems

SYSTEM	EP
Single Geosynchronous Satellite Single Earth Station	.60
Two Geosynchronous Satellites Two Earth Stations	1.00
Orbiting Satellite(s) Atlantic: 2 Earth Stations Pacific: 4 Earth Stations	.87 (482 n. mile orbit) .97 (800 n. mile orbit)
Orbiting Satellite(s) Atlantic: 2 Earth Stations Pacific:-4 Earth Stations	.94 (482 n. mile orbit) .97 (800 n. mile orbit)
Store and Forward Satellites 3 Earth Stations	1.00 (482 n. mile orbit) 1.00 (800 n. mile orbit)

6.6 LOCATING EFFECTIVENESS

6.6.1 Doppler Technique With Orbiting Satellite

Of the several satellite locating techniques listed in Paragraph 6.2, the use of an orbiting satellite to measure the Doppler frequency shift in emergency beacon transmissions has been demonstrated as a feasible alerting and locating method[8]. Polar orbiting satellites could be used to detect emergency beacon and/or transmitter signals and relay them to an earth station for computation of location data. The estimated accuracy of location is about 5 to 10 nautical miles based on use of 121.5/243 MHz. A clearer channel and less interference should be obtained with use of 406-MHz emergency transmissions, plus greater accuracy.

If the altitude of a proposed orbital satellite system is increased from 482 to 800 nautical miles to improve alerting through mutual visibility (no memory in satellite), the location errors by Doppler are increased. For the order of altitude ranges involved, the error in longitude varies as the square of the orbital altitudes and the error in latitude varies in direct proportion[9]. The increased altitude accordingly may double the longitudinal error and increase the error in latitude by 1.5 times.

The error in latitude increases with decreasing elevation angles, and the error in longitude increases for elevations higher than 60 degrees. The magnitude of error variations with elevation angle as computed in the Canadian study is shown in Table 6-2 (but changed from kilometers to nautical miles). The Canadian study, however, deals with high latitudes rather than the overall SAR Maritime Region. It provides an indication of maximum errors.

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[8] Report on Satellites for Distance Alerting and Locating (Final Draft), Ad Hoc Working Group, Interagency Committee for Search and Rescue, July 30, 1976.

[9] Feasibility of Orbiting Satellites for Search and Rescue (Technical Report TR-951099), Leigh Instruments Limited, 14 June 1974.

Table 6-2. Estimated Position Errors

Elevation of Satellite Above Horizon As Viewed by Beacon	Slant Range (n. miles)	Frequency Shift (Hertz)	Error in N. Miles	
			Latitude	Longitude
20°	1324	- 8.8	4.4	25.0
35°	987	-11.8	3.2	15.9
70°	682	-17.1	2.2	18.2
85°	649	-18.0	2.1	64.7

6.6.2 Retransmitted Navigational Air Data With Geosynchronous Satellite

The retransmission of navigational aid data as received at the emergency site is another locating technique listed in Paragraph 6.2, which is used with geosynchronous satellites. An example of this method is the early GRAN (Global Rescue Alarm Net) concept. This concept used a geosynchronous satellite to relay the emergency beacon signals which, by sequence keying, contained compressed OMEGA tones as received at the emergency site. The earth station processed the received tones to compute the location at which the OMEGA signals were received. The emergency or survival beacon system of the user must include an appropriate receiver and signal processor for the navigational data. A Canadian test of the OMEGA retransmission (OMRET) system used a simplified OMEGA receiver/frequency translator to compress OMEGA tones and convert them to 406 MHz for transmission to the satellite[10]. The satellite relayed these transmissions to an earth station for conversion and position calculation by an OMEGA receiver. The accuracy for OMRET or similar systems will be that for the basic navigation system. In the case of OMEGA, while high accuracies would be expected, in comparison to a Doppler type system, there is a two-position ambiguity that requires resolution in each case.

[10] Feasibility Study of Canadian Search and Rescue Satellite System Utilizing OMEGA Retransmission, (Technical Report TR-951111), Leigh Instruments Limited, 4 September 1974.

Estimated costs for an operational OMRET system are shown in Table 6-3. Also shown are cost estimates for the candidate satellite system (2A 9B) that was included in the SALTTI Coastal Study[11].

Table 6-3. NAVAID Retransmission System Cost Estimates

ITEM	Cost in $K	
	Canadian Estimate[10]	SALTTI, Coastal[11]
Spacecraft Including Development	31,300*	23,500*
Launch	10,300	15,000
Ground Station 1 each	1,700	2,500
Subtotal	43,300	41,000
Ground Station Operating Costs/Year	230	800
User Equipment, Unit Cost	750 **	350**

* Geosynchronous Satellite
**Based upon 3000 units

[11]SALTTI, Coastal Report, 18 September 1975.

SECTION 7 - LOCATION EFFECTIVENESS

7.1 OVERVIEW

Location effectiveness (EL) is the relative capability of each candidate locating system to lead SAR forces to an emergency site. The techniques used in these systems include position reporting, direction finding (DF), homing, and use of satellites. Satellite location techniques were included in Section 6; systems utilizing position reporting will have a relatively high effectiveness of fixed value and not be subject to the uncertainties and errors encountered in others. The remaining systems, employing DF and homing, are discussed in this section. These systems will use DF capabilities to obtain initial location information and bring SAR ships and aircraft within acquisition range of their homing lock-on to the emergency transmission, and eventual visual contact.

7.2 METHODOLOGY

Location effectiveness is primarily a system parameter and is based on characteristics of each system. The computational process uses system data in conjunction with variables arising from geographic or operational factors. The radius of uncertainty associated with the use of each system is a highly significant factor. Absolute location with zero uncertainty is indicated by an EL of 1.00, and a visual contact distance within 1 mile represents an EL of .999. Among all systems considered, a direct or ground wave acquisition and lock-on for direction finding occurs at approximately 30 nautical miles at which point the success of homing directly to the survivor beacon is assumed to represent .950 effectiveness. The relative effectiveness of various candidate locating techniques to lead SAR forces to this acquisition distance is scaled between .950 and .000. In order to have a lower limit for a relative scale, an arbitrary EL value of .100 is assigned to that candidate locating system with the highest area of uncertainty. This system involves shore DF

location of a low-powered survival radio at a 2000-nautical mile range and an associated radius of uncertainty of approximately 180 n. miles. If all other systems are scaled to their location capabilities based upon this assumed limit, the EL will be related to probable distances as shown in Figure 7-1.

7.3 ACQUISITION CAPABILITIES OF AIR AND SURFACE SAR PLATFORMS

7.3.1 General

Detailed procedures for electronic search are described in the National Search and Rescue Manual (CG 308). The final homing to the emergency emitter in this time frame is through direction finding principles. The capabilities to acquire homing are related to the sensitivity of the SAR homing equipment, the strength of the emergency transmitter to achieve a useful signal over electrical noise, and the radio propagation losses for the path. The accuracy of all amplitude direction finding systems is affected by signal strength, particularly at low signal levels. The movement of SAR DF platforms tends to enhance the accuracy of bearings because of the mathematics of an infinite baseline, and the degree to which this is observable in a short period is mainly related to speed and operator skill. For example, the 250-knot speed of a C-130 SAR platform may offset an instrumental DF error that would be unacceptable for fixed use. The most significant factor in this instance is receiver sensitivity. For DF performance,the required minimum sensitivity is 25 uv/meter for ship and aircraft systems. An aircraft platform has two additional advantages over surface craft for homing acquisition. Its altitude increases the radio path for very high or ultra high frequencies because of line-of-sight and less loss of direct ray. In addition, the aircraft capability to maneuver provides a controlled dimension to estimate distance to the emitter or to selectively differentiate between two or more simultaneous emitters. Both ships and aircraft in high seas areas are capable of more accurate homing than when near or over land because of the absence of terrain reflections, screening,or path variations.

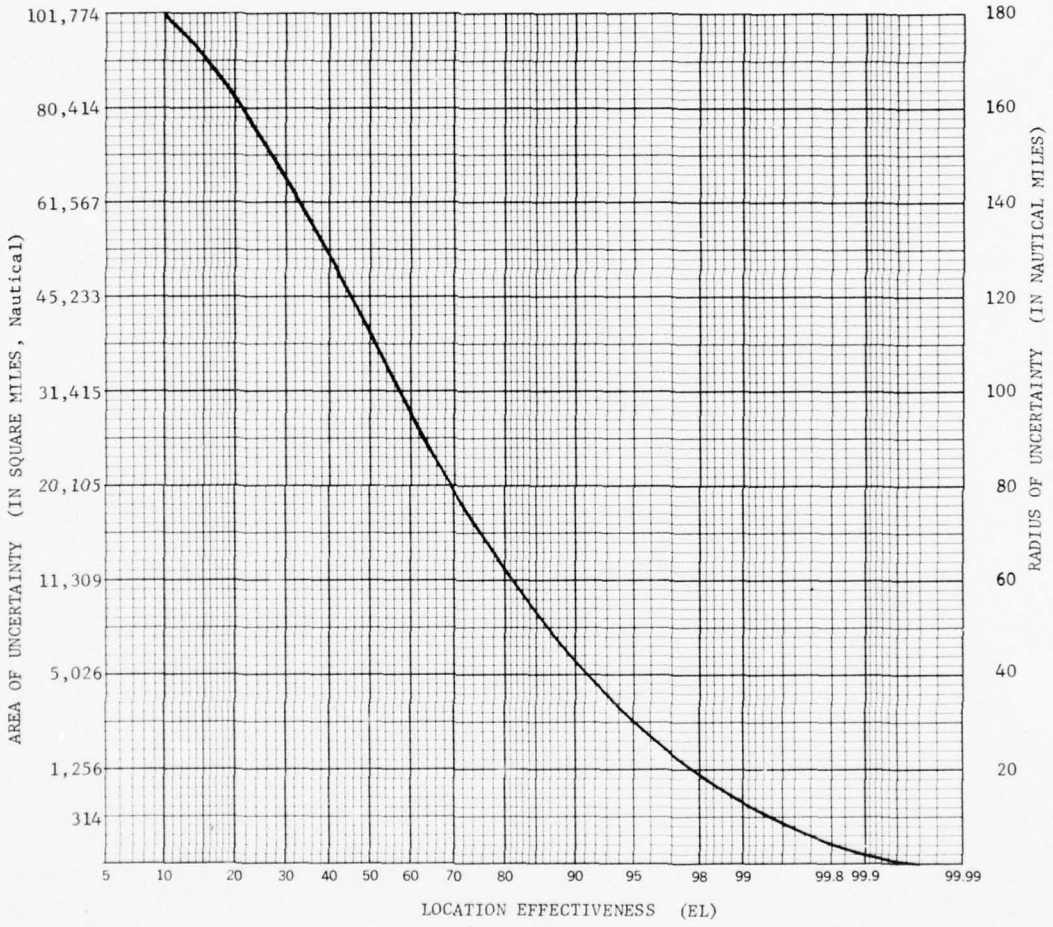

Figure 7-1. Location Effectiveness (EL) Scale for Location Capabilities of Candidate Systems in Oceanic Area

7.3.2 Aircraft Electronic Acquisition

As previously stated, the minimum receiver sensitivity for aircraft direction finding systems is assumed as 25 uv/m. If the received signal level is as high as 100 uv/m, a system accuracy of $\pm$ 1 degree is feasible at 500 and 2182 kHz. When the available signal is reduced to 50 uv/m, system accuracy is reduced to approximately $\pm$ 2 degrees for 500 or 2182 kHz. At VHF or UHF, system sensitivities are on the order of 1 uv/m.

The aircraft utilized for distant oceanic search is the HC-130 type. Its speed is 250 knots with a fuel consumption of 833 gallons per hour. In a search mode,and depending upon the weather situation, search in the target area may be performed at approximately 180 knots with a reduction in engines and fuel consumption. The electronic search altitude is approximately 1000 feet. Other aircraft capable of oceanic search and in the inventory are the HU-16E, HH-52A, and HH-3F. Unless specified for the mission, High Endurance Cutters are not normally at sea with helicopters aboard.

Aircraft are utilized in conjunction with ships in most SAR cases. The aircraft is used to locate the emergency, and either remains on station or leaves a datum marker buoy for ship homing.

Using standing search patterns for electronic search, the HC-130 can complete a search of 20,100 square miles in 36 minutes with fuel costs of $226. The confidence of finding the emitter in the first search based upon the National Search and Rescue Manual is 80 percent. If a second search is required, the confidence is 95 percent or better within an overall elapsed time of 1 hour and 12 minutes[2].

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[2] National Search and Rescue Manual and operational comment.

7.3.3 Ship Electronic Acquisition Characteristics

Electronic capabilities to acquire the emergency signal for homing to the scene are related to the sensitivity of the shipboard direction finder, the atmospheric and local shipboard noise, and the radiated power of the emergency emitter and its radio path. The accuracy of direction finder systems in ships varies with signal level above noise, and at initial receiving ranges may be $\pm$ 10 degrees. Typical accuracies are $\pm$ 5 degrees with a signal density of 100 uv/m, although operator skill and calibration practices may provide accuracies of $\pm$ 2 degrees. The system sensitivity is approximately 50 uv/m at 500 kHz, 25 uv/m at 2182 kHz, and 3 uv/m at VHF.

Movement of the ship during the homing process improves the instrumental accuracy achievable by theoretically extending the baseline and by continuous readjustments between signal and course. However, the rate of change is slow compared to aircraft, and requires particular skill by the shipboard operator in establishing an optimum course early in acquisition. As the ship closes on the emitter,the accuracy continually sharpens with increasing signal strength.

At VHF and UHF, the acquisition capabilities are more dependent upon antenna heights to provide a line-of-sight path. System sensitivity for typical receivers properly maintained are adequate for all signals within line-of-sight. For the 210- and 378-foot cutters, the antenna height is approximately 80 feet above water. VHF homing equipment is installed in High Endurance Cutters. Installations are scheduled for Medium Endurance Cutters by 1977. This will provide a radio horizon of 12 miles to a surface floating VHF beacon.

7.3.4 Beacon Transmission Capabilities

Emergency beacon design is a compromise of physical, environmental, primary power endurance, operational, and radio transmitting factors. As a result, beacons intended for final acquisition phases by SAR ship and aircraft

homing have limited ranges. It is therefore important to provide all possible guidance to the SAR force to eliminate excess area search before coming within range of the emergency beacon. A signal level that is too weak to obtain a good location fix may still serve a useful function by indicating general direction. Considering visibility constraints of small boats, rafts, or survivors, the emergency radio beacon provides advantages in any emergency. Of the low-powered beacons available, the VHF-aircraft configuration provides the greatest range for its size and weight. Beacon capabilities at 2182 kHz are primarily limited by the very poor radiation efficiencies due to antenna size, electrical noise levels, and propagation losses of the ground wave.

