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INTERAGENCY COMMITTEE FOR SEARCH AND RESCUE

AD HOC WORKING GROUP

REPORT

ON

SATELLITES FOR DISTRESS ALERTING AND LOCATING

FINAL REPORT

OCTOBER 1976

FOREWORD

This report was prepared to document the work initiated by the ad hoc working group on satellites for search and rescue (SAR). The ad hoc working group on satellites for distress alerting and locating (DAL), formed in November 1975 by agreement of the Interagency Committee on Search and Rescue (ICSAR), consisted of representatives from Maritime Administration, NASA Headquarters, Goddard Space Flight Center, U.S. Coast Guard Headquarters, Federal Aviation Administration, Federal Communications Commission, U.S. Air Force (USAF) Air Lift Division, USAF Aerospace Rescue and Recovery Service Headquarters, Aircraft Owners and Pilots Association, and National Association for Search and Rescue. This report represents a majority view of the participants, however, there was not unanimous agreement in all respects.

This report completes the assignment of the ad hoc working group on satellites for distress alerting and locating.

Submitted:

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Eugene Ehrlich, Chairman

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OCTOBER 1976

PREFACE

The ad hoc working group on satellites for search and rescue (SAR) was formed in November 1975 by agreement of the Interagency Committee on Search and Rescue (ICSAR) consisting of representatives from the Departments of Commerce, Defense, and Transportation; the Federal Communications Commission; and the National Aeronautics and Space Administration. The committee was directed to: (1) review the current situation and deficiencies for aircraft and marine distress alerting and locating (DAL); (2) examine advanced space and nonspace techniques to improve the present DAL situation; (3) configure an R&D and operational satellite system to meet the present and future DAL needs; and (4) provide an estimate of costs for the selected satellite system.

This report discusses the background behind the congressional legislation that led to the requirement for the Emergency Locator Transmitter (ELT) and the Emergency Position-Indicating Radio Beacon (EPIRB) to be installed on certain types of aircraft and inspected marine vessels respectively. The DAL problem is discussed for existing ELT and EPIRB equipped aircraft and ships. Alternative concepts to improve the current situation did not address other facets of SAR operations such as communications with SAR forces through geosynchronous satellites. It is recognized that the DAL requirement for CONUS and Alaska and the maritime regions are not identical. In order to address the serious DAL problem which currently exists in CONUS and Alaska, a low-orbiting satellite system evolves as the most viable and cost effective alternative that satisfies the overall SAR system design requirements. A satellite system designed to meet the needs of the maritime regions could be either low orbiting or geostationary. The conclusions drawn from this report support the recommendation to proceed with the implementation of a SAR orbiting satellite system.

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ABBREVIATIONS

A/C	Aircraft
AEROSAT	Aeronautical Satellite
AEM	Application Explorer Mission
AFB	Air Force Base
AFM	Air Force Manual
AFRCC	Air Force Rescue Coordination Center
AM	Amplitude Modulation
AMVER	Automated Mutual Assistance Vessel Rescue System
AOPA	Aircraft Owners and Pilots Association
ARRS	Aerospace Rescue and Recovery Service
ATA	Air Transport Association
ATS	Applications Technology Satellite
CAP	Civil Air Patrol
CCIR	International Radio Consultative Committee
CONUS	Continental United States
CY	Calendar Year
DAL	Distress Alerting and Locating
DF	Direction Finding
DOC	Department of Commerce
DOD	Department of Defense
DOT	Department of Transportation
EASCON	Electronic and Aerospace Systems Conference
ELT	Emergency Locator Transmitter
EPIRB	Emergency Position-Indicating Radio Beacon
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FCC	Federal Communications Commission
FY	Fiscal Year
GA	General Aviation
GPS	Global Positioning System
GRAN	Global Rescue Alarm Network
g-switch	gravity (force) activated switch
Hz	Hertz (cycles per second)

ICAO	International Civil Aviation Organization
ICSAR	Interagency Committee on Search and Rescue
ID	Identification
IF	Intermediate Frequency
IMCO	Inter-Governmental Maritime Consultative Organization
INMARSAT	International Maritime Satellite Organization
ITU	International Telecommunications Union
KHz	Kilohertz
KM	Kilometer
LOP	Line of Position
MARISAT	Maritime Satellite
MAROTS	Marine Orbiting Technology Satellite
MHz	Megahertz
MPS	Minimum Performance Standards
N.A.	Not Applicable
NATO	North Atlantic Treaty Organization
NASA	National Aeronautics and Space Administration
NASR	National Association for Search and Rescue
NASRC	National Association of Search and Rescue Coordinators
NAVSTAR	Navigation System Using Time and Ranging
NMI	Nautical Miles
NNSS	Navy Navigation Satellite System
NOAA	National Oceanic and Atmospheric Administration
POCC	Projects Operations Control Center
PLACE	Position Location and Aircraft Communications Experiment
PPM	Pulse Position Modulation
RAMS	Random Access Measurement System
RCC	Rescue Coordination Center
R&D	Research and Development
RF	Radio Frequency
RTCA	Radio Technical Commission for Aeronautics
SAR	Search and Rescue
SARSAT	Search and Rescue Satellite
SMC	SAR Mission Coordinator
SOLAS	Safety of Life at Sea Convention

SRU	Search and Rescue Unit
TBD	To Be Determined
T/M	Telemetry
USAF	United States Air Force
USCG	United States Coast Guard
UHF	Ultra High Frequency
UTC	Universal Time Code
VHF	Very High Frequency
VLF	Very Low Frequency
W	Watt
WG	Working Group

I. INTRODUCTION

1.1 BACKGROUND

1.1.1 Emergency Locator Transmitters (ELT)

The problem of knowing when aircraft are missing and where they are downed has been a problem for many years. The November 17, 1970 Senate Congressional Record on the Occupational Safety and Health Act of 1970, published an excerpt from the Airport and Airways Development Act of 1969 as follows:

> "Starting in 1961, when inadequate records were being kept, two airplanes were reported down. Both of them were in California, or one might have been in California or Oregon. Four persons were on board. They have never been found, neither the airplanes nor the people."

In testimony given by former Senator Peter H. Dominick (R., Colo.) during the same Senate congressional hearing regarding the aircraft emergency problem, he stated,

> "I think we can see the problem this creates not only in terms of rescue efforts involved in going to try to find these airplanes, but also the cost in human misery. Every family simply finds that it is in a position, legally speaking, where it has a missing relative of one form or another.

> "In many states, the estate is tied up for over 7 years because there is no presumption of death until the 7-year period has gone by. They cannot do anything about the estate or about the property situation.
>
> "In the meanwhile, they do not know where the missing persons are, whether they are injured or dead, or whether they have simply disappeared for reasons of their own."

As a result of persuasive arguments by Senator Dominick and Senator Barry Goldwater during the above cited hearings, an amendment to the Occupational Safety and Health Act of 1970 was approved by voice vote on November 17, 1970 calling for installation of emergency locator transmitters (ELT's) on private fixed-wing aircraft. The actual bill taken from the Occupational Safety and Health Act (P.L. 91-596) can be found in Ref. 1, Appendix A. Since P.L. 91-596 was put into effect, approximately 150,000 ELT's have been put in the field in the United States, primarily on aircraft. After a period of evaluation, Major General Saunders, Commander ARRS and the designated Inland SAR Coordinator described the deficiencies in the present ELT system as follows (full text can be found in Ref. 2, Appendix A:

> " Two major deficiencies exist in the present ELT system, transmitter malfunctions/misuse and receiver coverage. The initial problem can be overcome by educating the operator and by improving the equipment; however, the latter is a far greater problem. Due to low power output and line-of-sight transmission limitation, remote areas of the United States are not monitored by existing receiver stations. A high percentage of airplane crashes occur in the remote, rugged terrain areas, thus reducing the effectiveness of the ELT. A downed aircraft with survivors, in this environment, may not be located because the ELT signal could not be heard by ground stations or over flying aircraft." The National Search and Rescue Manual, AFM 64-2 states: "...that the life expectancy of injured survivors

> decreases as much as 80 percent the first 24 hours following an accident. Thus the requirement for immediate notification and dispatch of rescue forces is paramount. The ELT unit can provide this capability if it is detected immediately after the incident occurs."

1.1.2 Emergency Position - Indicating Radio Beacon (EPIRB)

Proposals have been made for certain classes of inspected vessels in ocean and coastal service to carry an EPIRB that would (a) be stowed in such a manner that should the vessel sink, it would float free and automatically activate, and (b) be placed in a location where it would be readily accessible for testing and emergency use. These proposals refer to the Coast Guard analysis of an extensive air-sea search for a distressed vessel off the East Coast of the United States. The Coast Guard group which was involved in preparing the U.S. position on radio-communications for the 1960 Safety of Life at Sea (SOLAS) Conference, proposed that EPIRB's operating on 121.5 and 243 MHz be required by international agreement. This SOLAS Conference recognized the need for EPIRB's, and Recommendation No. 48 was adopted by the final 1960 SOLAS Convention (Ref. March 15, 1973, Federal Register, Volume 68, No. 42). This recommendation states:

> "The Conference, recognizing that an automatic nondirectional emergency position-indicating radio beacon will improve safety of life at sea by greatly facilitating search and rescue, recommends that governments should encourage the equipping of all ships, where appropriate, with a device of this nature which shall be small, lightweight, floatable, watertight, shock resistant, self-energizing and capable of 48 hours continuous operation. The organization should consult with the International Civil Aviation Organization (ICAO) and the International Telecommunications Union (ITU) with a view to determining the standard of world-wide application to which the radio characteristics should conform."

Several reports of Marine Board of Investigation have noted the need for EPIRB's. In the report cited in the March 15, 1973 Federal Register, it stated:

"The SS V.A. Fogg was lost with all hands on February 1, 1972. The vessel exploded and as a result sank suddenly. When the vessel became overdue shortly thereafter, a massive search was launched which lasted 11 days before the sunken hull was located. An EPIRB would probably have shortened the search by several days.

"In the case of the Texaco OKLAHOMA, the stern section with 31 persons on board remained afloat for about 27 hours. Those on board the vessel attempted to make their plight known by use of the lifeboat radio, lights, and by flares, all without success. An AMVER plot indicated that there were 18 participating vessels within 120 miles of the stricken ship during this period. Numerous commercial and military aircraft frequent the area and would most likely have heard an EPIRB signal."

In the March 18, 1974 issue of the Federal Register (Vol. 39, No. 53), the comments made the previous year regarding EPIRB's were incorporated in Chapter I (Coast Guard, Department of Transportation) of Title 46 (Shipping) of the Code of Federal Regulations as an amendment. One section of the amendments regarding requirements for storage of EPIRB's can be found in Ref. 3 Appendix A.

Also in the March 18, 1974 Federal Register, and pursuant to the authority contained in Sections 4(i), 303(r), and 318, to the Communications Act of 1934, as amended, EPIRB specifications were promulgated as amendments to Part 2 (Frequency Allocations and Radio Treaty Matters; General Rules and Regulations) and Part 83 (Stations on Shipboard in the Maritime Services) of Chapter I (Federal Communications Commission) of Title 47 (Telecommunications) of the Code of Federal Regulations.

1.2 GENERAL

The Interagency Committee on Search and Rescue (ICSAR) consisting of representatives from the Departments of Commerce, Defense, and Transportation, the Federal Communications Commission and the National Aeronautics and Space Administration recommended at their November 1975 meeting that an ad hoc working group (W.G.) on satellites for SAR be established.

ICSAR's recommendation, in part, was stimulated by a letter from the Aircraft Owners and Pilots Association (AOPA) to the Commandant of the U.S. Coast Guard, which said, "AOPA makes the following recommendations: ICSAR recommends and actively supports a program to develop a SAR satellite monitoring system." AOPA also sent a letter of support to the NASA Administrator (full text of letters is given in Ref. 4, Appendix A). The National Association of Search and Rescue (NASAR), in a letter to the NASA Administrator of January 28, 1976 (see full text in Ref. 5, Appendix A) said, in part:

> "Due to low power output of ELT's and the line-of-sight transmission characteristics, many of our more remote and rugged areas of America are not monitored by receivers at all, or very infrequently by overflying high altitude aircraft at best. Therefore, there is a serious gap in present day monitoring capabilities by aircraft and ground stations. Prompt detection of ELT signals and accurate fixing of the signal sources geographically could well mean the difference between life and death or an expensive search for a non-distress signal activation.
>
> "NASARC, for these reasons, most heartily supports and encourages NASA initiatives and concepts for the development of a satellite monitoring system. We consider the development and launching of such a system to be a giant step forward in humanitarian concern for our fellow citizens."

And finally, Major General Ralph S. Saunders, USAF Inland SAR Coordinator, in a memorandum dated 23 September 1975, (see Ref. 2, Appendix A), said,

> "Today there exists the means by which to monitor ELT signals for the entire area of the United States. One low orbiting polar satellite system would provide coverage at any point in the world having an average scan interval of 5 hours. Presently, the National Aeronautics and Space Administration (NASA) is studying the capabilities of satellites to monitor ELT transmissions. Preliminary findings are encouraging. The Aerospace Rescue and Recovery Service (ARRS) supports the initiative and concepts of NASA and

concurs with the recommendations of the Search and Rescue Panel, conducted in May 1975, at Easton, Maryland."

The WG's task for ICSAR was to: (1) review the current situation and deficiencies for aircraft and marine distress alerting and locating (DAL); (2) examine advanced space and non-space techniques to improve the present DAL situation; (3) configure an R&D and operational satellite system to meet the present and future DAL needs; and (4) provide an estimate of costs for the selected satellite system.

In all the WG's activities, the following assumptions are made:

1. Efforts will include the DAL of existing ELT and EPIRB equipped aircraft and ships.
2. Vessels which do not normally proceed more than 20 nautical miles offshore (principally recreational boats) will not be equipped with an EPIRB operating on 121.5/243 MHz. However, the DAL system capability will extend to those high seas vessels carrying EPIRB's when operating with coastal region.
3. Requirements for detection and location of military combat distress incidents are not included in the scope of this study. Military distress on 243 MHz in the area of U.S. SAR responsibility will be considered, but not separately.
4. The unreliable operations of the ELT's and EPIRB's are expected to be improved within the next 5 years.

In order to set the tone of the importance and extent of SAR missions and that of the potential improvement by satellite-aided SAR system, some actual SAR mission cases are cited.

The first case shows how a SAR mission was carried out without an ELT. The second case shows how effective an ELT was in a SAR mission. The third case shows a lack of effective EPIRB monitoring on the high seas. The fourth case demonstrates how EPIRB monitoring can be effective in SAR missions.

With the aid of a satellite system to guarantee monitoring of an ELT and the ability of the system to locate the source of the ELT, the valuable time it takes to effect a SAR mission can be drastically reduced, thereby saving lives and dollars.

1.2.1 Case 1 - AFRCC Mission, 29 November 1974

The Los Angeles Air Route Traffic Control Center advised the AFRCC at 1920 hrs., that two USAF F-111s had collided and crashed over Milford, Utah. At 1931 hrs., the AFRCC diverted a USAF rescue aircraft to the area. At 1935 hrs., the National Warning Center advised the AFRCC that a flashing light had been seen on the ground and the Utah Highway Patrol was en route. The AFRCC established a conference call with the Nellis AFB Command Post and the Highway Patrol to brief all parties on events thus far. At 1946 hrs., Los Angeles Center advised the AFRCC that a civilian aircraft was also missing in the same area and that only one F-111 was missing. The other F-111 was not damaged and was en route to his home base at Nellis. The AFRCC debriefed the second F-111 crew and from their information deduced that the downed F-111 had collided with the missing civilian aircraft. The Nellis Command Post was continually updated throughout the mission. Army helicopters at Dugway Proving Ground and Air Force rescue helicopters at Hill Air Force Base were placed on alert. At 2052 hrs., the AFRCC learned from the highway patrol that the pilots from the F-111 had been picked up and were en route to a hospital, both suffering back injuries. The Utah CAP and Utah SAR Coordinator were alerted for possible search at first light for the missing civil aircraft. Another rescue aircraft was launched to replace the first rescue aircraft which was forced to depart due to low fuel. At 2128 hrs., the AFRCC was advised by the Richfield County Sheriff that the fuselage of the civil aircraft had been found. The next morning an intensive ground search was initiated for the missing civilian pilot. At 1415 hrs. that afternoon, the body of the pilot was found. All agencies involved were debriefed and the mission was closed.