System designs are being studied to identify optimum characteristics and concepts for future standardized emergency radio beacons. Currently available beacons at 2182 kHz being evaluated by the Coast Guard[3] have a broad range of radiated power and also some antenna inefficiencies and mechanical problems. Pending establishment of standardized characteristics for 2182-kHz emergency beacons, representative specifications are assumed for examination. The assumptions are:

Radiated Power	70 milliwatts
Receiver Sensitivity for DF	50 uv/m
Atmospheric Noise	74

The acquisition range for the assumed 2182 kHz beacon is 15.6 nautical miles which is limited by the DF antenna/receiver system. Currently available units for operation on 121.5/243 MHz have better radiation characteristics than the 2182 MHz and range from 225 milliwatts for compulsory oceanic aircraft ELTs to 75 milliwatts for ship use. Low-powered VHF emergency beacon range capabilities to aircraft provide maximum ratios of range to available power because of line-of-sight (direct wave propagation) paths feasible at these

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[3] "Emergency Position Indicating Radio Beacons Operating on 2182 kHz", LCDR W. K. May, Lt. F. N. Wilder, USCG, RTCM, San Diego, 26-28 April 1976.

frequencies. This includes 121.5, 243, 240, and 406 MHz systems. Propagation characteristics at these frequencies for paths to aircraft generally approach free-space assumptions. The range-field strength relationships for a representative spread of beacon powers are shown in Figure 7-2.

7.4 500-kHz AND 2182-kHz LOCATION

Beyond ranges of shore facilities, platforms-of-opportunity alerted to an emergency situation may provide location information. Direction finders are mandatory in ships of 1600 tons and over, and normally are installed in all oceangoing craft, which will permit an exchange of ship bearings and location at the time of the bearing. This requires alerting and information exchange between ship-shore-ship. This capability exists for 500- and 2182-kHz frequencies, but is unavailable for high frequencies or VHF aboard commercial ships. Direction finding range for installed 500-kHz transmitters is approximately 200 miles. Accuracy at this range is in the order of $\pm$ 8 degrees, but improves by 50 miles to approximately $\pm$ 3 degrees for typical installations. The range for direction finding of installed 2182-kHz transmissions is on the order of 60 miles, but accuracies are poor until distances are reduced by half.

Direction finding from shore stations is limited by electrical noise and transmitter power. However, site and technical facilities results in improved system performance over ship installations. Shore ranges are in the order of 270 miles for 500-kHz and 75 miles for 2182-kHz installed transmitters.

7.5 HIGH FREQUENCY DIRECTION FINDING

High frequency direction finding from shore facilities uses skywave propagation to provide a long-range capability. Accuracy is related to signal-to-noise ratios of received signals, instrumental accuracies of the installed system, and short-term variations in the propagational path created by polarization and magnetic effects in the ionosphere. Typical fixed installations achieve optimum accuracies with vertically-polarized components while the

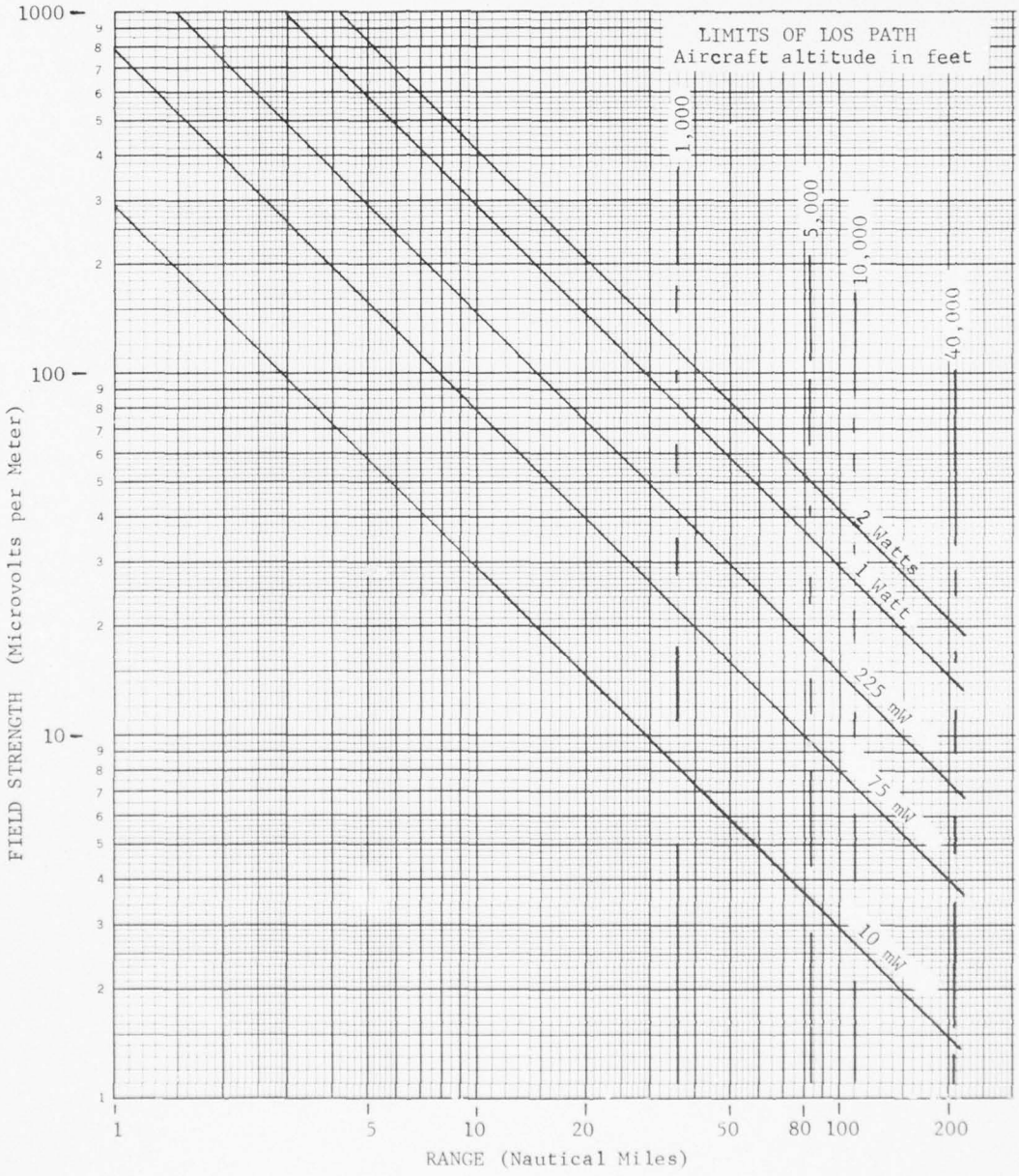

Figure 7-2. Free Space Field Strengths for VHF to Aircraft

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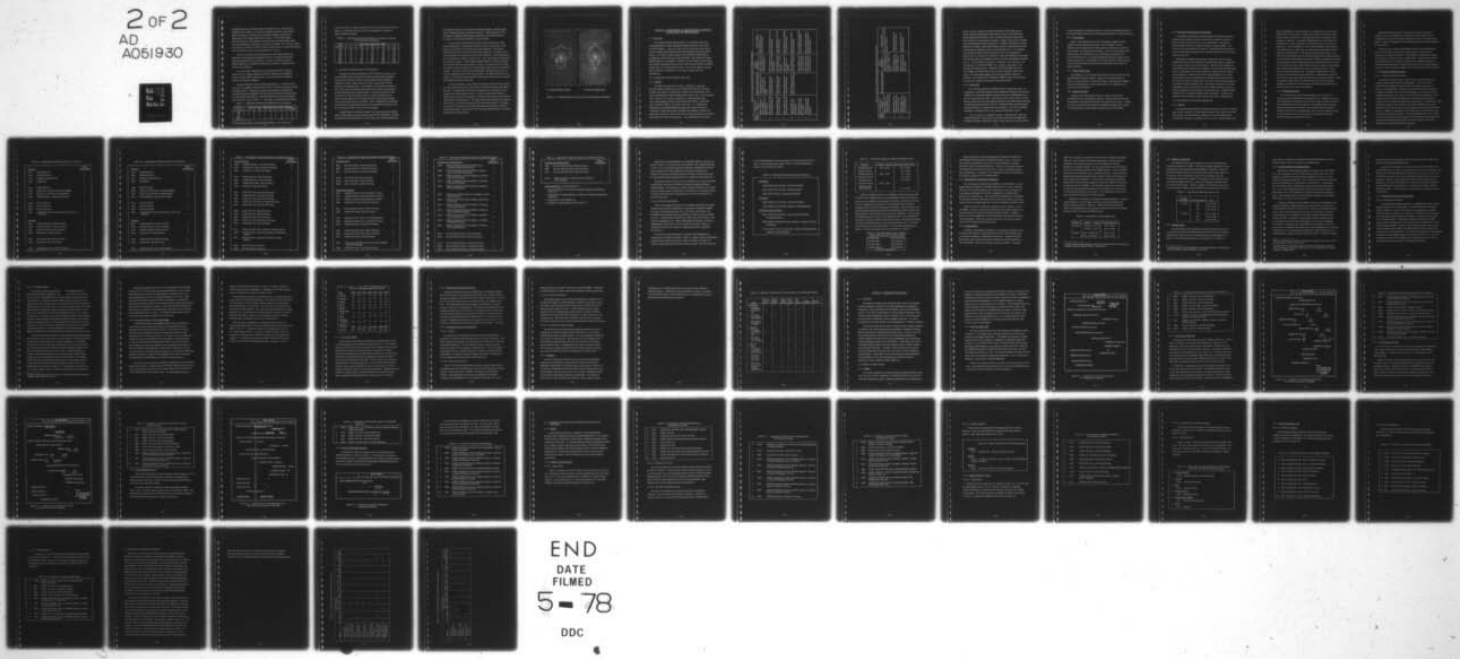

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propagational process produces random polarizations over a period of time. Techniques are available to correct for propagation variations if the distress signal is repeated or continues over a few hours, and also to estimate the signal source with a single-station line of position. If the distress signal arrives well above a 10-dB signal-to-noise (S/N) ratio, and propagation conditions are undisturbed, an accuracy of ±1 degree is possible. For 10 dB S/N signals, an accuracy of ±2 degrees is typical. Weaker signal levels may require measurement over a few hours, and may vary approximately ± 5 degrees.

In the case of distressed transmissions from ships using installed HF equipment, the probability of achieving 10-dB S/N is related to the propagational path predictions used in Section 3. However, if the ship can use installed equipment, it most likely would report its position or recent fix available from Deck Officers.

In a recent study conducted for the Coast Guard by ITS,[4] the highest signal levels for a single-frequency emitter were found to be for nighttime paths and in high sunspot number years. The worst case was for daytime, summer, low sunspot conditions.

Bearings obtained on survival craft transmitters (i.e., 8364 kHz) can be expected to be marginal except for short periods of optimum propagation through the diurnal period. Fortunately, this type of transmission probably will be repeated at intervals throughout the 24-hour day until located and should permit an eventual direction finding fix. Estimated accuracies based upon predicted signal levels are shown in Table 7-1. The impacts on geographical uncertainty

Table 7-1. Achievable Accuracies for Periods of Day and Distance

Distance (n. miles)	Hours Per Day in Which Indicated Accuracy Achieved				
	±1	±2	±3	±5	No Path
350	4	6	3	3	8
700	6	2	8	8	0
1400			12	12	0
2000			8	16	0

[4] "HF Emergency Calling Frequency Trade Off Study", J.E. Adams, ITS.

in nautical miles for a range of system accuracies and distances are shown in Table 7-2. This data illustrates LOP error magnitudes as a function of typical selected accuracies.

Table 7-2. Approximate Lateral Uncertainty (in N. Miles) as a Function of LOP Accuracy and Distance

Target Distance	Lateral Uncertainty in N. Miles				
	±1	±2	±3	±5	±6
500	16	34	52	86	104
750	26	52	78	130	157
1000	34	68	104	174	209
1250	42	86	130	218	261
1500	52	104	156	262	314
1750	60	122	182	306	366
2000	68	138	208	348	418

7.6 LOCATION BY AERONAUTICAL OVERFLIGHTS

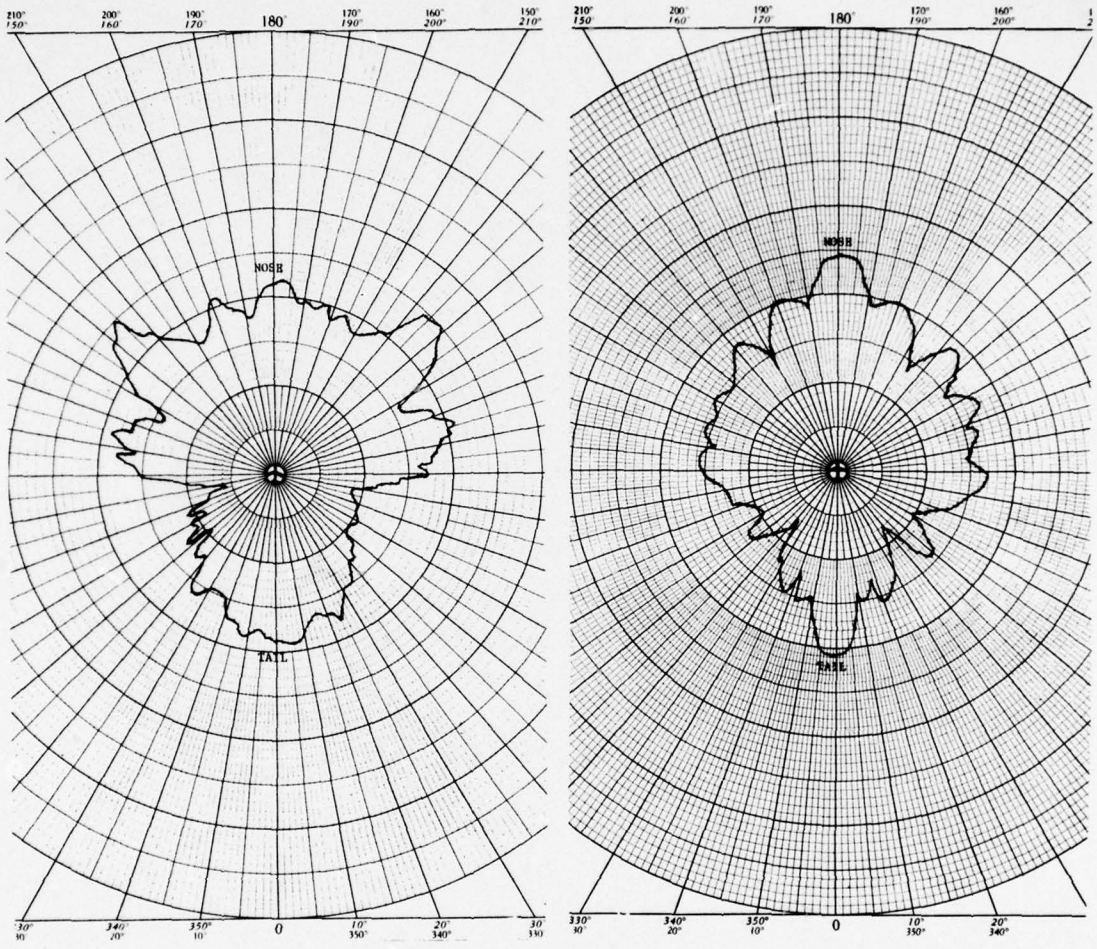
Emergency Location Transmitters (ELTs) detected by commercial aircraft overflights can be given general locations by noting signal audibility. Because of air traffic flow on the route and limited search capabilities, scheduled aircraft on oceanic routes report ELT transmissions without departure from planned tracks. The procedure is to note the time and position of first and last transmissions detectable and to report this information promptly through airways communications. The location procedure in the operations or rescue coordination center is to draw a probable line-of-position at right angles to the aircraft track and to bisect the first and last track positions where the ELT was heard. This is supplemented by additional aircraft reports to geographically bracket the most probable emergency area, and to send SAR aircraft to that area for investigation.

Although effective for general location, the concept assumes an antenna pattern of equal signal reception circular around the moving aircraft. Because commercial aircraft antennas fail to provide equal omni-directional gains and

are designed to emphasize fore and aft communication paths, potential errors exist in estimating survival transmitter locations. Antenna patterns of VHF communication antennas differ among aircraft types as well as between the two or three VHF antennas available in oceanic aircraft.

The use of aircraft antenna pattern guides in the rescue center might enhance judgment of probable LOPs and help to resolve the question as to the degree of error between the estimated and actual locations. For example, assume that the ELT is 150 nautical miles to the right of a DC-8 having a VHF antenna installed in the leading tip of the vertical stabilizer. The antenna pattern for this installation is shown in Figure 7-3(a). The aircraft speed is 580 knots or 9.66 miles per minute. If the threshold of signal detection is assumed constant and near the limits where antenna gain is a factor, the signal in this case would first appear 37 degrees off the nose and 199 nautical miles from the actual abeam position. The signal would drop beyond threshold at 92 degrees off the nose or 5 nautical miles beyond the actual abeam position. The signal would exist for 21 minutes. The LOP based upon one-half of 21 minutes transit would be 97 nautical miles different from the actual LOP.

In a second example, using a bottom VHF blade antenna (707 bype aircraft), the actual location of the ELT is assumed to be 100 nautical miles to the right of the track. Aircraft speed is 580 knots and signal levels are assumed to be at a margin where antenna patterns control. Using the antenna pattern shown in Figure 7-3(b), the signal first appears at 38 degrees off the nose and 127 nautical miles before the abeam position. The signal drops below threshold at 110 degrees off the nose, or 36 nautical miles beyond the actual abeam position. The signal is present for 17 minutes (13.2 minutes before actual abeam plus 3.7 minutes beyond actual abeam). The bisector LOP based upon signal duration is 45 nautical miles short of the actual LOP.



(a) Vertical Stabilizer Mount

(b) Bottom Fuselage Mount

Figure 7-3. Antenna Patterns of Two Types of Aircraft Antenna Installations

SECTION 8 - APPLICABILITY OF VIABLE HIGH SEAS SYSTEMS TO COASTAL AREA AND INLAND REGION

8.1 OVERVIEW

As an extension of the High Seas Study, an examination was made of the applicability of viable alerting and locating systems for the Coastal and Inland Regions. Both areas differ from the High Seas with regard to user population and conditions under which alerting and locating systems operate. As a result, direct comparisions of analytical results between the High Seas and Coastal Area is not practicable. Data required for Inland Region analysis is not available. Therefore, for the Coastal Area, the High Seas Systems examined were the top ten in rank order for total costs, benefit, benefit:cost ratio, and benefit minus cost. For the Inland Region, systems were selected for consideration on the basis of their utility and effectiveness.

8.2 APPLICABILITY FOR COASTAL AREA USE

8.2.1 General

The High Seas systems are listed in Appendix A with their SALTTI reference number used in the Coastal Area study. Rank ordering for high seas systems is summarized in Table 8-1 by total benefits, total costs, total benefit:cost ratio and total benefits minus costs. A more detailed rank ordering can be found in Appendix D, which provides break-outs of these category totals by ocean (Atlantic and Pacific), commercial ship and fishing vessels, and without SAR costs. In evaluating the applicability of the selected High Seas systems for coastal area use, no correlation is made with Coastal Area Study rank ordering. However, the value of the Coastal Area Study rank order for common systems can be found in the Coastal Area Study for comparison. Any comparisons of these rank

Table 8-1. Summary of Rank Ordering for High Seas Systems

Rank Order	BENEFIT:COST RATIO	BENEFITS MINUS COSTS	TOTAL BENEFITS	TOTAL COSTS
1	3B10A EPIRB 121.5/ 243 or 406 MHz. Alerts Satellite, Doppler Location	3B10A EPIRB 121.5/243 or 406 MHz Alerts, Satellite, Doppler Location	3B5C EPIRB Comb. Alerts Satellite, Aircraft DF 2182 kHz	2B5E EPIRB VHF-AM, Aircraft DF/Homing
2	2B5E EPIRB VHF-AM, Aircraft DF/Homing	2B5E EPIRB VHF-AM, Aircraft DF/Homing	3B6C EPIRB Comb. Alerts Satellite, Ship DF 2182 kHz	2B5A EPIRB VHF-FM, Aircraft DF/Homing
3	2B5A EPIRB VHF-FM, Aircraft DF/Homing	2B5A EPIRB VHF-FM, Aircraft DF/Homing	3B1B Installed 2182 kHz Alerts, Reports Location	2B5C EPIRB UHF-AM, Aircraft DF/Homing
4	2B5C EPIRB UHF-AM, Aircraft DF/Homing	2B5C EPIRB UHF-AM, Aircraft DF/Homing	3B3B Installed 2182 kHz Alerts, Aircraft DF	2B5D EPIRB 121.5/243MHz, Aircraft DF/Homing
5	2B5D EPIRB 121.5/ 243 MHz, Aircraft DF/Homing	2B5D EPIRB 121.5/243 MHz, Aircraft DF/Homing	3B4B Installed 2182 kHz Alerts, Ship DF	2B5B EPIRB 2182 kHz, Aircraft DF/Homing
6	3B8B Survival 2182 kHz Alerts, Aircraft DF Locates		3B5F EPIRB Comb. Alerts Satellite, Aircraft DF UHF-AM	1B2C EPIRB 121.5/243 MHz Alerts Orbiting Satellite
7	3B9B Survival 2182 kHz Alerts, Ship DF Locates		3B5G EPIRB Comb. Alerts Satellite, Aircraft DF VHF-AM	3B10A EPIRB 121.5/242 or 406 MHz Alerts Satellite, Doppler Location

Table 8-1. Summary of Rank Ordering for High Seas Systems (Cont'd)

Rank Order	BENEFIT:COST RATIO	BENEFITS MINUS COSTS	TOTAL BENEFITS	TOTAL COSTS
8	3B5D EPIRB Comb. Alerts Satellite, Aircraft DF 121.5/243 MHz		3B10A EPIRB 121.5/243 or 406 MHz Alerts Satellite, Doppler Location	2B7A EPIRB 121.5/243 MHz Doppler Location
9	3B5F EPIRB Comb. Alerts Satellite, Aircraft DF UHF-AM		3B5E EPIRB Comb. Alerts Satellite, Aircraft DF VHF-FM	2B9B Survival 2182 kHz, Aircraft DF/Homing
10	3B5G EPIRB Comb. Alerts Satellite, Aircraft DF UHF-AM		3B8B Survival 2182 kHz Alerts, Aircraft DF Locates	2B6B EPIRB 2182 kHz, Ship DF/Homing

orders, however, should also include consideration of the differences in system usage and effectiveness between the two areas. These differences include geographical distances, costs, alerting and location requirements and procedures, communications procedures, design requirements of alerting and locating equipment,and user population. Obviously, alerting and locating distances are greater, which affects equipment power requirements and costs, communications reliability, location errors,and SAR costs. The reliability and coverage offered by satellite systems becomes more important for high seas use in comparison to coastal use. Shore DF capabilities are limited to the longer range communications systems, but with accompanying increased errors. User population and density is different on the high seas, and passing ships or aircraft overflights are of greater importance in the alerting and locating process. Equipment used for the high seas that is more rugged, has longer battery life,or is more waterproof, will be more costly. DF and homing equipment must operate at greater acquisition distances. The number of SAR caseloads is different, and more costly SAR resources are required for the greater distances involved.

8.2.2 Total Costs

The total costs used for the candidate systems include SAR costs. An assumption is made that satellites used in alerting and locating are shared space systems; use of dedicated satellites would increase costs substantially and result in a much lower rank order. The total cost rank order in Table 8-1 shows that the predominant type of emergency equipment is the EPIRB and that alerting and locating primarily involves aircraft. Orbiting satellites using the Doppler locating technique is a characteristic of two systems. Use of 121.5/243 MHz frequencies is required in four of the systems and 2182 kHz in three.

The ten systems use equipment having a relatively lower cost than installed equipment. None involves more than one type of user equipment for alerting and locating, which also results in lower costs than for other systems.

From the standpoint of these cost factors, as well as the techniques involved, the selected high seas systems are particularly applicable for coastal region use.

8.2.3 Total Benefits

All of the top-ranked systems in the total benefits category have the capability for both alerting and locating. Six use EPIRBs to alert by satellite and the remaining four involve alerting on 2182 kHz by installed or survival radio. Six require aircraft homing. All have an effectiveness and responsiveness that contributes to the relatively greater benefits to be derived from their use. In considering applicability of these systems in the coastal region based on total benefits, two of them (3B5F and 3B5G) also were in the top ten for benefits in the Coastal Area Study and two in the top 20 (3B5C and 3B5E).

8.2.4 Benefits Minus Costs

This category of rank ordering utilizes the basic data for total costs and total benefits previously described. There are five systems shown in Table 8-1 since these have a net positive benefit. All systems use EPIRBs; four are for locating only, require only one kind of user equipment, and involve aircraft DF/homing.

8.2.5 Benefit:Cost Ratio

In the top rank-ordering for benefit:cost ratios, the cost factors predominate for four of the top five systems. These systems were the four top ranked for costs and within the top five for benefits minus costs. Eight of the systems selected in this category use EPIRBs and eight require aircraft in the locating process; half employ transmission on 121.5/243 MHz.

8.2.6 Summary of Coastal Area Considerations

In viewing the applicability for coastal regions of the High Seas system selected for this analysis, Annex A shows that all systems are common to those included in the Coastal Area study, except 3B10A. This system, involving EPIRB alerting and Doppler locating by orbiting satellite, is in the top ten rank ordering for all categories. Considering the characteristics of the selected High Seas systems, their potential applicability to the coastal regions is apparent.

Employment of EPIRBs and emergency frequencies, and the primary involvement of aircraft and satellites for alerting and locating, is applicable to the coastal region and its user community. However, the widespread use and availability of the coastal region EPIRBs on 121.5/243 and 406 MHz could result in a large false alarm rate in addition to a higher level of alerting on these frequencies. Doppler location with orbiting satellites in the coastal region may be much more complicated by multiple alerts and false alarms. In addition, the radio coverage time per day for the coastal region depends on the number of orbiting satellites used. The nature of emergencies involving recreational craft in the coastal area makes a highly responsive, real-time satellite alerting and locating system a primary objective. Although orbiting satellites offer a theoretical solution to this requirement, a method also is needed to reduce the effects of false alarms and to resolve multiple alerts.

8.3 APPLICABILITY FOR INLAND REGION USE

8.3.1 General

In analyzing the applicability of High Seas systems for inland use, comparisons of costs, benefits, and effectiveness parameters with results of the High Seas analyses are infeasible due to differences in the SAR requirements, environment, resources, and methods in the two areas. Inland resources and

formal organization are limited whereas, on the high seas, the specialized forces of the Coast Guard are available with assistance from civilian coast stations, ships, and aircraft. In the high seas areas, the missions, roles, procedures, equipment, and assigned responsibilities are well-defined and organized and, in many instances, are prescribed by law or international agreements. Also of significance are the radio propagation characteristics in the high seas areas, where they are relatively more predictable and less affected by terrain features. SAR activities inland mainly involve air and terrestrial transportation and are concerned primarily with avoiding fatalities; few SAR situations will provide benefits derived from avoiding property damage. The coverage of alerting and locating devices is limited primarily to commercial and military aircraft. SAR efforts will involve a number of organizations that are generally diverse private, state, or federal resources. Unity of effort is usually developed on-site. Recognized SAR procedures are few except for the National Search and Rescue Plan. SAR equipment other than aircraft ELTs is provided voluntarily with minimum voluntary guidance. Radio transmission ranges inland are adversely affected by terrain shielding, multipath, and reflection. Visual location in the final search phase may be hidden by forest cover and terrain features.

8.3.2 SAR Responsibilities

The coordinator for SAR in the Inland Region is the Air Force, in conformity with the National Search and Rescue Plan. Within the Air Force, this responsibility is assigned to the Aerospace Rescue and Recovery Service with headquarters at Scott AFB, Illinois. The principal SAR coordinating function is performed by the AFRCC at Scott AFB, primarily with field resources of the Federal (including DOD), state, local and volunteer groups. The RCCs maintain up-to-date inventories of SAR assets and provide continuing liaison and educational services.

Although the 2nd and 9th Coast Guard Districts appear to be inland activities, they are designated in the National Search and Rescue Plan as subregions (St. Louis and Cleveland respectively) of the U.S. Maritime SAR Region. These two subregions are not considered as being in the Inland Region for this analysis.