This mission is an example of the extensive and necessary coordination quickly established by the AFRCC between many different agencies. At least six different Air Force units were involved, two Army units, four FAA facilities, three law enforcement agencies, a civilian and military hospital, CAP, and a state SAR Agency.

1.2.2 Case 2 - AFRCC Mission, 15 December 1974

At 1918 hrs., 14 December 1974, the AFRCC received an alert notice from the Elko, Nevada, Flight Service Station. The alert notice was received by teletype and informed the AFRCC that a Cessna 180, with three persons aboard, was reported overdue on a flight from Elko, Nevada, to Carson City, Nevada. The Flight Service Station had been informed by associates of the pilot that the aircraft was overdue and that the Cessna 180 had departed Elko, Nevada, at 1138 hrs., not on a flight plan. At 1950 hrs., Lovelock Flight Service Station, also in receipt of the alert notice, reported that a local citizen had seen a low-flying aircraft matching the description of the Cessna 180. Lovelock also reported aircraft in their area were receiving emergency signals from an ELT. The AFRCC deployed an Air Force Aerospace Rescue and Recovery aircraft equipped with DF capability from McClellan Air Force Base, California. The Naval Air Station at Fallon, Nevada, was also requested to have a helicopter ready for deployment. At 2030 hrs., the Nevada Civil Air Patrol and the National Warning System were alerted. The ARRS aircraft from McClellan reported to the AFRCC at 2335 hrs. that the source of the emergency signal had been electronically located 37 km (20 miles) east of Lovelock, Nevada. This information was passed to the National Warning System to relay to the law enforcement agency in the area. At 0140 hrs., the Lovelock Sheriff found the downed aircraft with all three people. Two of the occupants were injured and in poor condition. All three were taken by the Sheriff's unit to the Elko Hospital. Ten days later, the most seriously injured person was still reported in poor condition. It is interesting to note that if the pilot had filed a flight plan, the alert notice would have been issued at least 5 hours earlier and the mission would have taken place during daylight, most probably leading to a much earlier arrival at the crash site.

1.2.3 Case 3 - Maritime Test of EPIRB Monitoring

In one of the few reported surveys of EPIRB alerting capability, the Norwegian government had the M/S NORSE LADY make calls on 121.5 MHz during her voyage from the United States to Europe. The tests were motivated by the loss earlier of four ships. Three of these ships carried EPIRB's, yet no signals were ever detected in any of the cases. On the NORSE LADY's voyage, 38 test calls were made; two were responded to. Whether the poor performance of the EPIRB alert detection capability was caused by lack of aircraft overflights, monitoring receivers turned down or turned off, or because the tests used voice transmissions in lieu of the swept frequency alarm could not be determined.

1.2.4 Case 4 - Coast Guard SAR Mission, 26 July 1975

On July 26, 1975, the New York OAC relayed reports from several overseas aircraft flights of EPIRB transmissions. An HC-130 aircraft was launched from the Coast Guard Air Station, Elizabeth City, N.C. When the aircraft arrived in the reported area, a weak signal on 121.5 MHz was heard. Using aural homing techniques, the HC-130 located the source of the signal 2 hours and 20 minutes later. It was coming from the sailing vessel BANJO. The initial range at which the signal was heard was estimated to have been 70 miles, but the DF needle was unable to point towards the EPIRB until the aircraft was approximately 10 miles from the target. The HC-130 diverted the Dutch tanker SS VEENDAM to the scene which rescued the crew of three. A few hours later, the badly damaged BANJO sank.

The BANJO had suffered severe structural damage in a storm. Except for the EPIRB, she was without any communications capability. A debriefing by the owner (one of the survivors), revealed that the EPIRB's signal was first heard by a passing aircraft approximately 1.5 hours after the signal was activated. Undoubtedly this device saved the lives of the BANJO's crew.

2. DISTRESS ALERTING AND LOCATING (DAL) PROBLEM

2.1 INTRODUCTION

In 1970, the Congress recognized the deficiency which existed in locating the scene of an aircraft crash by passing legislation which would require general aviation aircraft to carry an Emergency Locator Transmitter (ELT). Following implementation of Federal Aviation Administration (FAA) regulations, approximately 150,000 U.S. civil aircrafts had ELT's installed by 1 July 1974. For the U.S. maritime community, the special report "Survivor - Locator Systems for Distressed Vessels" published by the National Transportation Safety Board in 1972, recommended that the Coast Guard, in conjunction with the FCC, require all U.S. vessels, subject to the provisions of the 1960 SOLAS Convention, to carry EPIRB's which transmit automatically on 121.5 MHz, 243 MHz, and 2182 kHz.

Subsequent Coast Guard and FCC rulemaking brought approximately 1900 U.S. vessels under the mandatory regulations while limiting the EPIRB's transmit frequencies to 121.5/243 MHz. The radio characteristics of the aviation ELT and the marine EPIRB became identical. The differences, which are not of significant concern in designing a DAL system around the devices, are: (1) for the ELT, automatic activation on impact by means of a "g-switch"; and (2) for the EPIRB, an ability to float free of the vessel and automatically activate.

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The intent of both the ELT and the EPIRB rulemaking was to provide for carriage by vessels of an electronic device which would survive a severe casualty and eventually enable SAR resources to locate a distress scene or survivors. It was recognized, however, that EPIRB's would often serve as a distress alerting device when other methods of communication were not successful or available. Overwater alerting by shipboard EPIRB's is predicated on aircraft making long overwater flights monitoring 121.5 MHz in accordance with regulations of the International Civil Aviation Organization.

For the overland ELT's, the situation for detecting and locating ELT's at general aircraft crash sites is worse. Unlike the oceanic case, there are no mandatory guard requirements for monitoring 121.5 MHz, and significant opposition has been expressed about adding such duties to the cockpit environment of commercial airliners. However, recent experience has indicated that based on the number of ELT signals being reported to the U.S. Inland SAR coordinator, airborne monitoring is being accomplished.

2.2 PRESENT SAR SYSTEM

The National SAR Plan designates the U.S. Air Force as the Federal executive agency which has been delegated the responsibility for coordination of SAR activities within the inland region (CONUS) 24 hours a day as shown in Figure 2-1. The Aerospace Rescue and Recovery Service (ARRS) operates the Air Force Rescue Coordination Center (AFRCC) at Scott Air Force Base, Illinois, 12 miles east of St. Louis, Missouri. The U.S. Coast Guard performs the same function within the maritime region. Military SAR incidents are the responsibility of the affected military service. Other Federal agencies are available and utilized in accordance with their special capabilities, as prescribed in the National SAR Plan.

There is a national network of state Civil Defense agencies, some of which have been assigned state SAR responsibilities. Other states have designated state SAR coordinators, whereas others have vested this responsibility in civil aviation directors, emergency services groups, and other departments. On the local level, the county sheriff is usually assigned SAR responsibility within his jurisdiction. In cities and towns, the SAR function is usually assigned to the local fire chief. The relationship of the various SAR agencies in the inland region is shown in Figure 2-2.

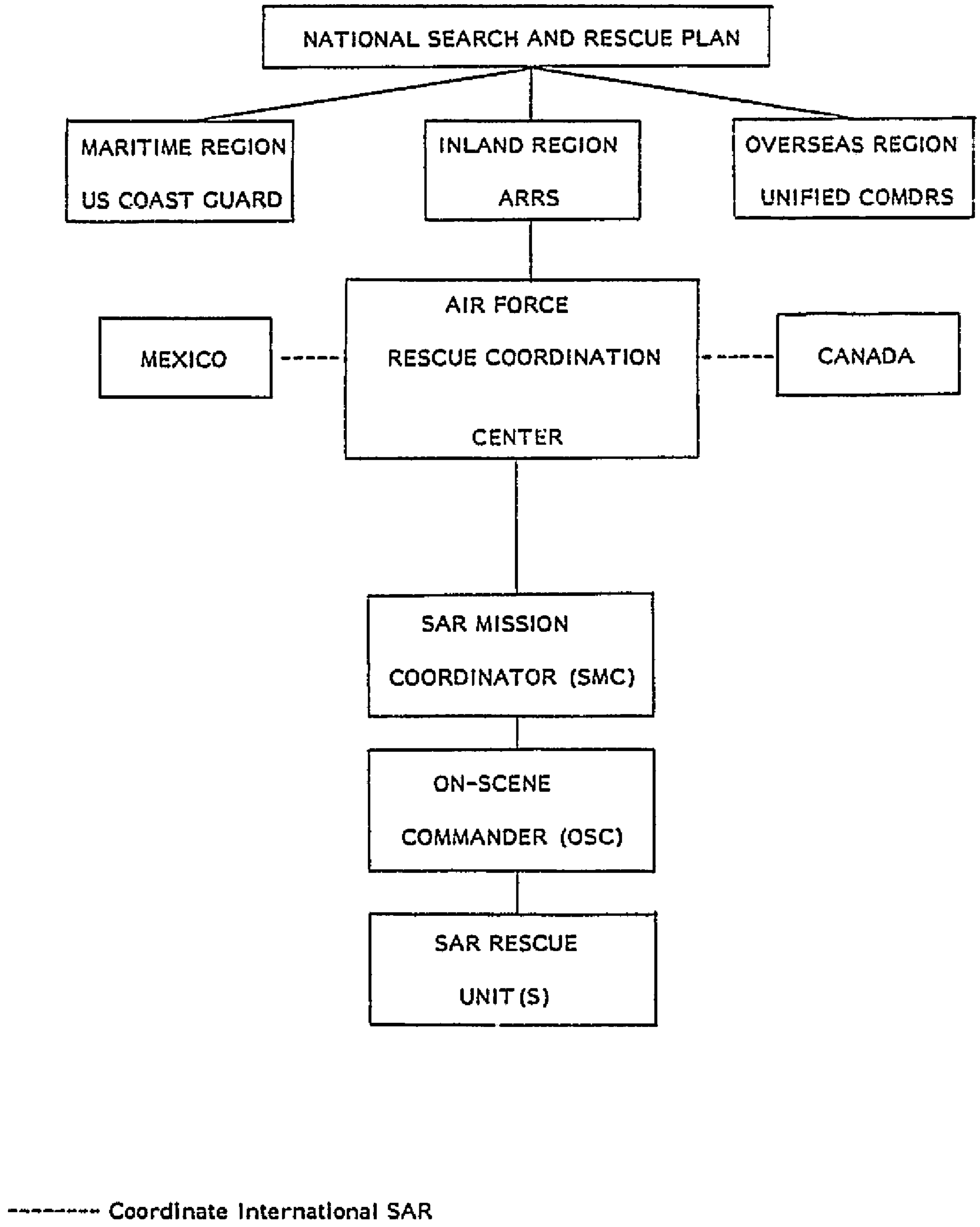

FIGURE 2-1. ORGANIZATION CHART

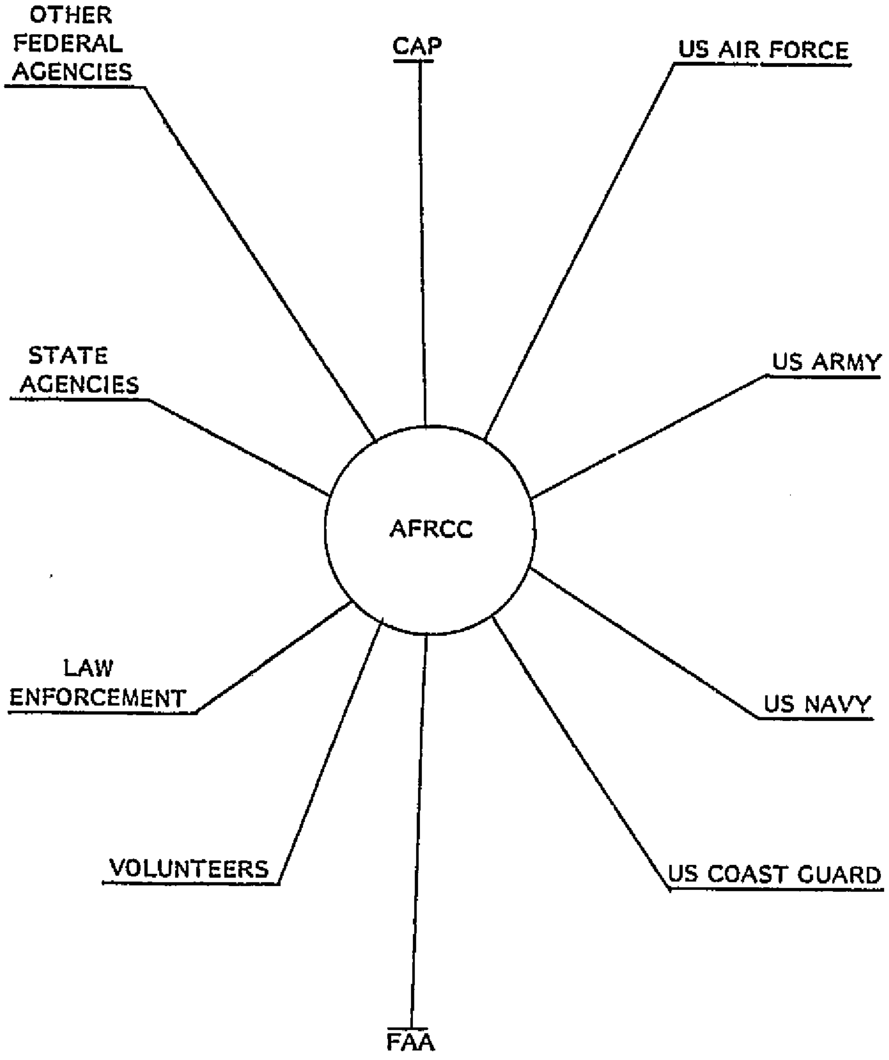

FIGURE 2-2. INLAND SAR AGENCIES

Volunteer organizations responding to SAR include the Civil Air Patrol (an auxiliary group of the U.S. Air Force), ski patrols, mountain climbers, scuba divers, dog trackers, man trackers, jeep patrols, citizens band radio organizations, and Boy and Girl Scout groups. In the marine coastal environment, the Coast Guard Auxiliary is the primary source of organized volunteer assistance. Assistance is also provided by marine police and marine rescue organizations which principally supply divers.

Other SAR support requirements can usually be obtained by calling upon local police units, fire departments, and appropriate military or National Guard units.

Prompt notification of search and rescue units (SRU) can make a difference in the life or death of aircraft and ship occupants. Records indicate the life expectancy of injured survivors decreases as much as 80% the first 24 hours following an accident, whereas the chances of survival of uninjured survivors rapidly diminishes after the first 3 days.1/

The present methodology for handling distress incidents is delineated in Table 2-1. The request for SAR agency support is first validated by the Air Force Rescue Coordination Center (AFRCC) with the requester. A SAR mission is planned by the SAR Mission Coordinator (SMC) who is an official designated by the AFRCC. The SMC coordinates the SAR mission with the appropriate command authority and the assigned SRU and keeps the AFRCC appraised of the progress of the mission.

2.2.1 Inland/Alaska Region

In the inland region, general aviation accidents are the primary source of SAR incidents. Of the 10,016 incidents reported to the AFRCC during CY 1975, 6,603 were ELT signal activations. This is an average of 18 per day. Of these, only 2,114 were located and reported silenced to the AFRCC. An additional 241 AFRCC search missions were initiated for ELT signals only. Of these, 51 aircraft crash site finds were attributable to ELTs. Close to 1,100 flying hours were logged during the 241 AFRCC searches. By contrast, 284 AFRCC search missions were initiated for overdue or missing aircraft. Over 22,000 hours of flying time were logged during the 284 aircraft searches. The ELT initiated

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1/ "A Study of Search and Rescue Operations for Aircraft That Did and Did Not File VFR Flight Plans," AFRCC HQ ARRS, Scott AFB, Illinois, 1974.

TABLE 2-1

SAR FLOW CHART FOR INLAND AREA

SEQUENCE	ACTION
REQUEST	REQUESTER
FEDERAL ASSISTANCE	AFRCC
VALIDATION	AFRCC – → REQUESTER
PLANNING	AFRCC — → SMC*
COORDINATION	AFRCC → COMMAND AUTHORITY → SRU ** → SMC
LAUNCH	SRU
MISSION PROGRESS	SMC → SRU → AFRCC
REPORTING	AFRCC
CLOSING	AFRCC

* SMU - SAR Mission Coordinator

** SRU - Search and Rescue Units

searches reduced the flying time per mission by an average of seventeen to one. Assuming a reimbursable cost of operative CAP aircraft at $18 per hour, an ELT initiated search would have cost $81 (4-½ hours) vs. $1,386 (77 hours) for a non-ELT initiated search. If military aircraft are used in the search, the costs increase dramatically, from $100 to $1,000 per hour. Of the search missions initiated for general aviation aircraft in 1974, more than half involved aircraft whose pilots had failed to file a flight plan. There were nearly twice as many recoveries from missions with VFR flight plans as there were from missions with no flight plans.[2]

The excessively high number of false alarms (96 percent of those reported to the AFRCC) is jeopardizing the ELT system integrity by creating an apathetic response to ELT signals. The large number of inadvertent activations greatly reduces the capability to rapidly and effectively locate and terminate all signals, both distress and nondistress. Without complete and accurate information, the decision made in the AFRCC of whether to launch an airborne search with DF equipment or to conduct time-consuming airport checks for an inadvertent or a malfunctioning source, is an extremely critical one to make. A wrong or an untimely decision made can impact the response of SAR for the 2 percent of signals that are bonafide distress signals. Without a reliable monitoring and alerting system, this decision becomes a "judgment call" weighted by the experience of the SAR coordinator.

Major deficiencies exist in the present ELT system: transmitter malfunctions, equipment misuse, lack of DF equipment, and receiver coverage. Although most of these deficiencies could be overcome by educating the operator and improving the equipment, locating the source of the signal presents a far greater problem. Each ELT signal must be treated as a Mayday call until the source is located and proven otherwise.

Most ELT reports coming to the AFRCC originate from airborne traffic. These reports are forwarded to the AFRCC by air route traffic control centers, flight service stations, control towers, approach controls, or fixed based operators. Most often, several reports are needed to determine the signal source owing to the lack of DF equipment on the majority of civilian aircraft. This problem is compounded by the fact that approximately 90 percent of the

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[2] Ibid.

ELT activations occur on or in the vicinity of airports. The majority of airports are not equipped to detect or locate ELT emissions in order that they may be silenced. In densely populated areas, there are generally many airports from which the signal could be emanating. Owing to the low power outputs and line-of-sight transmissions limitations, remote areas of the United States are not monitored by existing receiver stations.

A high percentage of airplane crashes occur in the remote, rugged areas where the terrain increases the difficulties in locating rapidly the ELT signal by traditional means. A downed aircraft with survivors in this environment may not be located by ground stations because of the line-of-sight shielding by terrain features and/or consequent multipath problems.

When extreme weather conditions are the primary or contributing cause of the air crash ELT activation, the use of general aviation aircraft for search may be severely curtailed because they would be subjected to the same weather that caused the original crash. These weather-caused delays may extend the SAR operations past optimum time for recovery of possible survivors of the crash.

There is a nationwide need to improve the capability to electronically locate ELT signals. A system is needed which will not only monitor ELT signals for the entire area of the United States, but also help localize and identify false alarms. Such a system would greatly increase the effectiveness of the SAR system and reduce operational costs. Additionally, to provide a viable ELT system, it is absolutely essential that the false alarm rate be reduced.

In a May 20, 1976 memorandum from Col. R. Dreibelbis, USAF Director, Inland SAR regarding the recent success with ELT missions (full text is given in Ref. 6, Appendix A), he stated:

> "It is becoming increasingly apparent to the Air Force Rescue Coordination Center (AFRCC) that Emergency Locator Transmitters (ELT's) are working better and are contributing to quicker finds of aircraft crashes, the saving of lives, and a reduction of flying hours necessary for search missions.

> "From 1 January 1976 through 30 April 1976, the AFRCC has coordinated air or ground searches for 54 civil aircraft. Twenty (37%) of these aircraft were located by operating ELT equipment; nineteen people survived these accidents, and hundreds of search hours were avoided. This is a significant improvement over previous ELT experience and may indicate a turning point in equipment reliability. This success rate, if continued, should increase pilot confidence in the system and motivate increased ELT reporting throughout the aviation spectrum."

Table 2-2 shows the current ELT/EPIRB characteristics. It can be seen from the table that the current transmitters are relatively low in power. The 121.5 MHz and 243 MHz frequencies are shared bands with aeronautical voice emergencies.

TABLE 2-2
EXISTING ELT/EPIRB CHARACTERISTICS

PARAMETER	
RF SIGNAL	
• TRANSMITTER POWER	75 MW AVG.
• TRANSMISSION LIFE	48 HOURS
• FREQUENCY	121.5/243 MHz
• FREQUENCY TOLERANCE	50 PPM *
• POLARIZATION	VERTICAL
MODULATION	
• SWEEP RATE	2–4
• RANGE	1600–300 Hz (AT LEAST 700 Hz)
• MODULATION TYPE	AM
• MODULATION FACTOR	85%
• DUTY FACTOR	33% TO 55%

* Parts per million

2.2.2 Maritime Region

The existing high seas maritime distress system has evolved principally from the techniques and frequencies internationally adopted for public correspondence (e.g., business and personal communications).[3] As a result, the present distress frequencies in the various maritime service bands are shared with ship-to-shore calling procedures to establish a communications circuit. This arrangement induces coastal and ship radio station operators to monitor the appropriate frequency(ies) and conventionally allows international standardization and agreement upon which to base a high seas distress system.

Distress on the high seas can involve aircraft as well as ships. Although most SAR cases in the maritime region involve ships, a smaller number of aircraft have been the subject of SAR cases. High seas SAR cases represent about 3 percent of the Coast Guard workload. While it is generally true that the high seas area offers potentially more severe, and often more sensational, types of maritime disasters, the problem, from a SAR systems viewpoint, is not on the high seas, but clearly in the coastal areas.

A review of the SAR case summaries over the past three years reveals that the problems usually encountered are getting adequate resources to the scene in a timely fashion under various weather/sea conditions. Merchant and commercial vessels normally have adequate communications equipment. Such vessels know their navigational positions fairly accurately, report to shore on a regular schedule, and have the capability to control minor casualties.

When a maritime incident involving a large commercial vessel does develop on the high seas, it normally is of the "severe" category, and the vessel is in bad shape when the distress call is sent. Historically, the Coast Guard encounters three to four maritime disasters a year, with the vast majority of these incidents involving hazardous cargo and/or heavy weather conditions (floundering, shifting cargo, etc.). Most vessels can execute distress calls and provide their approximate position. The search effort is minimal unless the ship goes down.

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[3] For this report, it is assumed that the majority of incidents within the coastal region will not involve ELT/EPIRB's. Should an incident occur with an ELT/EPIRB within that region, it would, of course, be received and acted upon.

Worldwide communication networks are the traditional alerting means. Exceptions do happen where the situation develops so fast that no distress call is transmitted. For example, the sinking of the SS TEXACO OKLAHOMA (March, 1971—tank ship broke in two off Cape Hatteras due to structural failure - loss of 31 lives) and the SS V.A. FOGG (February, 1972—tanker exploded off Texas coast - loss of all hands). While EPIRB's can minimize the search effort in these cases, they usually could not have saved the vessel.

The "high seas" SAR problem is not well defined. While there are classic examples of newsworthy maritime disasters involving mammoth search efforts and considerable loss of life and property, their rate of occurrence on the high seas is not very great. The number which occur annually within the Coast Guard's traditional maritime area of responsibility is even less. However, major maritime disasters do happen, and when they do, a substantially greater rescue effort is required in terms of time on sortie and the number of assisting resources.

Coast Guard communications and many commercial coast radio stations monitor the international distress frequencies in which the station handles traffic. These stations form a network providing coverage extending to approximately 600 km offshore on the radio telegraph distress, for a safety and calling frequency (500 KHz); for 150-250 km on the radio telephone distress frequency (2182 kHz), and for 40-100 km on the international VHF-FM distress frequency (156.8 MHz). In general, U.S. merchant vessels greater than 300 gross tons and foreign vessels of like size on international voyages are equipped with transmit and receive capability of either 500 kHz, 2182 kHz, or both. A continuous radio guard is required either by an aural watch or an automatic alarm detecting device.

The acknowledged limitation of the present high seas maritime distress system is communications coverage. The frequencies mentioned above plus the international life-boat frequency (8364 kHz), and the aeronautical emergency frequencies (121.5/243 MHz) form the basis for the present system. All these are limited by power, sky wave propagation dependency or line-of-sight constraints. Delays of hours have been reported in attempting to establish communications with a ship due primarily to propagation conditions and availability of the radio watch officer. As a recourse should the ship's installed equipment fail during a distress condition or have to be abandoned because of danger to personnel, survival radio equipment and EPIRB's attain only a very limited range. This is about 40 km or less to alert a passing ship and 250 km or less to alert an over-flying aircraft.

Based on statistics published by Lloyds of London, approximately 350 vessels are lost worldwide each year. Vessel disasters are not necessarily a daily occurrence, however, and the number which involve United States shipping or which occur within the confines of the U.S. maritime SAR regions is a minor fraction of the worldwide total. However, when a major vessel distress incident occurs, a sizeable crew and cargo can be imperiled. Past failure to successfully execute rescue in these cases has raised considerable public concern both nationally and internationally about the adequacy and effectiveness of the DAL techniques available to the mariner on the high seas.

EPIRB detection coverage provided by oceanic air traffic can be estimated from the major aircraft routes shown in Figures 2-3 and 2-4. The shaded area indicates the amount of ocean which would be swept by over flying aircraft on scheduled routes. The number of flights is also indicated. Although no systematic evaluation has yet been made to determine the probability of aircraft overflight for any particular ship position, clearly this monitoring alternative, when compared to the general distribution of shipping as depicted in Figure 2-5, has areas where an EPIRB could not contribute an alert.

Effective March, 1975, certain U.S. vessels were required to carry Coast Guard approved EPIRB's as part of their livesaving equipment. The new EPIRB rules apply to inspected vessels engaged in ocean and coast-wise service in the following categories: tank, passenger, and cargo vessels; and oceanographic vessels. The only exemption allowed applies to a coast-wise vessel whose certificate of inspection is endorsed for a route that does not extend more than 20 miles from a harbor of safe refuge; but only if that vessel carries a VHF radio-telephone that meets FCC requirements. About 1,900 U.S. vessels must carry the 121.5/243 MHz EPIRB.