Within each state, the forces potentially on-call for SAR include police, fire, park personnel, forest service, National Guard, assorted rescue activities, and organized volunteers. Participation in emergencies is subject to availability of resources and/or voluntary effort. Electronic alerting and locating capabilities are limited to communications equipment required for normal mission performance in agencies such as police, fire, and government activities. Records of funds available and used for SAR are limited and sketchy.

8.3.3 Selection of High Seas Systems

8.3.3.1 Applicable High Seas Systems

The high seas systems shown in Table 8-2 were used as the source for selecting systems applicable to the Inland Region. Table 8-2 has been annotated with comments to indicate reasons for choice or rejection of a system as being applicable. Basically, the systems selected are assumed to be capable of alerting SAR forces from the emergency site and can be used in locating the emergency site. That is, SAR forces can be expected to be maintaining a watch on the alerting frequency used (including alerts relayed by satellite) and the capability of locating the emergency site. An applicable system also must be capable of use anywhere in the region, although there may be differences in performance, for example, between open terrain and montainous areas. In addition, an assumption is made that users will carry only one type of alerting and locating equipment. For the Inland Region user, this is a practical view and consistent with findings in the High Seas study which showed that systems with the highest benefit:cost ratio involved only one type of user equipment in the alerting and locating processes.

Table 8-2. Applicability of High Seas Systems for Inland Use

		Inland Applicability
Alerting		
1B1A	Installed 500 kHz	1
1B1B	Installed 2182 kHz	1
1B1C	Installed L-Band SATCOM	2
1B1D	Installed HF	3
1B2A	EPIRB 2182 kHz	1
1B2B	EPIRB 121.5/243 MHz, Aircraft Overflight	4
1B2C	EPIRB 121.5/243 MHz, Orbiting Satellite	4
1B2D	EPIRB 406 MHz, Geostationary Satellite	4
1B3A	Survival 500 kHz	1
1B3B	Survival 2182 kHz	1
1B3C	Survival 8364 kHz	1
1B4A	Combination Survival Transmitting 500, 2182, and 8364 kHz	1
Locating		
2B1A	Installed 500 kHz, location reported	2
2B1B	Installed 2182 kHz, location reported	2
2B1C	Installed L-Band, location reported	2
2B1D	Installed HF, location reported	2
2B2A	Installed 500 kHz, Shore DF locates	2
2B2B	Installed HF, Shore DF locates	3
2B3A	Installed 500 kHz, Aircraft DF/Homing	2

Table 8-2. Applicability of High Seas Systems for Inland Use

		Inland Applicability
Alerting		
1B1A	Installed 500 kHz	1
1B1B	Installed 2182 kHz	1
1B1C	Installed L-Band SATCOM	2
1B1D	Installed HF	3
1B2A	EPIRB 2182 kHz	1
1B2B	EPIRB 121.5/243 MHz, Aircraft Overflight	4
1B2C	EPIRB 121.5/243 MHz, Orbiting Satellite	4
1B2D	EPIRB 406 MHz, Geostationary Satellite	4
1B3A	Survival 500 kHz	1
1B3B	Survival 2182 kHz	1
1B3C	Survival 8364 kHz	1
1B4A	Combination Survival Transmitting 500, 2182, and 8364 kHz	1
Locating		
2B1A	Installed 500 kHz, location reported	2
2B1B	Installed 2182 kHz, location reported	2
2B1C	Installed L-Band, location reported	2
2B1D	Installed HF, location reported	2
2B2A	Installed 500 kHz, Shore DF locates	2
2B2B	Installed HF, Shore DF locates	3
2B3A	Installed 500 kHz, Aircraft DF/Homing	2

Table 8-2. Applicability of High Seas Systems for Inland Use (Cont'd)

Locating (Cont'd)		Inland Applicability
2B3B	Installed 2182 kHz, Aircraft DF/Homing	2
2B3C	Installed 156.8 MHz, Aircraft DF/Homing	2
2B3D	Installed HF, Aircraft DF/Homing	3
2B4A	Installed 500 kHz, Ship DF/Homing	3
2B4B	Installed 2182 kHz, Ship DF/Homing	3
2B4C	Installed 156.8 MHz, Ship DF/Homing	3
2B4D	Installed HF, Ship DF/Homing	3
2B5A	EPIRB VHF-FM, Aircraft DF/Homing	2
2B5B	EPIRB 2182 kHz, Aircraft DF/Homing	2
2B5C	EPIRB UHF-AM, Aircraft DF/Homing	2
2B5D	EPIRB 121.5/243 MHz, Aircraft DF/Homing	4
2B5E	EPIRB VHF-AM, Aircraft DF/Homing	2
2B6A	EPIRB VHF-FM, Ship DF/Homing	3
2B6B	EPIRB 2182 kHz, Ship DF/Homing	3
2B6C	EPIRB UHF-AM, Ship DF/Homing	3
2B6D	EPIRB 121.5/243 MHz, Ship DF/Homing	3
2B6E	EPIRB VHF-AM, Ship DF/Homing	3
2B7A	EPIRB 121.5/243 MHz, Doppler by Orbiting Satellite	4
2B7B	EPIRB 406 MHz, retransmit NAVAID to Geostationary Satellite	2
2B7C	EPIRB 406 MHz, retransmit NAVAID to Orbiting Satellite	2
2B8A	Survival 500 kHz, Shore DF	2
2B8B	Survival 8364 kHz, Shore DF	2

Table 8-2. Applicability of High Seas Systems for Inland Use (Cont'd)

		Inland Applicability
Locating (Cont'd)		
2B9A	Survival 500 kHz, Aircraft DF/Homing	2
2B9B	Survival 2182 kHz, Aircraft DF/Homing	2
2B9C	Survival 8364 kHz, Aircraft DF/Homing	2
2B10A	Survival 500 kHz, Ship DF/Homing	3
2B10B	Survival 2182 kHz, Ship DF/Homing	3
2B10C	Survival 8364 kHz, Ship DF/Homing	3
Alerting and Locating		
3B1A	Installed 500 kHz, Alerts and Reports Location	1
3B1B	Installed 2182 kHz, Alerts and Reports Location	1
3B1C	Installed L-Band, Alerts and Reports Location	2
3B1D	Installed HF, Alerts and Reports Location	3
3B2A	Installed 500 kHz Alerts, Shore DF Locates	2
3B2B	Installed HF Alerts, Shore DF Locates	3
3B3A	Installed 500 kHz, Alerts, Aircraft DF/Homing	1
3B3B	Installed 2182 kHz Alerts, Aircraft DF/Homing	1
3B3C	Installed HF Alerts, Aircraft DF/Homing	3
3B4A	Installed 500 kHz Alerts, Ship DF/Homing	3
3B4B	Installed 2182 kHz Alerts, Ship DF/Homing	3
3B4C	Installed HF Alerts, Ship DF/Homing	3
3B5A	EPIRB 121.5/243 MHz Alerts by Aircraft Overflight, Aircraft DF/Homing	4
3B5B	EPIRB 2182 Alerts, Aircraft DF/Homing	1

Table 8-2. Applicability of High Seas Systems for Inland Use (Cont'd)

Alerting and Locating (Cont'd)		Inland Applicability
3B5C	EPIRB Combination Alerts by Satellite and is Located by 2182 kHz DF/Homing	2
3B5D	EPIRB Combination Alerts by Satellite, Located by 121.5/243 MHz DF/Homing	4
3B5E	EPIRB Combination Alerts by Satellite, Located by VHF-FM DF/Homing	2
3B5F	EPIRB Combination Alerts by Satellite, Located by UHF-AM DF/Homing	2
3B5G	EPIRB Combination Alerts by Satellite, Located by VHF-AM DF/Homing	2
3B6A	EPIRB 121.5/243 MHz Alerts by Overflight, Located Ship DF/Homing	3
3B6B	EPIRB 2182 kHz Alerts Ship in Range, Located Ship DF/Homing	3
3B6C	EPIRB Combination Alerts by Satellite, Located by 2182 kHz DF/Homing	3
3B6D	EPIRB Combination Alerts by Satellite, Located by 121.5/243 MHz DF/Homing	3
3B6E	EPIRB Combination Alerts by Satellite, Located by VHF-FM DF/Homing	3
3B6F	EPIRB Combination Alerts by Satellite, Located by 406 MHz DF/Homing	3
3B6G	EPIRB Combination Alerts by Satellite, Located by VHF-AM DF/Homing	3
3B7A	Survival 500 kHz Alerts, Shore DF Locates	1
3B7B	Survival 8364 kHz Alerts, Shore DF Locates	1
3B8A	Survival 500 kHz Alerts, Aircraft DF Locates	1
3B8B	Survival 2182 kHz Alerts, Aircraft DF Locates	1
3B8C	Survival 8364 kHz Alerts, Aircraft DF Locates	1

Table 8-2. Applicability of High Seas Systems for Inland Use (Cont'd)

Alerting and Locating (Cont'd)		Inland Applicability
3B9A	Survival 500 kHz Alerts, Ship DF Locates	3
3B9B	Survival 2182 kHz Alerts, Ship DF Locates	3
3B9C	Survival 8364 kHz Alerts, Ship DF Locates	3
3B10A	EPIRB 121.5/243 or 406 MHz Alerts, Doppler by Orbit. Satellite	4

Inland Applicability: (See Paragraph 2.2)

1 - Lack of capabilities to receive alert signals throughout Inland Region (Table 2-2)

2 - Alerting and/or locating equipment unlikely to be carried by inland users (Table 2-3)

3 - Inapplicable for Inland Region use

4 - Applicable to Inland Region use (See Table 2-1)

Based on the preceding discussion, the applicable High Seas systems are listed in Table 8-3. As can be seen, these systems involve EPIRBs operating on 121.5, 243, and 406 MHz emergency frequencies. Although aircraft ELTs are not included in the list of High Seas alerting and locating systems (Table 8-2), they are considered equivalent to EPIRB, and will be the source for alerting and locating transmissions for one category of inland SAR cases.

All systems listed in Table 8-3 also are included in the Coastal Area Study except 3B10A, which uses an EPIRB for alerting and Doppler location by orbiting satellite. The common use of these systems for high seas and coastal areas, as well as inland, enhances their overall value as an emergency device, increases total SAR benefits to be gained, and reduces costs because of an increased user base.

8.3.3.2 Bases for Non-Selection

Most of the High Seas systems are not considered applicable to the Inland Region because of limited capabilities to receive alert messages throughout the region on the frequencies used (e.g., 500, 2182, and 8364 kHz), low probability that the system would be carried by an inland user for emergency use (e.g., L-band SATCOM, Installed 156.8 MHz, Survival 8364 kHz), or the system is inapplicable (e.g., those involving ship D/F homing). Obviously, combinations of these occur as in survival 8364-kHz radio. Table 8-2 indicates the bases for non-selection of High Seas systems as applicable for inland use.

The systems not selected because of limited inland capabilities for receiving alert messages are shown in Table 8-4, together with the transmission ranges used in the high seas analysis. Where two ranges are shown, the smaller is applicable beyond the range of shore stations. Use of these systems

is not practicable inland at distances beyond a few hundred miles from the coast. Away from the coastal regions, there is a limited probability of watches on the frequencies involved.

Table 8-3. High Seas Systems Considered for Inland Use

ALERTING

1B2B EPIRB 121.5/243 MHz, Aircraft Overflight

1B2C EPIRB 121.5/243 MHz, Orbiting Satellite

1B2D EPIRB 406 MHz, Geostationary Satellite

LOCATING

2B5D EPIRB 121.5/243 MHz, Aircraft DF/Homing

2B7A EPIRB 121.5/243 MHz, Doppler by Orbiting Satellite

ALERTING AND LOCATING

3B5A EPIRB 121.5/243 MHz, Alerts Aircraft Overflight, Aircraft DF/Homing

3B5D EPIRB Combination Alerts by Satellite, Located by Aircraft DF/Homing

3B10A EPIRB 121.5/243 or 406 MHz, Alerts by Orbiting Satellite, Doppler by Orbiting Satellite

Table 8-4. Transmission Ranges for High Seas Alerting Systems

SYSTEM	RANGE TO SHORE	BEYOND SHORE RANGE
Installed 500 kHz	400 n. miles	270 n. miles
Survival 500 kHz		27 n. miles
Installed 2182 kHz	130 n. miles	70 n. miles
Survival 2182 kHz		37 n. miles
EPIRB 2182 kHz		12 n. miles
Survival 8364 kHz	350 n. miles	
Combination 500, 2182, 8364 kHz		27 n. miles

Systems considered to have a low probability of being carried by inland users are in this category because of the emergency frequencies involved or because of the complexity of the equipment being used. Obviously, users will not carry equipment for which there is a low probability that an alerting message will be received on the frequency being used. The most effective and economical alerting and locating means can be expected to have the widest use. Where possible, this will involve only one piece of equipment. On these bases, the techniques shown in Table 8-5 are considered to have a low probability of carriage by inland users, and are therefore not viable. The locating function is involved for all these systems, except L-Band SATCOM, either in a location only (LO) system or in the location portion of an alerting and locating (AL) system. The specific systems involved are identified in Table 8-2.

Table 8-5. High Seas Equipment and Techniques Having Low Probability of Inland Carriage

500 kHz Radio	156.8 MHz Radio
2182 kHz Radio	VHF-FM Radio
8364 kHz Radio	VHF-AM Radio
L-Band SATCOM	UHF-AM Radio
NAVAID Retransmission	

High seas systems considered inapplicable for inland use include those employing ship DF/homing and installed high frequency radio. In the High Seas analysis, installed HF is used only for radio telegraphy to exchange ship-shore traffic on assigned frequencies. There are no assigned emergency HF frequencies for general use and for which a watch is maintained throughout the Inland Region. In addition, radio telegraphy for general emergency use is considered impractical for the Inland Region.

8.3.4 Effectiveness of Emergency Frequencies

All of the equipment selected as applicable for inland alerting, or as the target emitter for locating, are EPIRBs operating on 121.5, 243 or 406 MHz. The 121.5 and 243 MHz frequences are, respectively, civil and military aircraft emergency frequencies; 406 MHz is designated as a satellite uplink frequency for emergency use. The 121.5/243 MHz frequencies are designated for emergency location transmitters (ELTs) that become activated on aircraft impact to provide alerting signals and a source for locating the downed aircraft.

Military aircraft are required to monitor 243 MHz. However, in overland flight, a voluntary watch may be maintained by FAA Flight Inspection aircraft and pilots for air carrier and general aviation aircraft. In addition, there is a limited capability for FAA and USAF ground monitoring and location of alerting signals. Where the capability does exist, the range of reception will be limited to approximately LOS (20 km).