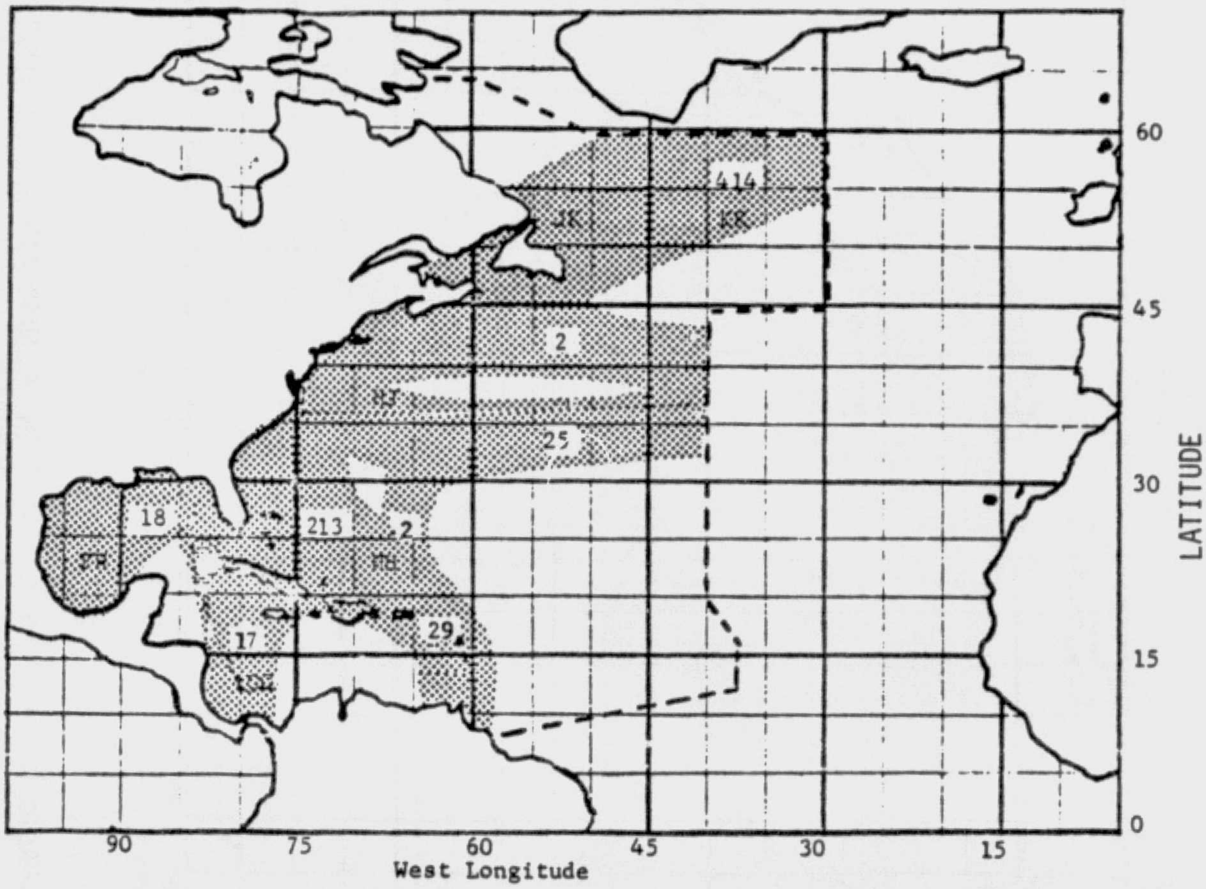

FIGURE 2-3. RADIO COVERAGE OF AIRCRAFT ON OCEANIC AIR ROUTES WITHIN SAR ATLANTIC REGION

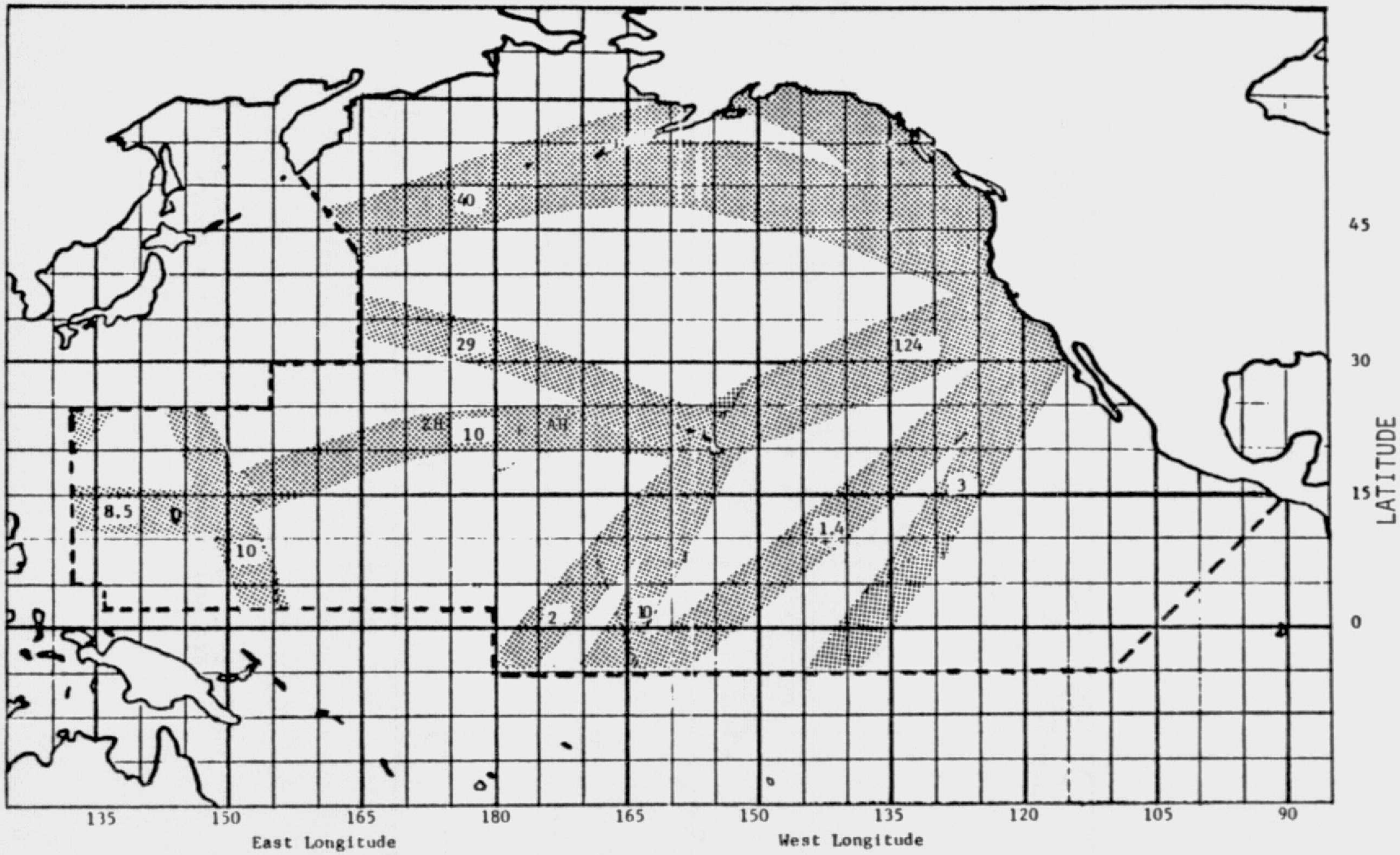

FIGURE 2-4. RADIO COVERAGE OF AIRCRAFT ON OCEANIC AIR ROUTES WITHIN PACIFIC SAR REGION

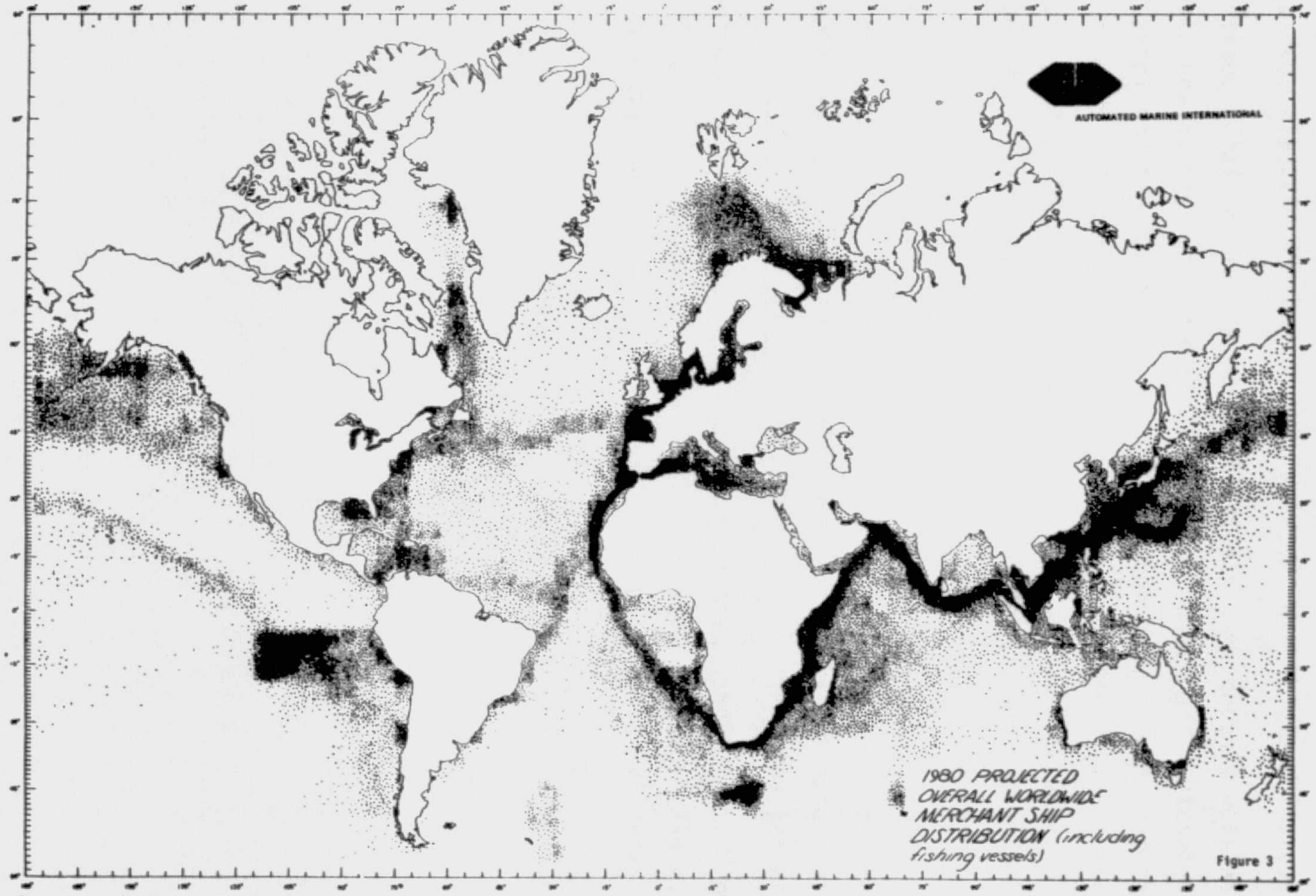

FIGURE 2-5. 1980 PROJECTED OVERALL WORLDWIDE MERCHANT SHIP DISTRIBUTION

Although present regulations do not require EPIRB's on uninspected vessels, FCC regulations permit, and the Coast Guard strongly encourages, their use by all vessels operating on the high seas beyond VHF distress coverage.

Direction finding nets are available to assist in fixing positions of distress broadcasts. The FCC operates a multiple purpose medium and high frequency DF net that may be used for SAR purposes. The FCC net considers SAR as its number one priority mission during an actual SAR case. The net operates between 300 kHz and 48,000 kHz. It covers the inland United States, Pacific Ocean, and Atlantic Ocean. Area coverage is limited by the range of whatever frequency is involved.

The Navy operates a military high-frequency DF net that may be used by the SAR system. The net has a frequency range between 3,000 kHz and 30,000 kHz, and covers both the Atlantic and Pacific Oceans. The distress frequency of 500 kHz is not covered.

The U.S. Air Force also operates an HF/DF net. This is interfaced with the Navy net. When the Navy net is alerted for SAR, the Navy will routinely alert the USAF HF/DF net. Results achieved are returned via the Navy net.

3. ADVANCED CONCEPTS TO IMPROVE DAL OF ELT/EPIRB'S

In this section, examples of future technology will be examined for DAL of ELT/EPIRB's. Many of these concepts have not been studied in depth, but are discussed to provide a number of alternative approaches. The potential of advanced concepts to improve DAL can be categorized as follows:

Terrestrial:
- ELT improvements (power, reliability, situation coding)
- Monitoring improvements (additional monitoring sites, improved DF equipments, improved receivers)
- Terminal homing (improved portable DF equipment)

Aircraft:
- Compulsory commercial aircraft monitoring, improved search aircraft, DF equipment, improved aircraft receivers

Satellite:
- Monitoring alert warning and position location services with world-wide, short interval coverage

Any concept to improve the aircraft DAL problem must address the ELT, its current situation, and any necessary improvements.[1] For this

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[1] A detailed discussion on this topic is given in the Satellite-Aided Search and Rescue Panel Report, Easton, Maryland, May 1975, published by Goddard Space Flight Center.

examination, the ELT must be discussed as a system consisting of a transmitter and a receiver, and the operational interface between the two.

Existing ELT (transmitter) problems are centered in two areas: the failure of the ELT to activate in a crash situation and the inadvertent actuation of the ELT when a distress situation does not exist. These two problems are currently being addressed by a Special Committee of the Radio Technical Commission for Aeronautics. This Committee will forward recommendations for the revised minimum performance standards (MPS) for ELT's to the FAA. In addition to technical recommendations on the MPS, the Committee is expected to forward follow-on recommendations, which are considered outside the normal scope of the Special Committee work. These recommendations will address the total ELT system and suggest improvements in the areas of ELT awareness, monitoring, signal location (both distress and nondistress), installation, maintenance inspection, and a continuing R&D improvement program. The revised MPS are expected to specifically deal with such areas as batteries, temperature tolerances, automatic actuation devices and their associated parameters, antenna and installation methods. At present, the Committee's report awaits test data on ELT acceleration forces from the FAA.

3.1 TERRESTRIAL

The 1975 year-end total of aircraft landing facilities in the United States was 13,251. Of these, 8,678 were privately-owned landing facilities and 4,573 were publicly-owned facilities.

If a new ground based DAL network were developed, it would monitor the emergency frequencies - 121.5 MHz and 243.0 MHz. The network could consist of automatic detection and DF equipment with an automatic telephone dialing unit associated with each installation to report directly to the appropriate SAR facility. This DAL network would include installation at all aircraft landing facilities and at selected high terrain or towers in strategic locations.

Considering the line-of-sight characteristics of the emergency frequencies, the nominal maximum radio horizon is directly related to the antenna heights, i.e., at 1.5 m this is approximately 5 km, at 15 m approximately 16 km, at 915 m approximately 125 km. If all airport network antennas were at 15 m, the area with a 16 km radius of each airport would receive adequate DAL coverage; discounting signal reflection and attenuation. An advantage of such a network would be rapid detection and location of those ELT signals, both false and actual, emanating from within the 16 km radius around each airport. This system would provide advantages that would proportionally increase according to the number of installations and antenna heights of other strategically selected sites. Disadvantages of such a system are:

a. The limitation in DAL local coverage due to signal reflection and ground attenuation.

b. The excessively large number of sites needed to provide DAL coverage (assuming line-of-sight transmission, approximately 11,300 antennas 15 m high would be required to completely cover CONUS).

c. The significant costs associated with equipment procurement, installation and maintenance for such a ground based network. If each installation cost $100,000, an initial outlay of over $1 billion would be required for CONUS coverage.

Since it has been shown statistically that nearly 90 percent of all ELT false alarms occur at landing facilities, the FCC is considering proposing rules which would require mandatory monitoring on 121.5 MHz by all FCC licensed Unicom stations (30 percent of uncontrolled landing fields have licensed Unicom stations). Such monitoring could be performed with inexpensive equipment adequate enough to provide coverage of the immediate area of landing facility. Thus, ELT false claims could be immediately detected.

There are approximately 277 DF units installed at FAA ATC facilities. This equipment was designed many years prior to development of the ELT. Its mode of operation was determined by electronic techniques then available and the purpose for which it was intended, i.e., to aid airborne aircraft. It must rely upon a continuously radiated signal with or without modulation. In addition, its sensitivity is directed to receive signals from aircraft in flight.

All the above features coupled with the ELT low power transmissions, signal line-of-sight limitations, reflections and ground attenuation make this DF network of very limited value as a DAL system.

The FAA has provided airway facility personnel with a small portable DF receiver to rapidly locate inadvertent ELT signal radiations emanating from aircraft on airports where there is an FAA presence. This effort is directed primarily toward rapidly locating and silencing these false alarms which degrade the intended functions of the emergency frequencies. Additionally, locating and identifying false alarms avoids activating extensive search missions.

3.2 AIRCRAFT

Airborne ELT monitoring in the contiguous 48 states consists of military overflights (243 MHz), FAA Flight Inspection aircraft, and pilots (both air carrier and general aviation) voluntarily guarding the emergency frequencies. Airborne ELT signal reports are forwarded to the AFRCC or other responsible agencies by FAA Air Route Traffic Control Centers or Flight Service Stations. Approximately 700 FAA facilities monitor the emergency frequencies. Because of line-of-sight characteristics of VHF/UHF ELT's, any monitoring system must be predominately airborne to be effective.

Downed aircraft location, if unknown, can be most effectively achieved (if the ELT is working) by airborne DF. Existing airbonne DF capabilities include the services of: the Air Force, the Coast Guard, FAA Flight Inspection Aircraft, the Civil Air Patrol (CAP), and SAR organizations and agencies. Air Force and FAA SAR resources are few in number and geographically dispersed. They provide SAR forces on a non-interference basis with their primary mission. The availability of Coast Guard search units in inland SAR is limited. As of January 1976, AFRCC records indicate that the CAP has 266 DF-equipped aircraft. Only 90 of these are capable of instrument flight.

Portable DF equipment is used by ground SAR teams to determine the location of downed aircraft when only a general search area has been defined by reports of airborne DF. There is a lack of sufficient ground DF equipment available to responsible agencies and organizations.

Any advanced "listening" system must be: (1) airborne; (2) organized and complete in coverage; and (3) rapid in reaction time. An FAA advanced proposal to require FAR Part 121 operators (air carriers) to carry an ELT monitor device by July 1977 is the only known plan to improve the DAL problem with aircraft. Reference 7 in Appendix A presents comments by the Air Transportation Association (ATA) relative to the Regulatory Proposal 446, FAR 121 concerning ELT alerting devices. The ATA opposed the FAA proposal as not being justifiable and estimated the costs of such a system to be $12.5 million initially and $3.75 million per year to maintain it. Appendix B presents comments by aircraft operators and pilots relative to FAR Part 121. This device would include a visual and an audio indication to the pilot that an ELT signal was radiating.

Although an improved airborne ELT monitoring system would greatly enhance today's coverage and provide the service at a reduced cost as compared to a new and expanded terrestrial SAR monitoring system, it would not provide adequate coverage in the mountainous and remote regions of CONUS and Alaska. Moreover, this system would provide only for the monitoring and alerting of ELT incidents and would not provide precise position location, a necessary requirement for rapid rescue and recovery operations.