8.3.5 Terrain Effects

In addition to multipath and reflections, the emergency frequencies used by the selected EPIRBs can encounter path losses due to terrain effects such as masking by mountains, overgrowth and snow cover. Masking will reduce the potential radio coverage by aircraft overflights and orbiting satellites, as will overgrowth or snow, for the relatively low power EPIRB. A Canadian

Study[1] of air crashes in mountainous areas provides an analysis of the effects of terrain on the reception of emergency transmissions and illustrates the reduction in LOS radio coverage for aircraft overflights and orbiting satellites as a result of masking. The area covered by the study included the site of an air crash that occurred in the Canadian Rockies. Terrain elevations varied from 1750 to 4000 feet over a 100-square mile area. Terrain analysis showed that the steepest mountain slopes reached an angle of 35 degrees with the average being 21.5 degrees. In this terrain, severe masking of EPIRB signals would occur below these angles and reduce their effective radius (EP) for alerting aircraft overflights. The LOS radio coverage area provided by aircraft and orbiting satellites depends on their altitude and the lowest angle at which unmasked signals can be received. For satellites and aircraft, the time available for alerting (ET) would be reduced.

Using 21.5 and 35 degrees as examples of mountain slopes (i.e., lowest angle of reception), LOS coverage areas for aircraft and satellites in the terrain studied are shown in Table 8-6. While the specific terrain under study is not representative of all mountains, the data shows the severe effects that may result from this type of difficult terrain.

Table 8-6. Comparisons of Line of Sight Areas

Platform	Altitude	Angle	Coverage Diameter
Aircraft	10,000 ft.	21.5°	6.4 n. miles
	40,000 ft.	21.5°	31.5 n. miles
Satellite	428 n. miles	21.5°	1515 n. miles
	1000 n. miles	35°	1850 n. miles

[1] Locating People in High Altitudes, Laboratory Technical Report (LTR-FR-32), Canadian National Research Council, January 1971.

8.3.6 Effects of Overgrowth

The presence of trees at an emergency site will reduce the effective transmission range for an EPIRB. The amount of signal attenuation will vary with the angle of the transmission path through the overgrowth. Heavy tree growth on mountain slopes can increase the lowest angle at which signals can be received. The Canadian Study referred to in Paragraph 8.3.5 also considered the effects of overgrowth. At 6 degrees, the transmission path is 9.57 times the height of the trees, whereas at 35 degrees, this path is only 1.74 times the tree height. A further analysis of transmission losses due to trees is provided in another Canadian Study[2] and is summarized in Table 8-7.

Table 8-7. Transmission Path Losses Due to Trees

Average Tree Height	Elevation Angle	Loss
≤ 15 feet	10^{o}	.75-2.0 dB
	35^{o}	.25-.50 dB
	60^{o}	.25-.50 dB
≥ 15 feet	10^{o}	2.0-9.0 dB
	35^{o}	.50-3.0 dB
	60^{o}	.50-3.0 dB

8.3.7 Effects of Snow

The transmission of radio signals also may be attenuated by deep snow. For example, operating an EPIRB through snow drifts or from snow covered structures will result in varying losses depending on the path angle for the signal. The Canadian Study referred to in Paragraph 8.3.5 states that

[2] Feasibility Study of Orbiting Satellites for Search and Rescue, Technical Report TR-951099, Leigh Instruments, 19 June 1974.

losses due to snow depend on its depth and the surface beneath the snow, but will add between 0 and 4 dB to losses over average ground.

8.3.8 Aircraft Alerting and Locating Systems

Alerting and locating systems using aircraft will use one of the EPIRBs (or an ELT) operating on 121.5/243 MHz that are listed in Table 8-3. This equipment is expected to be small and have relatively low power, a simple antenna, and moderate battery life. Such a device can be carried by an individual in the Inland Region or be mounted in an aircraft (ELT). An estimated 150,000 aircraft carry ELTs,[3] although all are not confined to Inland Region use. For the type EPIRBs considered in the High Seas Analysis, required transmitter power is 225 milliwatts for oceanic aircraft and 75 milliwatts for ships. The emergency signal is an audio frequency downward sweep between 300-1600 Hz at a rate of 2 to 4 per second.

Alerting an overflying aircraft requires a track over the emergency area, sufficient EPIRB/ELT signal strength to alert the aircraft, and monitoring of the emergency frequency by the aircraft. In contrast to the High Seas areas, where a radio watch is required by aircraft on 121.5/243 MHz, monitoring by inland aircraft is not required on 121.5 MHz; military aircraft normally monitor 243 MHz. In addition to no guaranteed emergency frequency watch by overflying aircraft, all of the Inland Region is not covered by scheduled air carriers. As pointed out by a Department of Transportation Study,[4] 90 percent of the Continental United States has aircraft overflights once a day; areas in which there is no coverage include West Texas, Northern Maine, the U.S./ Canadian border, Northern Nevada, and Eastern Oregon. Continuous coverage

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[3] Report on Satellites for Distress, Alerting and Locating (Final Draft), Ad Hoc Working Group, ICSAR, July 30, 1976

[4] Program Plan for Search and Rescue, Electronic Locating and Alerting System, Final Report, Report No. DOT-TSC-05 - 73-42, Department of Transportation, February 1974

is provided in areas of high density while in the Great Plains area; there will be hourly coverage during daylight hours.

Location of an emergency site by an aircraft involves DF/homing on one of the EPIRBs shown in Table 8-3 that operate on 121.5, 243, or 406 MHz. The general area of the alerting signal may be reported to an RCC by one or more overflying aircraft that receive the transmission through normal aviation communications channels. Search can then be made by SAR aircraft having DF equipment. The theoretical effectiveness of systems that include locating (EL) can be modified by the environment (e.g., reflection, absorption), reduced EPIRB/ELT power, aircraft altitude, and characteristics of installed aircraft DF equipment.

8.3.9 Satellite Alerting and Locating Systems

8.3.9.1 Geostationary Satellites

The geostationary satellite performs as a straightforward relay of emergency transmissions to a ground station. Of the selected high seas systems shown in Table 8-3, only two could involve use of a geostationary satellite (1B2D and 3B5D), and these are for alerting. An EPIRB/ELT alerting signal on the emergency uplink frequency will result in a transmission on the downlink to the ground station. Geostationary satellite coverage of the Inland Region would be continuous and cover a larger area, in comparison to a lower altitude orbiting satellite. Because of the longer transmission paths involved from the EPIRB to the satellite, the EPIRB must have greater power than is necessary for an orbiting satellite. The effectiveness factors for a geostationary satellite covering the Inland Region would normally be EP and ET = 1.00; ES will depend on the number of multiple alert signals being received at any instant and the ability of the system to distinguish among them.

8.3.9.2 Orbiting Satellites

The orbiting satellite systems selected for the Inland Region have alerting and/or locating capabilities. For the alerting role, the space platform is a relay for the EPIRB/ELT, retransmitting the emergency signal to a ground station. Locating by orbiting satellite involves ground station processing of the relayed Doppler signal. Expected location accuracies using the Doppler technique are on the order to 5 to 10 nautical miles with the 121.5/243 MHz emergency frequencies; improved accuracy is expected with use of 406 MHz (1 to 3 nautical miles). The orbiting satellite provides a wide, moving coverage area. Coverage area is related to satellite altitude; in the High Seas analyses, altitudes examined were 482 and 800 nautical miles, which provide maximum coverage diameters of approximately 3400 and 4300 nautical miles, respectively. These maximum coverage diameters will be less as a result of masking, overgrowth, or reduced EPIRB power and the lowest visibility angle for satisfactory signal reception from the satellite by the ground station.

The orbit interval for the high seas satellite alerting and locating systems provide radio coverage twice daily by a single satellite. This coverage would be reduced to one hour using a five-satellite constellation. The changing satellite orbit over the earth requires placement of one or more ground stations at locations that ensure reception of relayed emergency signals as satellite radio coverage moves from coast to coast. Spacing of stations is related to satellite altitude and the lowest elevation angle at which ground stations can receive satisfactory signals from the satellite. The orbiting satellite alerting and locating system proposed by NASA (3B10A) would use an approximate 450 nautical mile orbit and ground stations at St. Louis, Missouri and San Francisco, California.[5] An assumption is made that there is a minimum 5 degree elevation angle between ground station and satellite.

[5] Execution Phase Project Plan for Search and Orbiting System (Preliminary), Goddard Space Flight Center, 1976

The orbiting satellite system will provide a propagation coverage effectiveness (EP) of 1.00 with proper ground station placement. Time coverage (ES) effectiveness provided for the Inland Region is considered to be 1.00. Location effectiveness (EL) for the Doppler techniques will be .995. Signal environment effectiveness (ES) will depend on the number of simultaneous transmissions that occur within the coverage area of the satellite and the ability of the system to distinguish among them. The ICSAR Ad Hoc Working Group estimates that a maximum of ten actual and false SAR signals will be present in the Inland Region at any one time. It is assumed that this number will be increased by SAR signals originating in the coastal area.

8.3.10 Search and Rescue Data for Inland Region

Available information on Inland Region SAR activities is insufficient to permit an in-depth analysis of alerting and locating systems such as performed for the coastal and high seas areas. Data sources are limited and inconsistent in defining the types of emergencies experienced, SAR capabilities used, and the costs involved. As a result, current consideration of high seas systems applicability to the Inland Region are based primarily on technical feasibility and estimated utility rather than benefits and costs. Due to differences between the High Seas and Inland Region environments, as well as organization and capabilities for SAR, there is little value to be derived from using results of the High Seas Analysis as a standard of comparison. However, information on SAR in the Inland Region can be used in examining the applicability of selected high seas alerting and locating systems.

There are few known sources of useful data regarding the extent of Inland Region SAR activities. Potential sources include the Aerospace Rescue and Recovery Service (ARRS), National Transportation Safety Board, Federal Aviation Administration, and the CONUS states. The ARRS publishes periodic

reports of its SAR activities related to aviation. In addition, SAR data is available from the State of Washington. Undoubtedly, other states maintain records on activities that could be classified as SAR.

Recent ARRS reports show the magnitude of ELT transmissions reported to the AFRCC versus actual emergencies. For the period April through June 1976, there were 1616 ELT incidents (actual emergencies, false alarms, unexplained) reported. Of this total, 11 were ELT on crashed aircraft that were located by SAR missions. Other data shows that for September through December 1975, an average of five aircraft emergency sites per month were located by ELT signals. Other aircraft emergencies occurred (crashes, forced landings) in which there were no ELT transmissions.

Within the State of Washington, emergencies for which there was a recorded SAR response have increased significantly between 1969 and 1975 as shown in Table 8-8. The projected level of such emergencies in 1976 is 500. Recreational activities, as a group, comprise the major source of emergencies, although nonrecreational emergencies are the largest single category. To be useful for benefit:cost analyses, additional information is needed on the alerting and locating methods used, casualties, and costs.

Table 8-8. Washington State SAR Activities

Type	1969	1970	1971	1972	1973	1974	1975
Aircraft	12	10	7	17	21	15	24
Climbing	15	12	12	24	27	27	30
Fishing	10	16	18	12	9	23	21
Hiking	28	54	41	35	67	44	69
Hunting	27	29	36	43	79	51	74
Motor Equipment	8	12	12	13	12	8	19
Water	31	34	51	69	38	43	47
Other Recreational	22	18	17	17	27	23	38
Non Recreational	54	45	51	63	137	236	106
TOTALS	206	230	245	298	417	470	422

8.3.11 ELT False Alarms

A difficult and costly problem confronting use of EPIRB/ELT for SAR in the Inland Region is false emergency signals from ELTs. False alarms originate from inadvertent ELT activations, both in flight and on the ground. ARRS reports show that only a small number of reported ELT signals originate from emergency sites; approximately 95 percent are false alarms. These false transmissions must be investigated and checked for validity, and terminated if found to be inadvertent. They can reduce overall system effectiveness by increasing response time. Use of the 406-MHz emergency frequency would reduce this problem if its use is restricted and/or some method is employed to prevent accidental transmissions. Proposals for a new EPIRB/ELT design include a coding technique for user identification; the added coding feature would significantly increase the cost of equipment.

8.3.12 Alerting and Locating with Aircraft

Alerting overflying aircraft with an EPIRB/ELT is a valuable technique for the Inland Region in spite of the high false alarm rate, voluntary watch on emergency frequencies, and lack of aircraft coverage in some areas. Current use of aircraft DF/homing to locate an emergency site is an effective capability. The ARRS organization and procedures are responsive to aircraft incidents involving ELT transmissions. This includes approximately 260 DF-equipped aircraft of the Civil Air Patrol. Limitations on the use of this type of system include weather that can prevent DF/homing for some aircraft and variations in densities of aircraft overflight coverage. The continued use of aircraft DF/homing for final location of emergency sites is foreseen even if a satellite alerting and locating system provides the initial map location data.

8.3.13 Alerting and Location with Satellites

8.3.13.1 General

Use of satellites for alerting and locating in the Inland Region would probably be in conjunction with SAR operations in the Maritime Regions. This offers benefit:cost advantages to be derived from a broader base of users and participating SAR forces. For all satellite systems, a shared spacecraft will be less costly than one dedicated to SAR activities. From the standpoint of SAR improvements, satellites will provide complete coverage within the Inland Region. In addition, locating emergency sites will not be affected by adverse weather which would disrupt aircraft operations.

8.3.13.2 Alerting Only Systems

There are two systems selected for inland use in which satellites relay alert signals; one with an EPIRB operating on 121.5/243 MHz and an orbiting satellite, and the other with an EPIRB on 406 MHz and a geostationary satellite. The geostationary satellite has the advantage of continuous coverage of the Inland Region, as contrasted with the periodic coverage by

orbiting satellites and variable coverage by aircraft overflights. Both types of satellites provide a positive watch on the emergency frequency being used.

8.3.13.3 *Locating Only System*

The satellite system used only for locating employs an EPIRB on 121.5/243 MHz with Doppler by orbiting satellite. Compared to the other locating only system, which employs aircraft DF/homing, the satellite system can reduce the search effort and costs. Location information from a single satellite may not be available more quickly than for aircraft DF/homing, depending on the time lag before the satellite orbit brings coverage over the emergency area. With more than one satellite, this lag can be eliminated and location information made available immediately after EPIRB transmission.

8.3.13.4 Alerting and Locating Systems

The two alerting and locating systems employing satellites use either a combination of satellite alerting and aircraft DF/homing, or an orbiting satellite for alerting and Doppler location. The same emergency frequencies are available for both systems. Both systems are more advantageous than the alerting and locating system that uses only aircraft for coverage and system responsiveness. In comparing the two satellite systems, alerting and locating with a single satellite will result in faster location of the emergency site than will use of aircraft DF/homing after a satellite alert.

8.3.14 Summary

A review of the factors associated with use of the selected High Seas systems in the Inland Region, shows that all candidates are applicable. Significant considerations for the Inland Region use are shown in Table 8-9. The utility and advantages of systems for both alerting and locating are more readily apparent than for those that only alert or locate, although situations can exist where these limited systems are appropriate. The problem of false alarms on 121.5/243 MHz will continue to cause unnecessary effort,

although this does not affect applicability of the system using EPIRBs on these frequencies. If EPIRB use in the Inland Region increases, particularly for recreational purposes, there probably will be a corresponding increase in false alarms without some type of controls.

Table 8-9. Significant Considerations for Inland Region Use of High Seas Systems

System	Possible Environment Effects	Positive Frequency Watch	Complete Region Coverage	False Alarm Effects	High Use Population	Location Capabilities	Real-Time Coverage
Alterting Only							
1. 1B2B EPIRB 121.5/243 MHz Aircraft Overflight	X			X	X		
2. 1B2C EPIRB 121.5/243 MHz Orbiting Satellite		X	X	X	X		
3. 1B2D EPIRB 406 MHz Geostationary Satellite		X	X				X
Locating Only							
4. 2B5D EPIRB 121.5/243 MHz Aircraft Overflight	X			X	X	X	
5. 2B7A EPIRB 121.5/243 MHz Orbit Sat. Doppler		X	X	X	X	X	
Alerting and Locating							
6. 3B5A EPIRB 121.5/243 MHz Aircraft & Aircraft DF/Homing	X			X	X	X	
7. 3B5D EPIRB Comb. Alert Sat., Aircraft DF/Homing	X			X	X	X	X
8. 3B10A EPIRB 121.5, 243, 406 MHz Alert Orbiting Sat., Doppler location		X	X	X	X	X	

SECTION 9 - SUMMARIES OF ANALYSES

9.1 OVERVIEW

The High Seas Analyses has considered a wide variety of alerting and locating techniques as well as the associated effectiveness, geographical parameters, system parameters and SAR data for each of the 97 candidate systems. The results of this analyses are the narrative descriptions in this volume and the computational results in Volumes 2 and 3. This information provides reference material as well as detailed source data. The scope and depth of this material permits a broad application for a variety of purposes.

The bases for relative rank order of systems involve a number of factors in Volumes 2 and 3 that require detailed examination to identify and analyze. Such an examination is beyond the scope of this report. However, as an aid in considering results, the discussions that follow briefly examine the relative standing of systems based on the type equipment used, alerting and locating technique employed, costs and benefits. Visual summaries are provided which display relative rank order ranges for costs, benefits, benefit: cost and benefit minus cost. In addition, broad comparisons are made of system characteristics for the top ten in rank order of several categories of consideration. These latter comparisons are based on total benefit:cost ratio (Appendix D) as the most representative and inclusive factor in preference to costs, benefits or benefit minus cost.

9.2 RANGES OF RANK ORDER

9.2.1 General

The relative standing of the individual high seas systems within the rank orders given in Volume 3, Appendix D is readily discernible in any of the 24 rank order categories provided. Additional significance can be obtained from

this type of information by examing rank orders for systems on the basis of the technique or equipment being used for alerting and/or locating. Examination of Appendix D on this basis shows a range of rank order as well as groupings for shared and dedicated satellite use or for alerting/locating (A/L) versus alerting only (AO) and locating only (LO) systems. In the following discussions, visual portrayals of rank order ranges are provided to show relative rank orders among the total list of candidate high seas systems, based on the type equipment used. These comparisons are for total cost, total benefit, total benefit:cost ratio and total benefit minus cost. Accompanying each visual comparison of these categories is a listing of the systems that are in the top rank order for that category.

9.2.2 Total Cost Rank Order

The range of total cost rank order for transmission techniques is shown in Figure 9-1. This figure shows rank order number across the top with transmission techniques listed below. The sequence of listing has no significance but is the same in Figures 9-1 through 9-4 to facilitate comparisons. In Figure 9-1, the EPIRBs will be noted as in the left portion of the diagram, indicating a high standing of some systems in relative rank order. However, the EPIRB Combination and EPIRB 406 MHz extend to the lower rank order when dedicated satellites are used. Note the high standing of 2182 kHz Survival, which also will be found in the comparisons that follow. Also, note the lower standing of certain types of installed equipment.

Table 9-1 lists systems that are in the top ten of the rank order for total cost. The predominant systems listed are for LO, all use EPIRB except one, and most use aircraft DF homing or orbiting satellites.

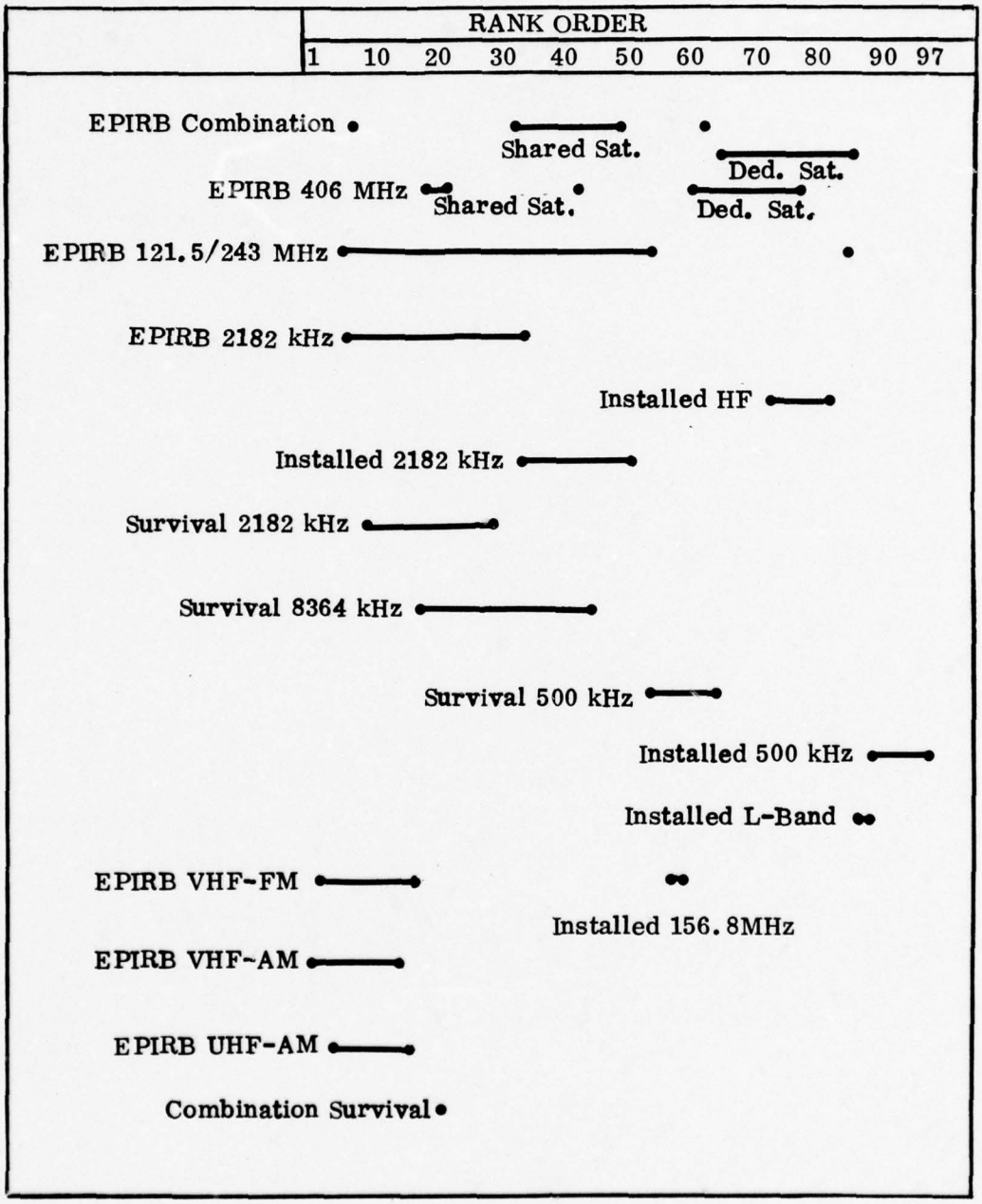

Figure 9-1. Comparison of Total Cost Rank Order for Transmission Techniques

Table 9-1. Comparison of Systems by Rank Order for Total Cost

1.	2B5E	EPIRB VHF-AM, Aircraft DF/Homing
2.	2B5A	EPIRB VHF-FM, Aircraft DF/Homing
3.	2B5C	EPIRB UHF-AM, Aircraft DF/Homing
4.	2B5D	EPIRB 121.5/243 MHz, Aircraft DF/Homing
5.	2B5B	EPIRB 2182 kHz, Aircraft DF/Homing
6.	1B2C	EPIRB 121.5/243 MHz, Alerts Orbiting Satellite (shared)
7.	3B10A	EPIRB 121.5/243 or 406 MHz Alerts Orbiting Satellites (shared), Location by Doppler
8.	2B7A	EPIRB 121.5/243 MHz, Doppler Location by Orbiting Satellite (shared)
9.	2B9B	Survival 2182 kHz, Aircraft DF/Homing
10.	2B6B	EPIRB 2182 kHz, Ship DF/Homing

9.2.3 Total Benefit Rank Order

A comparison of total benefit rank order is shown in Figure 9-2. This is similar to Figure 9-1 with some notable differences. There is no real distinction in rank order range for shared and dedicated satellite use with the EPIRBs on 121.5, 243 and 406 MHz. However, rank order range distinctions appear for the techniques of AL and AO and LO. In addition, the rank order range for several techniques slipped lower than in the last comparison including 8364 kHz survival and the EPIRBs operating VHF and UHF. On the other hand, the installed HF and 500 kHz rank order range is higher.

In Table 9-2, a comparison is made for the systems that appear in the top ten of the rank order for total benefit. The EPIRB Combination is used in six of the systems to alert by satellite, and four systems alert by either installed or survival equipment operating in 2182 kHz. Location by aircraft DF/Homing is used in six of the systems. All systems have A/L capabilities.

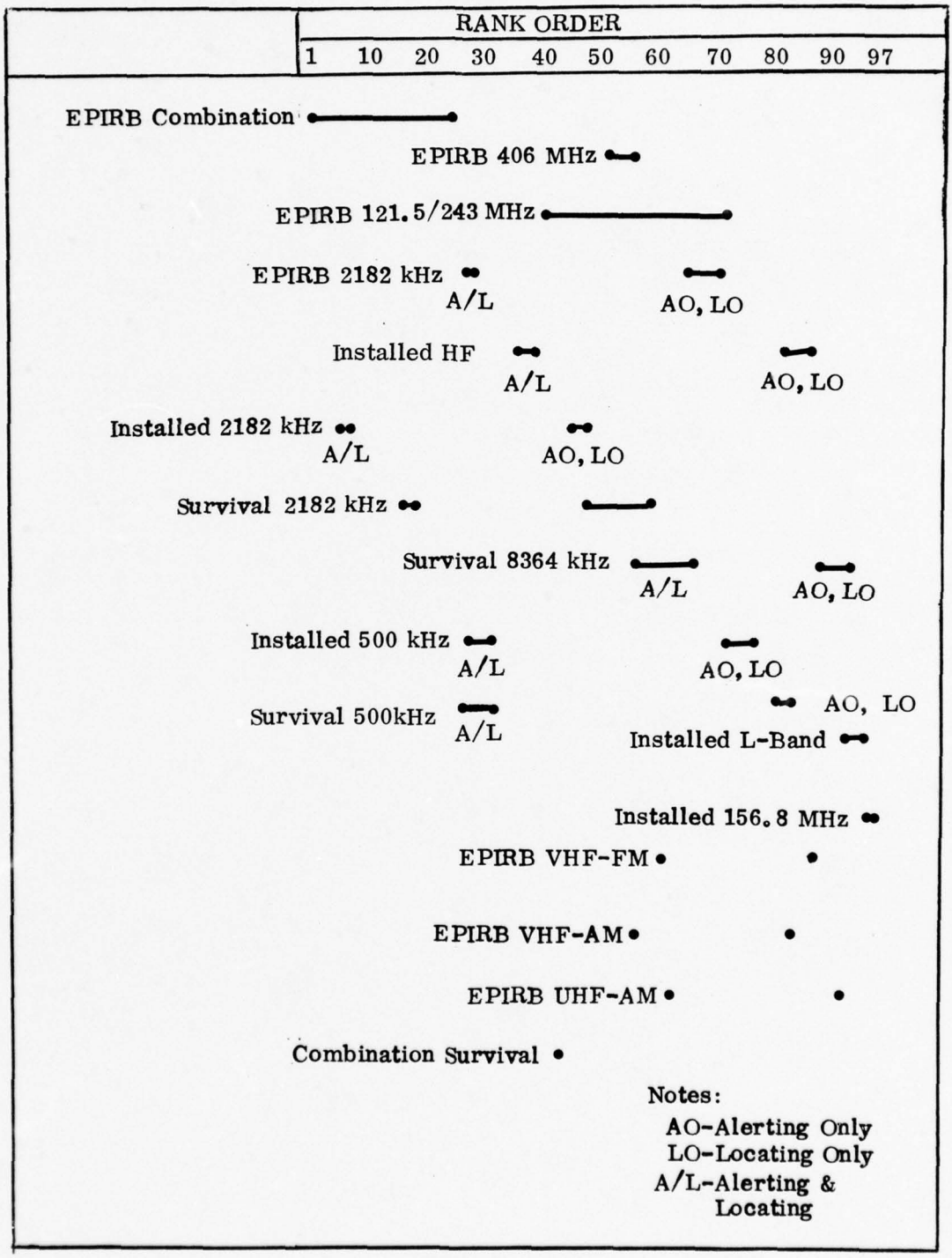

Figure 9-2. Comparison of Total Benefits Rank Order for Alerting Transmission Techniques

Table 9-2. Comparison of Systems by Rank Order for Total Benefit

1.	3B5C	EPIRB Combination Alerts by Satellite (shared), Location by Aircraft DF on 2182 kHz.
2.	3B6C	EPIRB Combination Alerts by Satellite (shared), Location by Ship DF on 2182 kHz
3.	3B1B	Installed 2182 kHz Alerts, Reports Location
4.	3B3B	Installed 2182 kHz Alerts, Located by Aircraft DF/Homing
5.	3B4B	Installed 2182 kHz Alerts, Located by Ship DF/Homing
6.	3B5F	EPIRB Combination Alerts by Satellite (shared), Located by Aircraft DF/Homing on UHF-AM
7.	3B5G	EPIRB Combination Alerts by Satellite (shared), Located by Aircraft DF/Homing on VHF-AM
8.	3B10A	EPIRB 121.5/243 or 406 MHz Alerts by Orbiting Satellite (shared), Location by Soppler
9.	3B5E	EPIRB Combination Alerts by Satellite, Located by Aircraft DF/Homing on VHF-FM
10.	3B8B	Survival 2132 kHz, Alerts, Aircraft DF Locates

9.2.4 Total Benefit:Cost Ratio

Figure 9-3 shows a comparison of rank order ranges for total benefit:cost ratio. In this comparison, the relatively high standing of most EPIRBs is readily apparent. The Survival 2182 kHz for A/L is also shown to have a high rank order.