3.3 SATELLITES

To meet the alert warning and location requirements of SAR, two basic satellite systems are possible: (1) spacecraft at synchronous altitude, and/or (2) spacecraft at nonsynchronous altitude. Depending on the satellite orbit type, position location techniques that can be used are: (1) the ELT distress signal that implicitly contains the position information (position location must be extracted from the signal); or (2) the ELT distress signal that explicitly contains the position information. Figure 3-1 shows the various measurement techniques that can be considered as possible candidate position location options for a SAR-aided satellite system. It can be seen from the figure, that many of the same position location techniques can be used for both a synchronous as well as a nonsynchronous satellite system

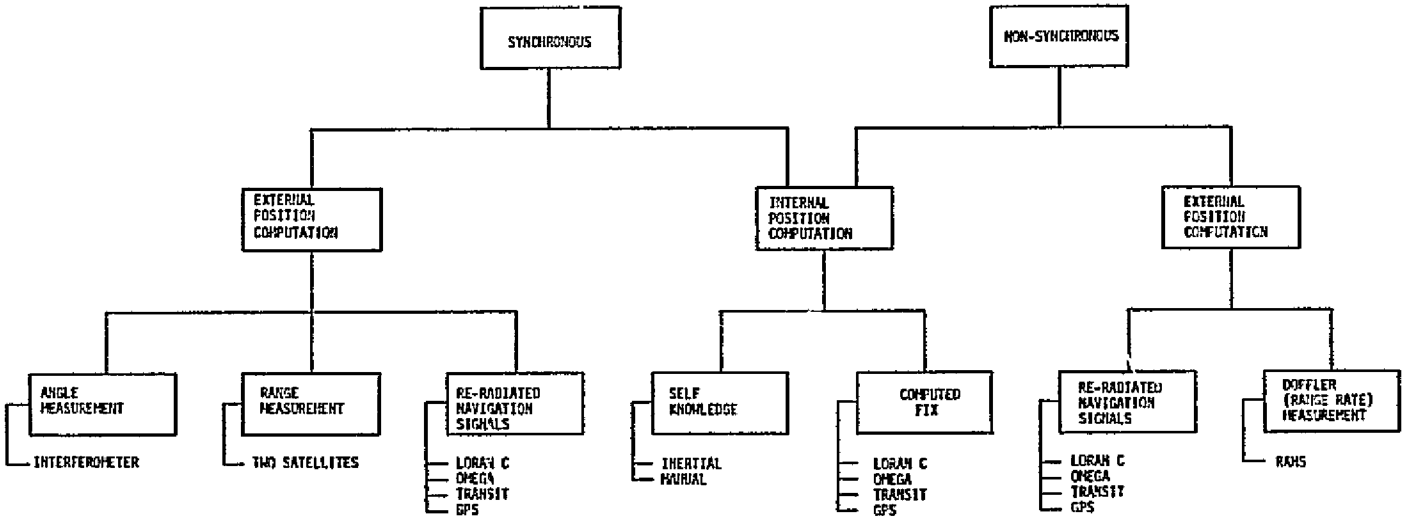


FIGURE 3-1. POSITION LOCATION OPTIONS

(i.e., LORAN C, TRANSIT, etc.). Other position location techniques are unique (i.e., a doppler measurement system to define position location can only be accomplished by a low orbiting satellite system).

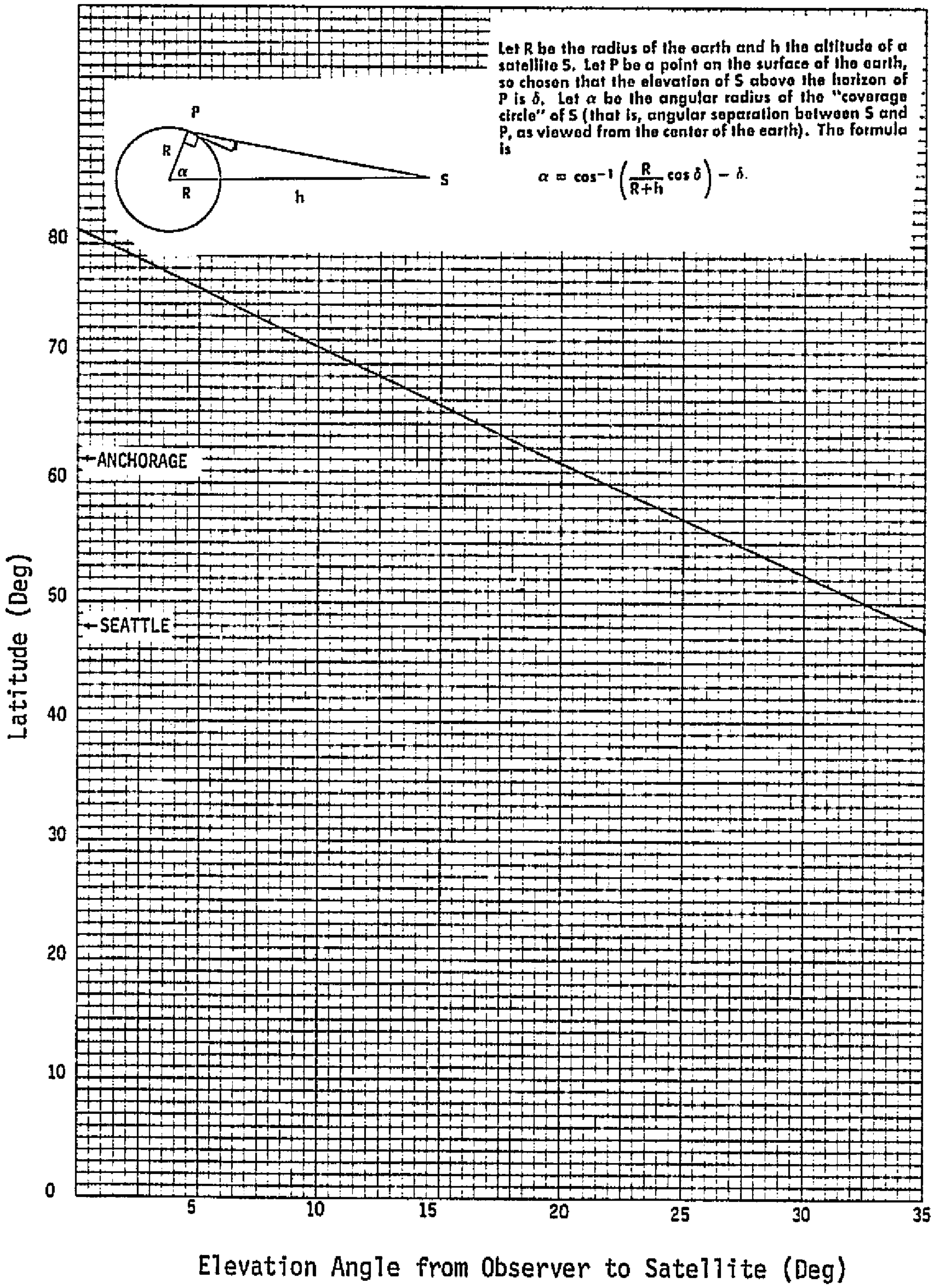
This section will discuss ground coverage capabilities for both the synchronous and nonsynchronous satellite systems, as well as each position location technique shown in Figure 3-1.

3.3.1 Synchronous Satellite Systems

3.3.1.1 Coverage. Although synchronous satellites can be launched into any desired inclination with respect to the equator, there are two preferred inclinations for synchronous altitude satellites: (1) 0°, also known as geosynchronous; and (2) inclined at 28.5° (due east launch from Cape Kennedy).

For the geosynchronous case, the satellite appears to remain stationary in space over the equator from a point visible to it on the earth's surface. For the SAR mission, such a satellite would provide continuous and instantaneous coverage for detection and notification of an emergency. Limitations in polar coverage relative to the ELT local elevation angle (as measured from the horizon) are shown in Figure 3-2. It can be seen from the figure that, practically speaking, Alaska as well as other polar regions cannot be serviced by such a satellite.

For the inclined orbit case, the satellite appears to move in a figure 8 pattern where the peak latitude obtained during the day occurs at precisely 28.5° every 24 hours. For the SAR mission, such a satellite would provide continuous and instantaneous coverage for detection and notification of an emergency for the lower latitudes. Once a day, when the satellite was near the peak latitude, service could be provided to Alaska (add 28.5° to the latitude scale in Figure 3-2). As an example, for a single synchronous satellite inclined at 28.5°, there would be continuous coverage for 50% of the time for an ELT located at a latitude of 70° with a local elevation angle of 10° as shown in Figure 3-3. If two such satellites were placed at the same altitude but 180° out of phase, the coverage time would double (100%).



Let R be the radius of the earth and h the altitude of a satellite S. Let P be a point on the surface of the earth, so chosen that the elevation of S above the horizon of P is δ. Let α be the angular radius of the "coverage circle" of S (that is, angular separation between S and P, as viewed from the center of the earth). The formula is

$$\alpha = \cos^{-1}\left(\frac{R}{R+h}\cos\delta\right) - \delta.$$

FIGURE 3-2. COVERAGE FOR A GEOSYNCHRONOUS SATELLITE

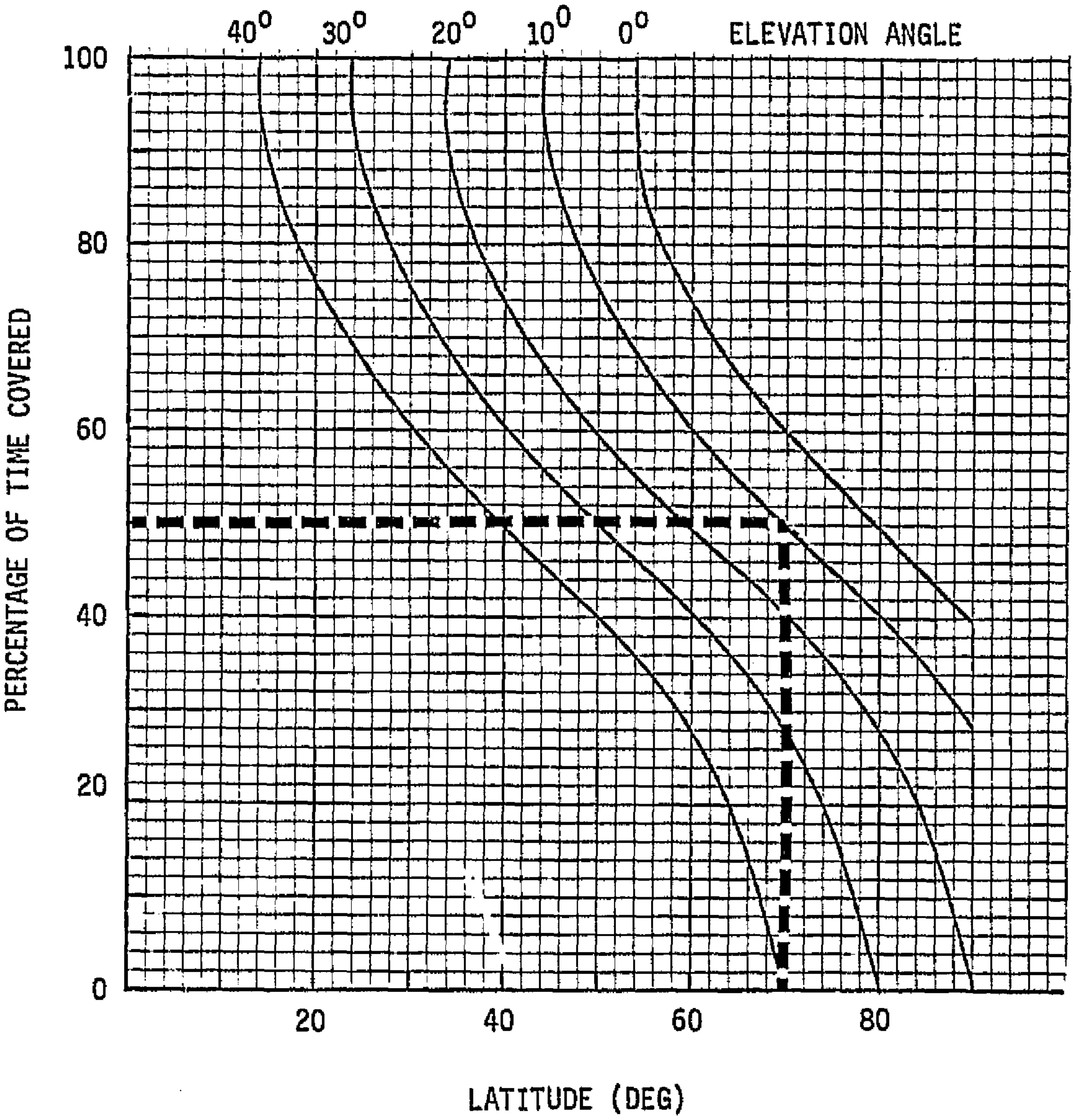


FIGURE 3-3 SYNCHRONOUS (28.5° INCLINED) SATELLITE GROUND COVERAGE

3.3.1.2 ELT Distress Signal Implicitly Contains the Position Information. In this method of position location, the position location function is performed externally to the ELT. As such, the system complexity is placed on the ground station signal processing and possibly the satellite transponder design, while the ELT design is simplified with no changes necessary for some measurement techniques. Figure 3-1 shows there are four potential methods for formulating position location externally: (1) re-radiated navigation signals; (2) range measurement; (3) angle measurement; and (4) range rate measurement. Table 3-1 presents examples of various position location types and measurement techniques. Only the first three methods are applicable to synchronous satellites. The fourth method, range rate measurement, can only be accomplished by a low orbiting satellite system and will be discussed in Section 3.3.2.

3.3.1.2.1 Angle Measurement (Interferometer). Precision angle measurements from a synchronous satellite have been demonstrated by the ATS-6 satellite with its C-band interferometer system. The interferometer is a phase measuring system which converts the received signals from two orthogonal antenna sets mounted on the satellite into electrical counts which are proportional to the cosine of the angles. The antenna sets are used to measure the rotation about their axes. Extrapolation of data from the ATS-6 experiment as well as data obtained by ground testing at L-Band (1600 MHz) indicates it may be feasible to measure position from synchronous altitude (beacon signal of 5 W would be required at L-Band). Additional studies and spacecraft demonstration experiments would be required to determine the feasibility of the technology required for this concept. Although this technique would require a simple, albeit new ELT transmitter, it would require a very large and complex satellite antenna system at the existing ELT frequencies. The antenna feed separation at 121.5 MHz and 406 MHz would be approximately 49.4 m and 14.8 m, respectively. Spaceborne technology for an interferometer operating in the 121.5 MHz-406 MHz frequency has not been developed.

3.3.1.2.2 Range Measurement. The Position Location and Aircraft Communciation Equipment (PLACE) experiment using NASA's ATS-5 and ATS-6 geosynchronous satellites has demonstrated the concept of position location by range measurements from pairs of satellites. The concept consists of side-tone ranging

TABLE 3-1
POSITION LOCATION TYPES

ORBIT	SYNCHRONOUS					NON-SYNCHRONOUS				
POSITION LOCATION	EXTERNAL POSITION COMPUTATION			INTERNAL POSITION COMPUTATION		EXTERNAL POSITION COMPUTATION				
MEASUREMENT TECHNIQUE	ANGLE MEASUREMENT	RANGE MEASUREMENT	RE-RADIATED NAVIGATION SIGNALS	SELF-KNOWLEDGE	COMPUTED FIX	RE-RADIATED NAVIGATION SIGNALS	DOPPLER (RANGE RATE) MEASUREMENT			
APPROACH								ADVANTAGES	DISADVANTAGES	APPLICABLE TECHNOLOGY
INTERFEROMETER	X							o REQUIRES ONLY A TRANSMITTER	o MOST COMPLEX SATELLITE USING SYNTHETIC APERATURE TECHNIQUES o VERY LARGE SATELLITE ANTENNA	ATS-6 INTERFEROMETER
RANGING		X						o MULTIPLE SIGNALS SIMULTANEOUSLY o VERY GOOD POSITION ACCURACY o NEAR REAL TIME RESPONSE	o REQUIRES TWO GEOSYNCHRONOUS SATELLITES o NEW ELT/TRANSCEIVER REQUIRING A)MORE PWR B)MORE OSC STABILITY	ATS-5 and -6 PLACE
LORAN-C			X		X	X		o VERY GOOD POSITION ACCURACY o NEAR REAL TIME RESPONSE FOR SYNC SAT o SIMPLE SATELLITE TRANSPONDER	o NEW ELT/TRANSCEIVER (COMPLEX) o NOT WORLD WIDE COVERAGE	U.S.C.G. DALS
OMEGA			X		X	X		o GOOD POSITION ACCURACY o SIMPLE SATELLITE TRANSPONDER o NEAR REAL TIME RESPONSE FOR SYNC SAT	o NEW ELT/TRANSCEIVER A) MORE COMPLEX o AMBIGUITY PROBLEM	GRAN
TRANSIT			X		X	X		o EXCELLENT POSITION ACCURACY o SIMPLE SATELLITE TRANSPONDER o NEAR REAL TIME RESPONSE FOR SYNC SAT	o NEW ELT/TRANSCEIVER A) VERY COMPLEX B) MORE POWER	NAVY OPERATIONAL SYSTEM
GPS			X		X	X		o BEST POSITION ACCURACY o NEAR REAL TIME RESPONSE FOR SYNC SAT	o NEW ELT/TRANSCEIVER A) VERY COMPLEX B) MORE POWER o NEW SYSTEM	FUTURE OPERATIONAL SYSTEM
INERTIAL				X				o SELF-CONTAINED POSITION LOCATION	o NEW ELT o REQUIRES COMPLEX EQUIPMENT	MILITARY AIRCRAFT OPERATIONS
DOPPLER							X	o USE EXISTING ELTs o COVERAGE AT ALL LATITUDES o SIMPLE SATELLITE TRANSPONDER	o COVERAGE NOT CONTINUOUS	NIMBUS RAMS

via satellite operating in the aeronautical L-band combined with aircraft altitude to produce circular line-of-sight positions (LOP) which contain the aircraft position and which are centered at the subsatellite points. The two LOP's intersect in two locations, one in the northern hemisphere, the other in the southern hemisphere. The resulting ambiguity in aircraft position is resolved by a priori knowledge of the aircraft's predefined flight path (northern or southern hemisphere). This position location method would not provide coverage for Alaska. The ELT/EPIRB equipment must have a receiver as well as transmitter to receive and retransmit ranging signals relayed through the two satellites from a central ground station where the position is computed. Because such a system would exclude the use of current ELT's and EPIRB's (power too low for synchronous altitude) and the lack of total area coverage, it is not a viable candidate for the near term system. A range measurement system using a low orbiting satellity system could also be employed; however, no apparent advantages over the doppler system would be derived from this approach.

3.3.1.2.3 Reradiated Navigation Signals. Figure 3-1 shows that the same four kinds of navigation signals that could be used for locally computing position location could, instead, be reradiated to a satellite. By reradiating the navigation signals, a potential exists for keeping the user equipment simple and low cost. Omega has been successfully retransmitted through synchronous satellites (Navy's GRAN experiment). But, the phase ambiguities have never been successfully resolved in night-time tests in spite of extensive analysis and retransmission tests from widely dispersed locations. Because of the technical difficulties involved in resolving the lane in which the distressed vehicle should be in, using the GRAN technique for position location, funding for this program has been discontinued.

Global Position System (GPS) signals are to be transmitted in a very wide bandwidth employing a double-nested code structure. Direct retransmission of this signal structure without signal processing is not feasible in the bandwidths available for satellite uplinks. Retransmission of navigation signals requires an appropriate receiver which adds cost, weight, and power drain in addition to the above problems.

3.3.1.3 Postion Information Explicitly Contained in ELT Distress Signal. In this method of position location, the navigation function is performed internally to the ELT. As such, the system complexity is placed on the ELT design while simplifying the satellite transponder design and ground station signal processing. Figure 3-1 shows that there are two potential methods of formulating position location internally: (1) self knowledge of position; and (2) position computed from received navigation signals. Table 3-1 presents examples of various position location types and measurement techniques.

3.3.1.3.1 Self-Knowledge of Position. Figure 3-1 suggests two ways in which self-knowledge of position can be obtained: (a) inertial, and (b) manual.

a. Inertial - would utilize aircraft inertial navigation equipment. A new ELT/EPIRB would be required. Inertial navigation gear is presently used in civil aviation aircraft and in ships.

b. Manual - would utilize knowledge of position such as visual or memory. A new ELT/EPIRB would be required. Position location may be unreliable or unavailable in the event that personnel were unconscious or physically unable to input the information into the units.

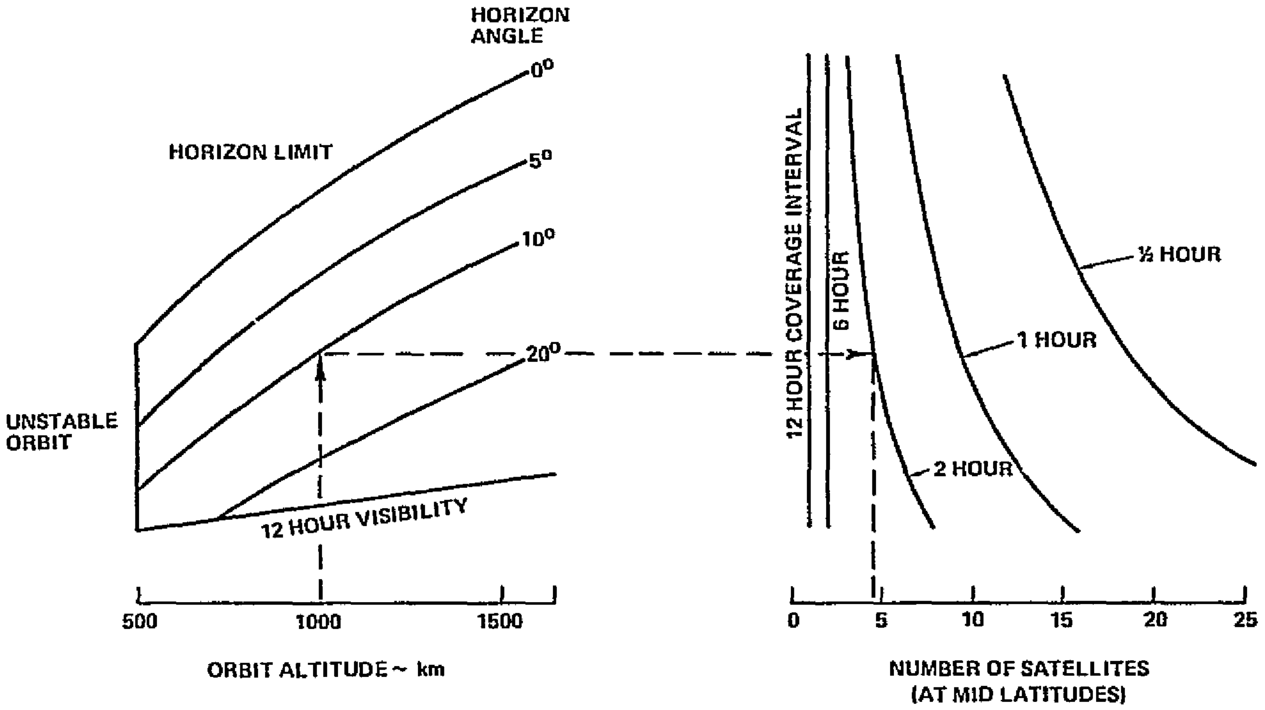
3.3.1.3.2 Locally Computed Navigation Fix. Figure 3-1 suggests four kinds of navigation signals that could be used for computing position location. Existing navigation signals with wide area coverage include OMEGA, LORAN-C and TRANSIT. Future potential navigation signals would be from the Global Positioning System (GPS). Good East Coast and Alaska coverage is available with LORAN-C; however, large gaps in coverage exist in inland and maritime regions. OMEGA signals contain periodic position ambiguities which are not resolvable with the existing signal structure and variations of night-time ionosphere. TRANSIT, although providing excellent position-location accuracy, requires a rather sophisticated computing system for determination of position location. Use of these methods for determination of position location by an ELT will require the new ELT to receive the signals, compute position location, and radiate this information to a satellite. The ELT would probably be complex (depending on the signal source selected) and more costly. Appendix C discusses various radiating position location systems.

LORAN C ground wave coverage cannot be obtained for large regions of the world including many deep ocean areas. Skywave coverage is sporadic and would add to the complexity of any computational algorithm which could result in large, random errors without preknowledge of position to discard erroneous fixes. Additionally, the ELT or EPIRB would require addition of a receiver and LORAN C processor. This would be a substantial monetary penalty compared to the relatively inexpensive ELT or voluntarily carried EPIRB. For the more expensive marine EPIRB's mandatorily carried by certain vessels, however, the cost increase might be about 25 percent or less. less.

3.3.2 Nonsynchronous Satellite Systems

Although satellites can be launched into any desired inclination with respect to the equator, the inclination selected is generally mission dependent. Since the SAR mission includes coverage of Alaska, and the instantaneous coverage for such a satellite is much less than for the synchronous satellite, the inclination angle must be large. For a polar-orbiting satellite (near or equal to 90°), the polar region will be provided coverage once every orbit (approximately 2 hours). For lower altitudes, coverage will be provided at least once every 12 hours. If two such satellites were placed at the same altitude but in orthogonal planes (90° to each other), coverage for the lower latitudes would be provided at least once every 6 hours. Three satellites whose planes are phased 60° apart from each other, would provide coverage at least once every 4 hours and so on, as shown in Figure 3-4.

Although most of the position location methods discussed for synchronous satellites (Section 3.3.1) are also applicable for low altitude satellites (see Figure 3-1 and Table 3-1), there is no inherent advantage in using these methods with a low altitude satellite over a synchronous satellite. The advantages of using low-orbiting satellites are that the doppler location technique can be used and coverage of high latitude and mountainous terrain can be achieved.



FOR A SINGLE SATELLITE	
Probability of Detection	Response Time, (hrs)
100%	12
80%	9
50%	5

FIGURE 3-4. DETECTION TIME VS. NUMBER OF SATELLITES (POLAR ORBITS)

3.3.2.1 Doppler (Range Rate) Measurement. Position location from a low orbiting satellite using doppler measurements has been successfully demonstrated by the NIMBUS-6 data collection experiment and TRANSIT. Theoretical analysis indicates that successful doppler measurement can be accomplished at satellite altitudes up to 1000 km using the existing ELT's and EPIRB's that are currently in the field. A single satellite in a 700-1000 km near polar orbit could provide complete coverage at least once every 12 hours. (Five satellites could provide coverage every 2 hours or less.) For this system the distressed user need only have a simple low power transmitter to permit a position to be obtained from a satellite. This particular method (doppler measurement) is the only known method of computing position location with the existing ELT/EPRIB's.

In order to gain experience in the use of satellites for ELT detection and positioning, an experiment using the Radio Amateur OSCAR 6 and OSCAR 7 satellites was developed by the NASA Goddard Space Flight Center (GSFC). The OSCAR satellites have an uplink receive mode operating at 145.9 MHz and a downlink 29.5 MHz. The downlink carrier introduces a degradation in the received ELT signal that would not exist in a system designed for SAR. These satellites are roughly at 1400 km in altitude and provide a satellite platform which is similar in altitude and receive frequency to that which might be used for an actual SAR satellite. An existing ELT was modified from the normal 121.5/243 MHz operation to 145.91 MHz operation with minor change to the crystal oscillator circuits in the ELT. This signal was clearly heard through the satellite relay link although insufficient time was available to obtain a doppler track. Preliminary results of testing conducted by GSFC during the latter part of 1975 showed beacon location recovery of about 10 km with the characteristic ELT warble clearly audible. These tests were carried out using an ELT retuned to 145.9 MHz and slightly amplified in power to about 0.5 W.

The Canadian Ministry of Defense has also performed SAR experiments with the OSCAR satellites and achieved similar results to that obtained by NASA.

3.4 CONSIDERATION OF OTHER EXISTING OR PLANNED SATELLITE SYSTEMS

This section provides a short description of the existing and planned satellites for the aeronautical and maritime communities. These satellites provide, as their main function, two-way communication services from a ship or aircraft to ground terminals. Additionally, the satellites are/will be placed in geosynchronous orbit in order to provide continuous and instantaneous communication services over the ocean areas and not over land. Existing ELT/EPIRB's could not be used since these satellites would not provide the means to determine position location which is a prime requirement for a SAR satellite system. Moreover, geosynchronous satellites cannot provide geographic coverage for the high latitudes. Additionally, although it is possible to determine position location from synchronous altitude by ranging techniques, two such satellites giving mutual visibility would be required.

In the future, however, these satellites can play an important role in SAR activities in several ways. These are:

a. The use of on board satellite communications equipment for communications via satellite. For MF/HF communications in the maritime region, a distressed ship or aircraft can advise of a distress and announce its geographical location, if known.

b. The use of a buoy carried by ships operating on the appropriate satellite uplink frequency is automatically energized as soon as it is immersed in water and transmits the call sign of the ship. If the ship has been participating in AMVER, a predicted location can be computed. R&D may result in additional techniques, such as interferometer, etc. Simultaneous transmission on other distress frequencies may be made for homing purposes.

c. Effective SAR involves not only DAL, but also requires adequate communications for SAR coordination. These future satellite systems have the potential to provide immediate communications between SAR participants thereby improving response time.

The international interest in development and tests for the use of such systems is exemplified by the ATS-6 SAR experiments made in 1974-1975. There was international participation in these experiments and the Federal Republic of Germany subsequently submitted a paper based upon the experiments to IMCO.

3.4.1 Maritime Satellites

The first commercial maritime satellite (MARISAT-1) was launched successfully on February 19, 1976, and is in geostationary orbit over the Atlantic Ocean at 15^{o} W. longitude. MARISAT-2 was launched on June 9, 1976, and placed above the Pacific Ocean at 176.5^{o} W. longitude. Real-time end-to-end connections between ships equipped with satellite communications terminals and the rest of the world is provided by two earth stations, one located on the east and one on the west coasts of the United States, and existing commercial or government telecommunications circuits to the intended destination. TELEX, a form of telegraph service, and high quality voice will be offered.

In addition to the MARISAT system, the European Space Agency (ESA) is developing the experimental maritime satellite MAROTS (MARitime Orbiting Technology Satellite), for launch in 1977. MAROTS will have limited operational capability and may eventually be located over the Indian Ocean to cover areas outside the MARISAT system.

Future maritime satellite communications will most likely be integrated and managed by the proposed International Maritime Satellite Organization, INMARSAT. INMARSAT will function in a parallel fashion to INTELSAT which provides point-to-point telecommunications services between points on land.

3.4.2 Aeronautical Satellites

AEROSAT is an international program sponsored by the United States (FAA), Canada, and ESA to develop, launch, and evaluate satellite systems for providing voice and data communications and surveillance to aircraft in oceanic areas. The purpose of the program is to provide data and other information required for international agreement concerning operating, configuration, and technical specifications for a possible follow-on operational system. The space segment will consist of two geosynchronous satellites and should be operational in the early 1980s. The satellites will use both VHF and L-band frequencies for communication services. As part of the AEROSAT, the FAA is planning a series of wideband technical tests which will serve as inputs to studies concerning the possible future use of constellations of satellites over the continental United States for communication and surveillance purposes. (Reference: AEROSAT - Current Status and the Test and Evaluation Program, - F. Carr, EASCON, 1975).

3.5 SUMMARY AND CONCLUSIONS

After examination of the factors discussed in this section, it is clear that synchronous and low orbiting satellites each has advantages:

1. Low orbiting satellites have the ability to see distress incidents at high latitudes and in mountainous regions, the ability to doppler track the existing ELT/EPIRB's, and provide DAL services within two hours or sooner of a distress over the total earth's surface.
2. Only low orbiting satellites can operate with existing ELT and EPIRB equipments currently carried by approximately 150,000 general aviation aircraft and 1,900 inspected marine vessels.
3. Synchronous satellites have the ability to provide continuous and immediate DAL over large areas of the earth's surface between 70° N and S latitudes.

The inland and maritime SAR regions each has its own set of requirements and considerations when considering satellite assistance for DAL.

1. Since the Government requires general aviation aircraft and inspected marine vessels to carry ELT/EPIRB's, the doppler method using low orbiting satellites emerges as the most viable system compatible with current ELT/EPIRB standards.
2. As a result of the large open water expanse and the type of environment of the maritime region, and the different nature of ocean distress incidents as compared to land, it is concluded that synchronous satellite DAL concepts show promise for the future.