Table 9-3 shows the rank order standing of the top ten systems by total benefit:cost ratio. The orbiting satellite system with Doppler location has the highest standing. Eight of the systems use EPIRBs for alerting and eight use aircraft DF/homing for locating. A comparison with Tables 9-1 and 9-2 shows that 3B10A is the only system appearing in both lists. The cost is the main factor that results in LO systems appearing in this list.

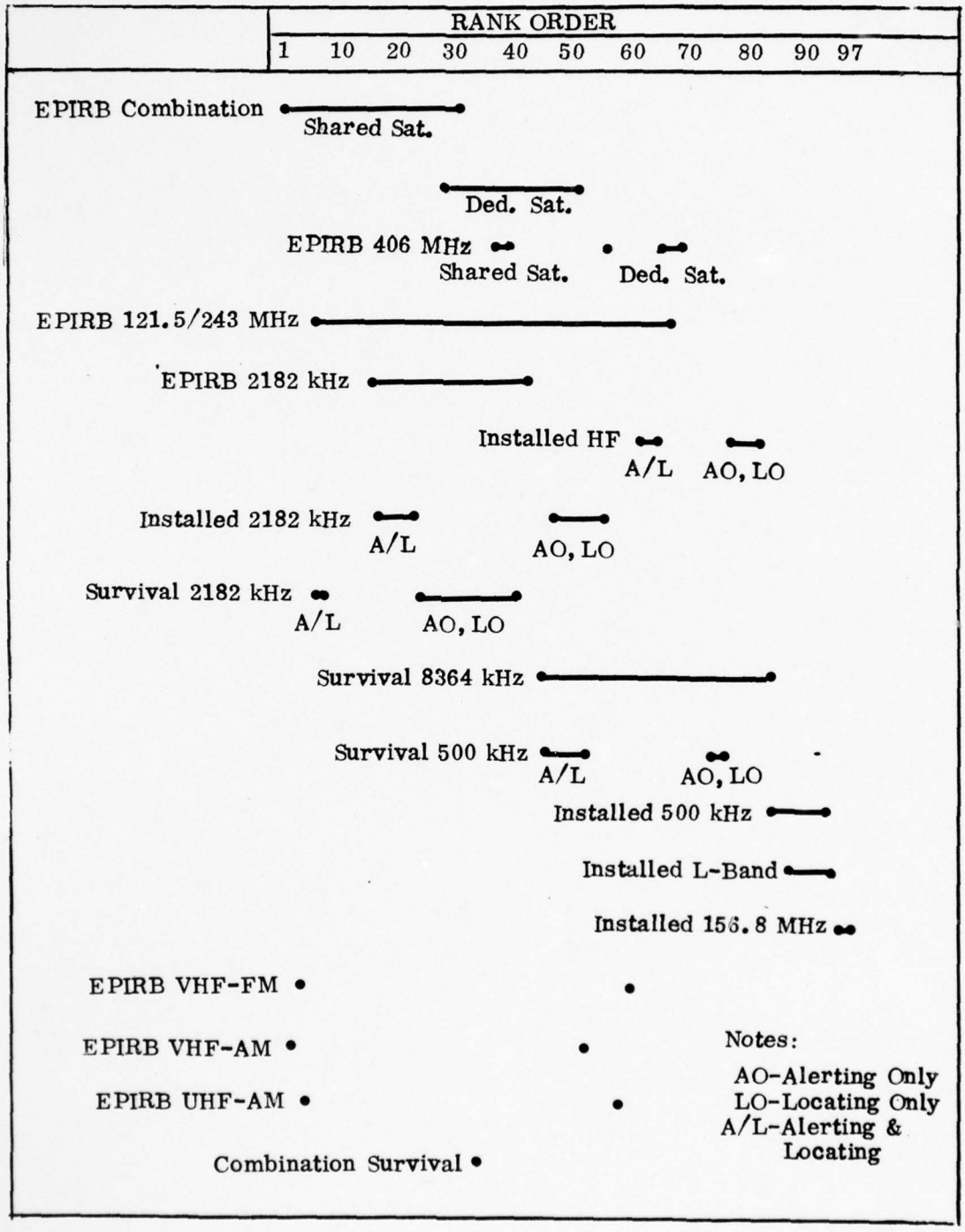

Figure 9-3. Comparison of Total Benefit: Cost Rank for Alerting Transmission Technique

Table 9-3. Comparison of Systems By Rank Order For Total Benefit:Cost Ratio

1.	3B10A	EPIRB 121.5/243 or 406 MHz Alerts Orbiting Satellite (shared), Location by Doppler
2.	2B5E	EPIRB VHF-AM, Aircraft DF/Homing
3.	2B5A	EPIRB VHF-FM, Aircraft DF/Homing
4.	2B5C	EPIRB UHF-AM, Aircraft DF/Homing
5.	2B5D	EPIRB 121.5/243 MHz, Aircraft DF/Homing
6.	3B8B	Survival 2182 kHz Alerts, Aircraft DF Locates
7.	3B9B	Survival 2182 kHz Alerts, Ship DF Locates
8.	3B5D	EPIRB Combination Alerts by Satellite (shared), Location by Aircraft DF/Homing on 121.5/243 MHz
9.	3B5F	EPIRB Combination Alerts by Satellite (shared), Location by Aircraft DF/Homing on UHF-AM
10.	3B5G	EPIRB Combination Alerts by Satellite (shared), Location by Aircraft DF/Homing on VHF-AM

9.2.5 Total Benefit Minus Cost

Total benefit minus cost rank order ranges are shown in Figure 9-4. The vertical dashed line separates the positive net value on the left from the negative values on the right. Only five systems have positive benefit minus cost values, all of which use EPIRBs.

The listing in Table 9-4 shows the relative rank order for benefit minus costs. The only systems listed are those having positive values. The high benefits compared to costs of 3B10A and low cost compared to benefits of the other systems that provide LO, results in this listing.

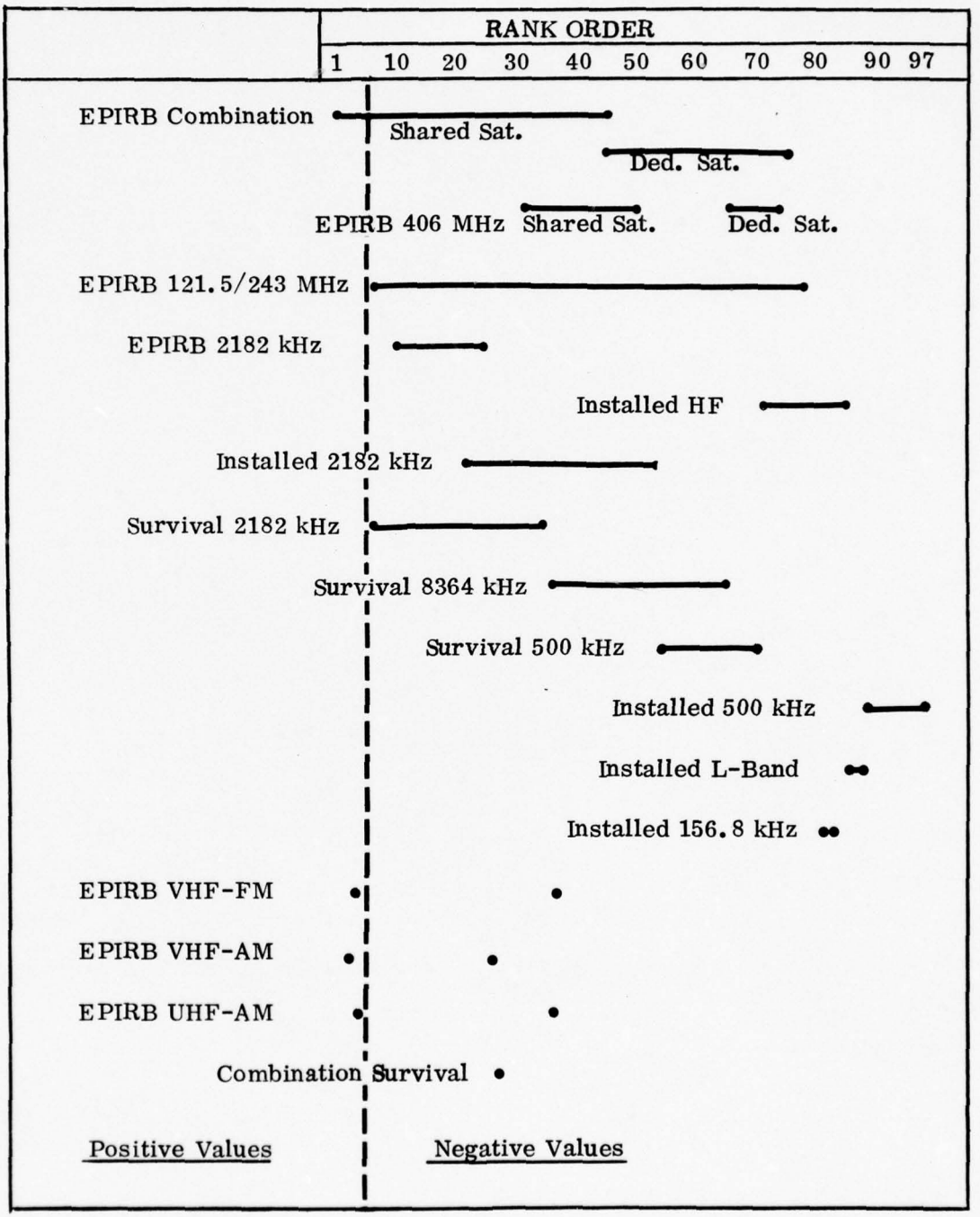

Figure 9-4. Comparison of Total Benefits Minus Cost Rank Order for Transmission Techniques

Table 9-4. Comparison of System Rank Order By Total Benefit Minus Cost

1.	3B10A	EPIRB 121.5, 243 or 406 MHz, Alerts by Orbiting Satellites, Location by Doppler
2.	2B5E	EPIRB VHF-AM, Aircraft DF/Homing
3.	2B5A	EPIRB VHF-FM, Aircraft DF/Homing
4.	2B5C	EPIRB UHF-AM, Aircraft DF/Homing
5.	2B5D	EPIRB 121.5/243 MHz, Aircraft DF/Homing

9.2.6 Shared and Dedicated Satellites

A comparison of rank order ranges for systems using shared and dedicated satellites is shown in Figure 9-5. This comparison is based on total benefit:cost ratio. The shared satellite for alerting and locating systems has the best range of rank orders with the dedicated satellite system having the lowest range when used for AO and LO.

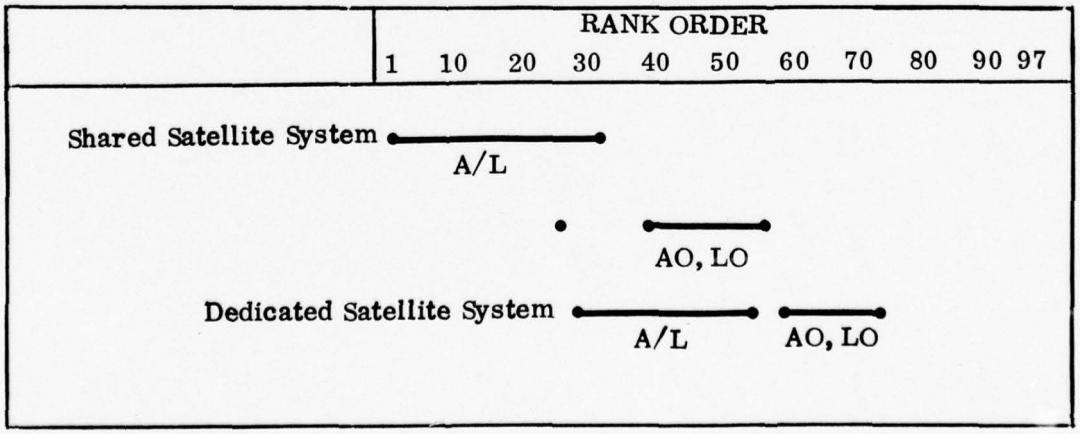

Figure 9-5. Comparison of Systems Using Shared and Dedicated Satellites

Ten systems that use satellites are listed in Table 9-5 in the relative rank order sequence by total benefit:cost ratio. The rank order range of these systems is from 1 through 20. As Table 9-5 and Figure 9-5 show, these are shared satellite systems. The systems using dedicated satellites are in the rank order range of 29 through 72 for total benefit:cost ratio.

Table 9-5. Comparison of Systems Using Satellites

1.	3B10A	EPIRB 121.5/243 or 406 MHz Alerts by Satellite (Shared), Location by Doppler
2.	3B5D	EPIRB Combination Alerts by Satellite (shared), Located by Aircraft DF/Homing on 121.5/243 MHz
3.	3B5F	EPIRB Combination Alerts by Satellite (shared), Located by Aircraft DF/Homing on UHF-AM
4.	3B5G	EPIRB Combination Alerts by Satellite (shared), Located by DF/Homing on UHF-AM
5.	1B2C	EPIRB 121.5/243 MHz Alerts Orbiting Satellite (shared)
6.	3B5E	EPIRB Combination Alerts by Satellite (shared), Located by Aircraft DF/Homing on VHF-FM
7.	3B6F	EPIRB Combination Alerts by Satellite (shared), Located by Ship DF/Homing on 406 MHz
8.	3B5C	EPIRB Combination Alerts by Satellite (shared), Located by Aircraft DF/Homing on 2182 kHz
9.	3B6E	EPIRB Combination Alerts by Satellite (shared), Located by Ship DF/Homing on UHF-FM
10.	3B6C	EPIRB Combination Alerts by Satellite, Located by Ship DF on 2182 kHz

9.3 COMPARISON OF SYSTEM RANK ORDER BY FUNCTIONS AND EQUIPMENT

9.3.1 General

In the following discussion, comparisons are provided showing the rank order of systems by function and type equipment used. For example, systems used for alerting only, locating only or alerting and locating can be compared by rank order. Or, the type equipment used for alerting and locating (e.g., EPIRB, Installed 2182 kHz) provides another basis for comparison. Numerous such analyses are possible using the various rank order categories in Appendix D. The following comparisons are a basic cross-section of these types of analyses. The total benefit:cost ratio is used for making comparisons.