Synchronous systems for DAL still require development and planning on an international scale with international aviation and maritime cooperation. However, it does appear that the basic technology presently exists through use of low orbiting satellites to respond to the serious problem which now exists in the inland region and Alaska.

4. SYSTEM DESIGN REQUIREMENTS

4.1 CLASS AND NUMBER OF USERS TO BE SERVED

Congressional legislation required general aviation aircraft to be equipped with a radio device which would emit a signal on the aviation distress frequencies 121.5 MHz/243.0 MHz upon crash or forced landing impact. The legislation which required these to be on board aircraft not later than July 1974, excluded 6 general types of aircraft:

a. Turbojet
b. Commercial air carriers
c. Agriculture, test, design and R&D aircraft
d. General aviation aircraft able to carry only one person on board
e. General aviation training aircraft which operate only within 50 miles of departure
f. Military aircraft (Note: most carry ELT's).

All other general aviation aircraft whether for business, pleasure, or charter are required to be equipped with an operational device. At present, and although an amendment to the legislation is pending, pilots must have an operational ELT aboard the aircraft, which creates a problem when the pilot's own ELT is inoperative. At present, there are about 150,000 aircraft equipped with ELTs. Based on a recent memo analyzing SAR incidents, the maximum number of SAR signals (both actual and false alarms) present at any one time in CONUS was 10.[1] A capability of handling 10 simultaneous ELT transmissions should provide an adequate safety factor.

Approximately 1900 U.S. vessels are currently under the mandatory regulations requiring the carrying of EPIRBs and limiting the EPIRB's transmit frequencies to 121.5/243 MHz. In addition to those vessels under the mandatory regulations, there are currently another 1300 (approximately) small passenger vessels whose routes require the carrying of EPIRBs or who may elect to carry them voluntarily. The radio characteristics of the aviation ELT and the marine EPIRB are identical. The differences, which are not of significant concern in designing an alerting and locating system around the devices, are: (1) for the ELT, automatic activation on impact by means of a "g-switch"; and (2) for the EPIRB, an ability to float free of the vessel and automatically activate.

4.2 SYSTEM DESIGN REQUIREMENTS

4.2.1 Coverage Area

Although the U.S. SAR responsibility as defined by the National SAR Plan includes the Inland (CONUS), maritime and overseas (including Alaska) regions, the primary emphasis on coverage, using the existing ELT/EPIRB's for the proposed satellite-aided SAR system, will be for CONUS and Alaska. The coverage for the maritime region could be provided by a new ELT/EPIRB unit with different design characteristics that could employ low altitude and/or synchronous satellite systems.

4.2.2 Alerting Time Delay

An alerting system should provide timely receipt of a distress call. Such an alerting system should provide adequate spatial and temporal coverage (nonexistent now) with a desirable time delay of less than one hour. However, a time delay of 1 to 4 hours would provide a meaningful and significant improvement over the existing system where notification of a distress situation is frequently delayed because of an inadequate monitoring system.

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[1] "Distribution of ELT Incident Reports," memorandum from G. Selz, Operations Research, Inc., to B. Trudell, GSFC, 12 March 1976.

4.2.3 ELT/EPIRB Identification

An identification symbol and employment of situation coding is desirable for the next generation ELT and considered mandatory for the next generation EPIRB. Such coding should indicate the severity and nature of the life or death situation, if out of gas, if disabled, and/or a situation requiring assistance only. Such information is desirable for rescue forces to furnish the appropriate response. Information provided on the description of the distressed craft will allow for an orderly, localized search to be performed. Knowledge of the color, size, class, and possibly survival equipment carried onboard the craft would provide for a systematic survey of the area. Acknowledgment of a survivor's distress signal can be at most comforting, but is not critical to successful SAR. A voice capability from the survivor to the rescue and recovery unit is also desirable. Even if the system can be made to accommodate these features, they should remain a user option because of the large retrofit problem.

4.2.4 Location Accuracy

The accuracy of pinpointing distressed vehicles directly affects the search time and the resultant savings of lives and property. Rescue operations involve two phases, initial position information on the distressed vehicle followed by localization normally accomplished by the rescue units. Initial position information of less than 10 km is adequate for land, coastal, and high seas operation, since most land and sea DF equipment can receive ELT/EPIRB signals at that distance.

4.2.5 Frequency Allocation

Present concepts for SAR assume terrestrial methods, (aircraft, airports, etc.) for detection, alerting, and locating. For ELT/EPIRB's, the frequencies designated for this purpose are 121.5 MHz and 243.0 MHz. Seen from a satellite, these frequencies have a potential RFI problem. Although the overall system design must be able to receive and process the existing ELT/EPIRB's presently in the field, the system should also allow for improvements and expansion of future ELT/EPIRB's. Appendix D addresses the frequency bands that the international radio regulations allow for possible use in connection with distress, safety, and emergency communications.

It is recommended that appropriate frequencies for the SAR satellite telemetry downlink and uplink be coordinated through IRAC.

4.2.6 Future Growth Capability

The present frequency band allocated solely for the use and development of low-power (not to exceed 5W) EPIRB systems using space techniques is 406-406.1 MHz. Operation at this frequency would provide a clearer channel with fewer interfering sources. With the incorporation of such features as identification coding, a new ELT with representative characteristics as shown in Table 4-1 will aid SAR efforts. Additionally, burst transmission techniques will allow higher ELT effective isotropic radiating power (EIRP) transmitters using the same power source as today's units as well as providing for a vast improvement in multiple access capability (up to 200 signals simultaneously). This type of new ELT/EPIRB would be used operationally to improve the satellite-aided system for CONUS and Alaska as well as provide coverage for the maritime region through the use of on-board satellite storage of ELT/EPIRB signals and forward dumping of the signals to a participating ground station. Internal or self testing of the 406 MHz ELT will be accomplished by a built-in operating unit. The new 406 MHz ELT would also be designed to operate with both low orbiting and synchronous satellites.

TABLE 4-1

NEW ELT/EPIRB CHARACTERISTICS AT 406 MHz

PARAMETER	NEW
RF SIGNAL	
• TRANSMITTER POWER	TBD (5 W max)
• TRANSMISSION LIFE	100 HOURS
• FREQUENCY	406 MHz *
• FREQUENCY TOLERANCE	20 PPM
• POLARIZATION	VERTICAL
MODULATION	
• MODULATION TYPE	ANGLE
• DUTY FACTOR	2%
EPIRB INFORMATION CODING	
• IDENTIFICATION	COMMERCIAL FISHING RECREATIONAL NAVAL OCEANOGRAPHIC
• SITUATION	FIRE/EXPLOSION FLOODING COLLISION GROUNDING LISTING, ENDANGER OF CAPSIZING SINKING ENDANGERED BY WEATHER DISABLED AND ADRIFT COMMUNICATIONS FAILURE-NO DISTRESS DISABLED BUT NOT IN IMMEDIATE DANGER

*Capability on 121.5/243.0 MHz will be incorporated to allow final phase location by the SAR forces.

5. POTENTIAL SATELLITE SYSTEM

5.1 INTRODUCTION

The immediate objective of a SAR orbiting satellite mission is to augment the existing SAR system capabilities to detect and locate ELT's and EPIRB's by significantly improving the distress monitoring coverage of the Continental United States (CONUS), Alaska, and the U.S. maritime areas, and by a significant improvement in the position location of the distressed incident. Figure 5-1 defines the area of responsibility of the National Search and Rescue Plan.

Early detection of downed aircraft and maritime distress incidents can reduce the overall SAR operation as shown pictorially in Figure 5-2. The advantage of using satellites to monitor large geographic areas holds great promise for reducing the time between occurrence and detection of a distress incident (awareness stage). In addition, the ability of a satellite system to provide a distress incident location position to within 10-20 km using the present ELT/EPIRB's and to less than 5 km for improved ELT/EPIRB's will improve the efficiency of mission planning and operational response.

5.2 SATELLITE SYSTEM

The use of satellites to detect and locate existing ELT's and EPIRB's requires signal acquisition and processing techniques emphasizing

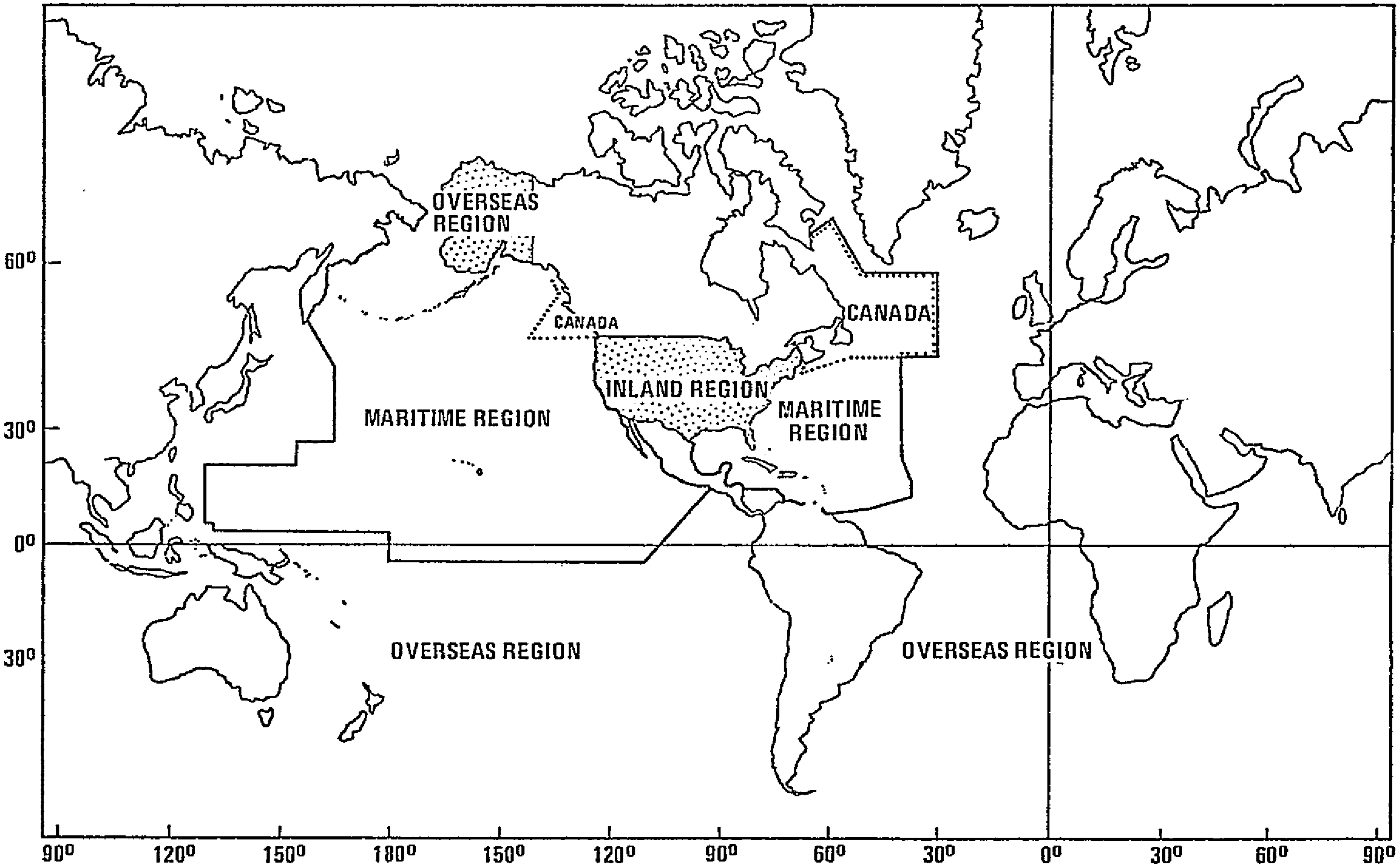
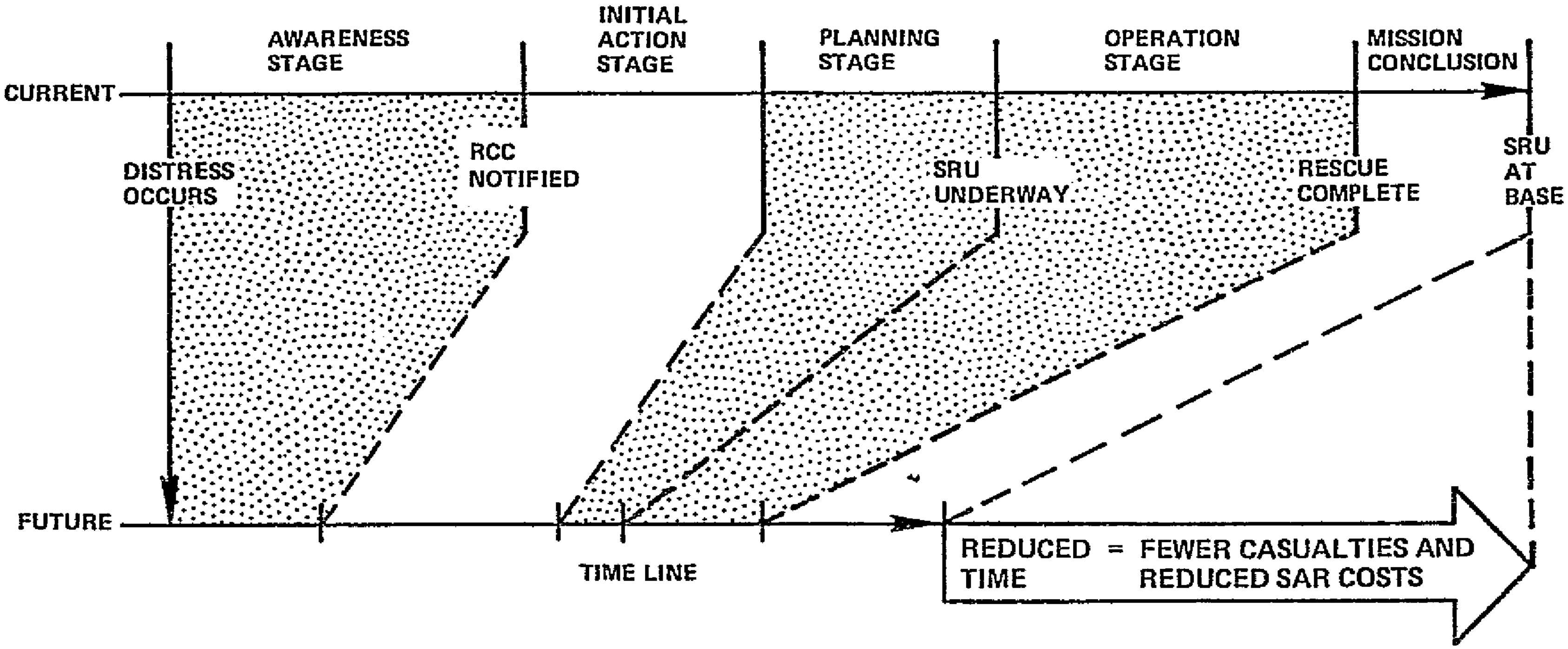


FIGURE 5-1. CHART-NATIONAL SEARCH AND RESCUE PLAN



R.C.C. – RESCUE COORDINATION CENTER
S. R.U. – SEARCH & RESCUE UNIT

▨ – OPERATIONAL STAGES WHERE SATELLITE WILL REDUCE TIME

FIGURE 5-2 SEARCH AND RESCUE OPERATIONAL STAGES current problems of low signal strength, poor frequency stability, and the variety of modulation techniques being employed. The operational system proposed (see Figure 5-3) is to use satellite-aided detection and location to fulfill the needs for alerting and locating "distress" for the SAR user community. The satellite system envisioned would be a near polar, 700-1,000 km orbit satellite which can detect and locate ELT's and EPIRB's that are currently in the field operating at 121.5/243.0 MHz. In addition, the satellite would carry a more advanced system which would operate with a new class of emergency transmitters on a frequency of 406 MHz. These new transmitters would access the satellite via a coded address and would provide an identification (I.D.) of the user as well as the capability for situation coding.