9.3.2 Systems Used for Alerting

9.3.2.1 Alerting Only

Table 9-6 compares 10 of the 12 systems in Appendix A that are used for AO. The sequence shown is based on individual system rank order that ranges from 11 to 74. The top rank system uses an EPIRB with a shared orbiting satellite. The gap between the rank order for this system (# 11) and those following is quite large with 1B2A being #27 and 1B4A at #34.

Table 9-6. Comparison of Alerting Only Systems by Total Benefit:Cost Ratio

1.	1B2C	EPIRB 121.5/243 MHz Alerts Orbiting Satellite (shared)
2.	1B2A	EPIRB 2182 kHz
3.	1B4A	Combination Survival 500, 2182, 8364 kHz
4.	1B2D	EPIRB 406 MHz Alerts Geostationary Satellite (shared)
5.	1B3B	Survival 2182 kHz
6.	1B1B	Installed 2182 kHz
7.	1B2B	EPIRB 121.5/243 MHz Alerts Aircraft Overflight
8.	1B2C	EPIRB 121.5/243 MHz Alerts Orbiting Satellite (dedicated)
9.	1B2D	EPIRB 406 MHz Alerts Geostationary Satellite (dedicated)
10.	1B3C	Survival 8364 kHz

9.3.2.2 Alerting and Locating

The rank order sequence for systems capable of both alerting and locating are shown in Table 9-7. The rank order of these systems range from 1 to 15. As in the previous case, the top ranking system involves an EPIRB and shared orbiting satellite. Six of the systems employ the EPIRB Combination, plus a shared satellite and two employ the Survival 2182 kHz equipment; eight systems use aircraft DF/homing for the locating process.

9.3.2.3 Alerting and Alerting/Locating

The rank order comparison for all systems having a capability for alerting or A/L will result in the list shown in Table 9-8. This list is similar to Table 9-7 except that 1B2C has been inserted and 3B5B omitted.

Table 9-7. Comparison of Alerting and Locating System by Total Benefit: Cost Ratio

1.	3B10A	EPIRB 121.5/243 MHz or 406 MHz Alerts Orbiting Satellite, Location by Doppler
2.	3B8B	Survival 2182 Alerts, Aircraft DF Locates
3.	3B9B	Survival 2182 Alerts, Ship DF Locates
4.	3B5D	EPIRB Combination Alerts by Satellite (Shared), Located by Aircraft DF/Homing on 121.5/243 MHz
5.	3B5F	EPIRB Combination Alerts by Satellite (Shared), Located by Aircraft DF/Homing on UHF-FM
6.	3B5G	EPIRB Combination Alerts by Satellite (Shared), Located by Aircraft DF/Homing on VHF-AM
7.	3B5E	EPIRB Combination Alerts by Satellite (Shared), Located by Aircraft DF/Homing on VHF-FM
8.	3B6F	EPIRB Combination Alerts by Satellite (Shared), Located by Ship DF/Homing on 406 MHz
9.	3B6G	EPIRB Combination Alerts by Satellite (Shared), Located by Ship DF/Homing on VHF-AM
10.	3B5B	EPIRB 2182 Alerts, Aircraft DF/Homing

Table 9-8. Comparison of Systems Used for Alerting and Alerting/Locating

1.	3B10A	EPIRB 121.5/243 or 406 MHz Alerts Orbiting Satellite (shared), Location by Doppler
2.	3B8B	Survival 2182 Alerts, Aircraft DF Locates.
3.	3B9B	Survival 2182 Alerts, Ship DF Locates
4.	3B5D	EPIRB Combination Alerts by Satellite (shared), Located by Aircraft DF/Homing on 121.5/243MHz
5.	3B5F	EPIRB Combination Alerts by Satellite, (shared), Aircraft DF/Homing in UHF-AM
6.	3B5G	EPIRB Combination Alerts by Satellite, (shared), Aircraft DF/Homing on VHF-AM
7.	1B2C	EPIRB 121.5/243 MHz Alerts Orbiting Satellites (shared)
8.	3B5E	EPIRB Combination Alerts by Satellite (shared), Aircraft DF/Homing on VHF-FM
9.	3B6F	EPIRB Combination Alerts by Satellite (shared), Ship DF/Homing on 406 MHz.
10.	3B6G	EPIRB Combination Alerts by Satellites (shared), Ship DF/Homing on VHF-AM

9.3.2.4 Alerting Equipment

A listing of the top ranking types of alerting equipment is shown in Table 9-9. These are the basic types of equipment used in the alerting process. Their rank order range is from 1 to 16.

Table 9-9. Highest Ranking Types of Alerting Equipment

Installed:

3B1B Installed 2182, Alerts and Reports Location.

EPIRB:

3B10A EPIRB 121.5/243 or 406 MHz, Alerts Orbiting Satellites, Location by Doppler.

Survival:

3B8B Survival 2182 Alerts, Aircraft DF Locates.

9.3.3 Systems Used for Locating

9.3.3.1 Locating Only

Systems used for locating only are compared in Table 9-10. The rank order for these systems is from 2 to 42. However, the first six, employing aircraft DF/homing, are within the top 24 system rank orders for all high seas systems. All of these systems except 2B10B and 2B7C are also listed in Table 9-1 as being in the highest rank order for the total cost.

Table 9-10. Comparison of Locating Only System by Total Benefit:Cost Ratio

1.	2B5E	EPIRB UHF-AM, Aircraft DF/Homing
2.	2B5A	EPIRB VHF-FM, Aircraft DF/Homing
3.	2B5C	EPIRB UHF-AM, Aircraft DF/Homing
4.	2B5D	EPIRB 121.5/243 MHz, Aircraft DF/Homing
5.	2B9B	Survival 2102 kHz, Aircraft DF/Homing
6.	2B5B	EPIRB 2182 kHz, Aircraft DF/Homing
7.	2B7A	EPIRB 121.5/243 MHz, Doppler by Orbiting Satellite (Shared)
8.	2B10B	Survival 2182 kHz, Ship DF/Homing
9.	2B7C	EPIRB 406 MHz, Retransmit NAVAID to Orbiting Satellite (Shared)
10.	2B6B	EPIRB 2182 kHz, Ship DF/Homing

9.3.3.2 Locating Only and Alerting/Locating

A comparison of the rank order for all systems having a locating capability, either LO or A/L results in the listing of Table 9-3 for total benefit:cost ratio.

9.3.3.3 Locating Method

Table 9-11 shows a listing of locating method by their relative rank order. The rank order range for this listing is from 1 through 45. Only the system having the highest rank order for each method is listed. All of the systems listed, except 2B5E, have both an alerting and locating capability.

Table 9-11. Highest Ranking Locating Method for Each Category of Alerting, Locating and Alerting/Locating

1. Orbiting Satellite:
   - 3B10A Doppler Location by Orbiting Satellite
2. Aircraft:
   - 2B5E Aircraft DF/Homing
3. Ship:
   - 3B9B Ship DF/Homing
4. Location Report:
   - 3B1B Reported Location
5. Geostationary Satellite:
   - 2B7C NAVAID Retramemission
6. Shore:
   - 3B7A Shore DF

9.3.4 Types of Equipment Used

9.3.4.1 Installed Equipment

The top ranking installed equipment is basically the 2182 kHz equipment; followed by installed HF. The range of rank order for systems using this equipment is 11 through 63. The relative standing of this type equipment is shown in Table 9-12.

Table 9-12. Comparison of Systems Using Installed Equipment

1.	3B1B Installed 2182 kHz, Alerts and Reports Location
2.	3B3B Installed 2182 kHz, Alerts, Aircraft DF/Homing
3.	3B4B Installed 2182 kHz, Alerts, Ship DF/Homing
4.	2B3B Installed 2182 kHz, Aircraft DF/Homing
5.	2B4B Installed 2182 kHz, Ship DF/Homing
6.	1B1B Installed 2182 kHz, Alerts
7.	2B1B Installed 2182 kHz, Location Reported
8.	3B1D Installed HF, Alerts and Reports Location
9.	3B2B Installed HF, Alerts, Shore DF Locates
10.	3B3C Installed HF, Alerts, Aircraft DF/Homing

9.3.4.2 Survival Equipment

The top ranking of systems using Survival equipment is shown in Table 9-13. The rank order range of systems using this equipment is from 6 through 50.

Table 9-13. Comparison of Systems Using Survival Equipment

1.	3B8B	Survival 2182 kHz Alerts, Aircraft DF Locates
2.	3B9B	Survival 2182 kHz Alets, Ship DF Locates
3.	2B9B	Survival 2182 kHz, Aircraft DF/Homing
4.	2B10B	Survival 2182 kHz, Ship DF/Homing
5.	1B4A	Combination Survival 500, 2182, and 8364 kHz Alerts
6.	1B3B	Survival 2182 kHz Alerts
7.	3B8C	Survival 8364 kHz Alerts, Aircraft DF Locates
8.	3B7A	Survival 500 kHz Alerts, Shore DF Locates
9.	3B8A	Survival 500 kHz Alerts, Shore DF Locates
10.	3B9C	Survival 8364 kHz Alerts, Ship DF Locates

9.3.4.3 EPIRB Equipment

A comparison of rank order for the system ranking where EPIRBs are used is shown in Table 9-14. The range of rank order for the systems using this equipment is from 1 through 12. This table is similar to Table 9-2 for total benefit:cost ratio in that eight of the systems in Table 9-14 are also in Table 9-3.

Table 9-14. Comparison of Systems Using EPIRB

1.	3B10A	EPIRB 121.5/243 406MHz Alerts Orbiting Satellite, Location by Doppler
2.	2B5E	EPIRB VHF-AM, Aircraft DF/Homing
3.	2B5A	EPIRB VHF-FM, Aircraft DF/Homing
4.	2B5C	EPIRB UHF-AM, Aircraft DF/Homing
5.	2B5D	EPIRB 121.5/243 MHz, Aircraft DF/Homing
6.	3B5D	EPIRB Combination Alerts by Satellite (shared), Aircraft DF/Homing on 121.5/243 MHz
7.	3B5F	EPIRB Combination Alerts by Satellite (shared), Aircraft DF/Homing on UHF-AM
8.	3B5G	EPIRB Combination Alerts by Satellite (shared), Aircraft DF/Homing on VHF-AM
9.	1B2C	EPIRB 121.5/243 MHz Alerts Orbiting Satellite (shared)
10.	3B5E	EPIRB Combination Alerts by Satellite (shared), Aircraft DF/Homing on VHF-AM

9.4 SUMMARY OF RANK ORDER LISTINGS

Before firm conclusions are reached regarding the candidate high seas systems, the material in Volumes 2 and 3 should be thoroughly examined. However, certain preliminary conclusions may be made based on the discussions of rank order in the previous paragraphs. As indicated previously, systems using EPIRBs, aircraft DF/homing, and shared satellites are generally in the high rank order range. Systems capable of both alerting and locating have the highest benefits; those with capabilities for only alerting or locating generally have lower rank order standings. The exceptions to this are the top four LO systems that are also among the highest rank order for total benefit:cost ratio and total benefit minus cost. All but two of the systems (1B2C and 3B10A) in the top rank order for total cost have LO capabilities. Systems using 2182 kHz survival equipment also are in a high rank order, although not as prevalent as EPIRBs. On the other hand, systems using installed equipment (except 2182 kHz) are generally lower in rank order.

In the previous discussion of rank order for various system features, the repeated appearance of some systems in this listing was apparent. In general, this repetition shows that the systems involved have the highest rank order for cost, benefit, benefit:cost ratio, and benefit minus cost. The number of times that the systems appeared should provide a general indication of their overall standing for these factors among high seas systems. An examination was, therefore, made to identify the ten systems with the most prevalent appearance in the previous rank order listings. The results are shown in Table 9-15. The selected systems are based on the number of appearances in high rank order listings. The top of this table shows the system features for which they were listed by rank order. Under each of these system features is listed in rank order number for the system as shown in Tables 9-1 through 9-14. The numerals indicate rank order for total cost, total benefit, total benefit:cost

ratio, total benefit minus cost, standing among systems using satellites, basic type of alerting equipment used, type locating method, installed equipment, survival equipment EPIRB, alerting system, and locating system.

Table 9-15. Systems with Prevalent Rank Order Listings

System	Cost	Benefit	Benefit: Cost Ratio	Benefit Minus Cost	Sat. System	Alert. System	Loc. Meth.	Inst. Equip.	Surv. Equip.	EIPIB	Alert Syst.	Loc. Syst.
1. 3B10A EPIRB 121.5/243/406 MHz, Doppler Loc.	7	8	1	1	1	2	1			1	1	
2. 2B5E EPIRB VHF-AM, Aircraft DF/ Homing	1		2	2			2			2		1
3. 2B5A EPIRB VHF-AM, Aircraft DF/ Homing	2		3	3						3		2
4. 2B5C EPIRB UHF-AM, Aircraft DF/ Homing	3		4	4						4		3
5. 2B5D EPIRB 121.5/ 243 MHz, Aircraft DF/Homing	4		5	5						5		4
6. 3B5F EPIRB Comb. Alerts Sat., Aircraft DF/Homing		6	9		3					7	5	
7. 3B5G EPIRB Comb. Alerts Sat., Aircraft DF/Homing		7	10		4					8	6	

Table 9-15. Systems with Prevalent Rand Order Listings (Cont'd)

System	Cost	Benefit	Benefit: Cost Ratio	Benefit Minus Cost	Sat. System	Alert. Equip.	Loc. Meth.	Inst. Equip.	Surv. Equip.	EIRPB	Alert. Syst.	Loc. Syst.
8. 3B8B Surv. 2182kHz Alerts., Aircraft DF/ Homing		10	6			3			1		2	
9. 3B9B Surv. 2182 kHz Alerts, Ship DF/Homing		7					3		2		3	
10. 3B1B Inst. 2182 kHz Alerts, Reports Loc.		3				1	4	1				