The ELT's and EPIRB's presently in the field will transmit their signals to the orbiting spacecraft. The spacecraft will relay the signals, in real time, to an earth station which will detect the signal using phase lock loop techniques and process the doppler information to determine position location. The data will then be relayed to the nearest rescue coordination center where the SAR forces will be alerted and deployed. These SAR forces can then use the same emergency transmitting signal for the final phases of the SAR mission. The position location capability of the satellite-aided system will give a distress situation location to an accuracy of about 10-20 km which is well within the SAR force detection range.

Signal processing of the "new" distress transmitters at 406 MHz would be done on-board the satellite. The satellite would look for and accept only valid RF transmission and then subsequently read the I.D. and doppler track the signal. The doppler data, time tagged and including the I.D., would be transmitted simultaneously as part of the satellite telemetry data while at the same time the data would also be stored on-board the satellite using a solid-state memory. This approach would then allow for receiving signals when the satellite was not in view of a ground terminal and readout of the data by command from a ground station. In either the real-time or stored data mode, the data would be used by the small terminal to compute

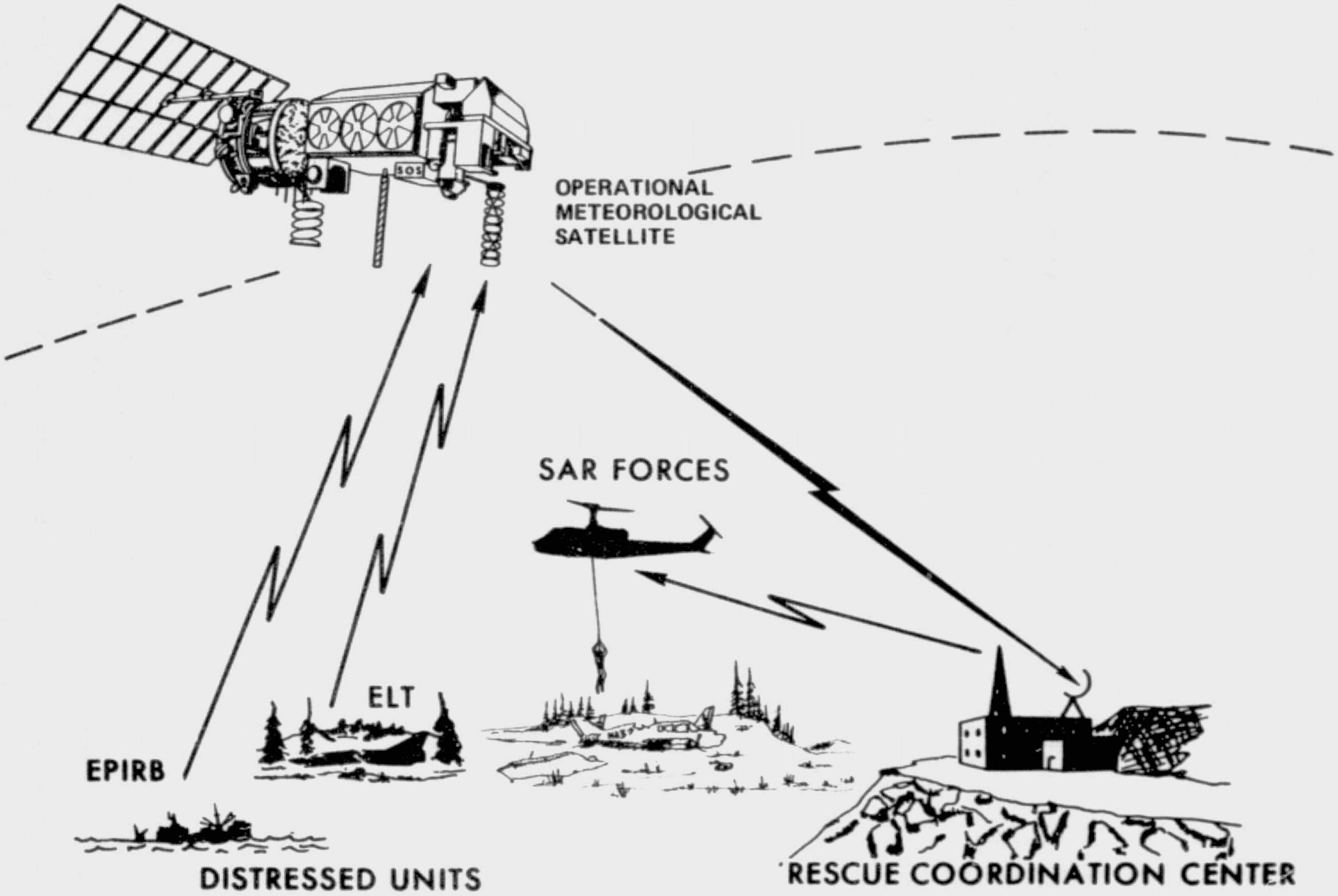


FIGURE 5.3. SEARCH AND RESCUE SATELLITE SYSTEM CONCEPT

the position of the distress, identify the user and display any message concerning the distress situation (e.g., ship on fire, sinking, or medical emergency). Inclusion of this capability would allow for the gradual phase-in of the "new" ELT/EPIRB's as new equipment is bought for new users or for replacement purposes.

Inherent in the proposed satellite system is the ability to not only detect ELT/EPIRB signals from a wide area coverage, but also to locate the position of the ELT/EPIRB by doppler tracking techniques. A well known operational system that uses the doppler shift in the satellite signals for position location is the TRANSIT system developed for the Navy. Details of the TRANSIT system are discussed in Appendix C.

The satellite-aided SAR system consists of the ELT's and EPIRB's, the satellite, the ground terminals, and the existing rescue coordination centers. The interface relationship among the various segments of the total system is shown in Figure 5-4. The satellite command and control center will be located in Alaska providing maximum contact with the satellite polar orbiter. The ELT/EPIRB location data will be sent from the ground stations to appropriate rescue coordination centers. For the satellite system proposed, the satellite downlink composite signal would be demultiplexed at the ground station. Each ELT/EPIRB signal would then be individually processed to extract the appropriate segment containing position location information before being fed to a minicomputer called the Doppler Position Processor. Within five minutes after the ELT/EPIRB signal is first detected by the ground terminal (including four minutes of doppler tracking), the location data will be displayed at the ground terminal control console for subsequent forwarding to the appropriate rescue coordination center.

Signal processing for the current ELT's and EPIRB's would be accomplished at small ground terminals located at or near rescue coordination centers. The small terminal concept would use a small 1.5-3.0 m diameter dish antenna driven automatically to track the satellite by a minicomputer program. As the satellite is in view of both the distress transmitter and the ground terminal, the ELT/EPIRB signal would be detected and phase lock-loop tracked to extract the doppler data which would then be used to calculate the position of the distress incident.

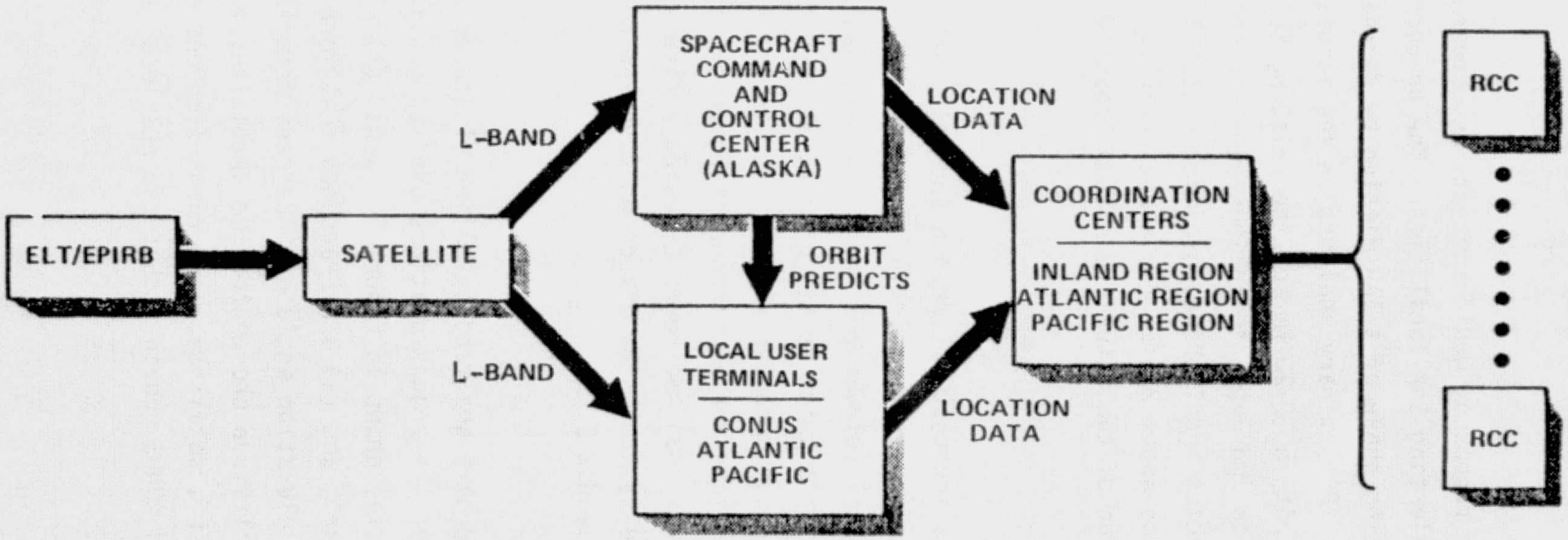


FIGURE 5.4. SEARCH AND RESCUE SATELLITE SYSTEM BLOCK DIAGRAM

The satellite system, as proposed, would augment, as opposed to change, the existing methods of alerting SAR facilities. The proposed system would improve, however, the alerting phase of a SAR mission by decreasing the time of detection of an incident. Preliminary analyses on the accuracy of determining position location is within 10-20 km for the existing ELT/EPIRB's at 121.5/243 MHz frequency. Due to improvements in ionospheric propagation characteristics at higher frequencies and improved oscillator stability, location accuracy should improve to about 2-5 km for a new ELT/EPIRB operating at 406 MHz. A detailed description of the satellite system proposed is contained in Appendix F.

5.3 COVERAGE AREA

The time between distress incident occurrence and detection by a satellite depends on a number of parameters including satellite orbit altitude and inclination, ELT/EPIRB local (elevation) horizon angle, and number of satellites in the system. A single polar orbiting satellite system will be able to guarantee coverage at least once every 12 hours. In the example shown in Figure 3-4, the detection time for a polar-orbiting satellite system can be reduced from 12 hours to less than two hours by using a five-satellite system rather than a one-satellite system. The effect on coverage due to ELT/EPIRB latitude is discussed in Appendix E.

5.3.1 CONUS and Alaska Regions

Studies conducted to date have analyzed satellite altitudes ranging from 700-1,000 km. The location of the ground stations used to provide coverage for the U.S. (CONUS and Alaska) shown in Figure 5-5 are: (1) Elmendorf AFB, Alaska; (2) St. Louis, Missouri; and (3) San Francisco, California. The coverage contours assume a ground elevation angle of 5 degrees from the horizon (sea level). For the 850 km altitude chosen for the satellite, simultaneous coverage is provided between the ELT, satellite, and ground stations at least once every 12 hours for Alaska and CONUS provided that the ELT local elevation angle is less than 20 degrees.

5.3.2 Maritime

Analysis of the maritime area was conducted for a satellite altitude of 700 km to provide worst case coverage conditions. A large number of

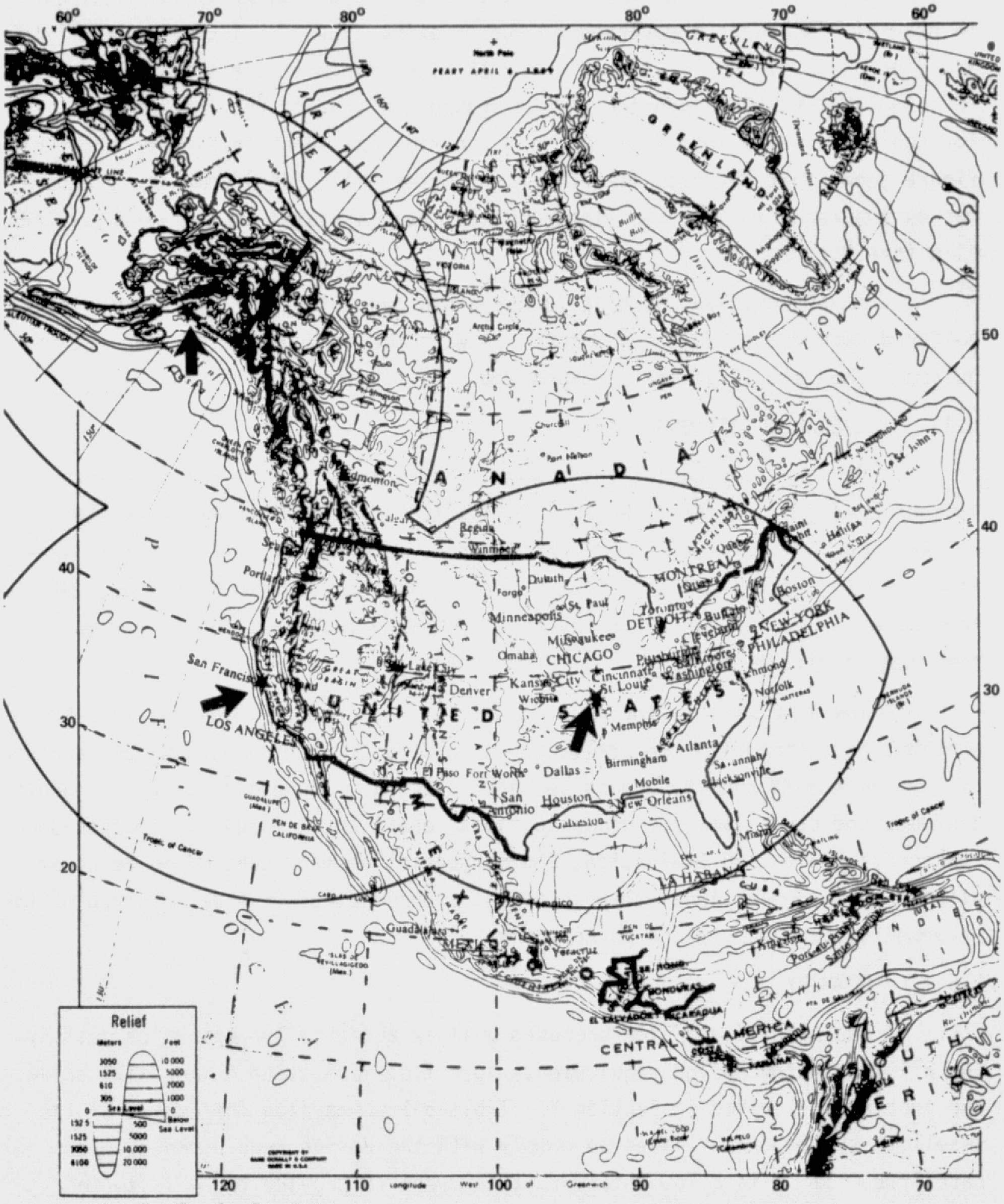


FIGURE 5.5. GROUND COVERAGE CONTOUR FOR 850 KM SATELLITE

ground stations (10 in the Pacific and 3 in the Atlantic) would be required to provide simultaneous coverage of the existing type of ELT/EPIRB, satellite, and ground station at least once every 12 hours for a single satellite doppler locating system. The location of the ground stations to provide coverage for the maritime regions (Atlantic and Pacific) are shown in Figure 5-6. This figure shows that the satellite coverage (outer solid line) completely encompasses the required coverage (inner solid line) as stated in the National SAR Plan (see Figure 5-1).

An alternative would be to use a new type of ELT/EPIRB (see Table 4-1) designed such that simultaneous coverage with the ground stations was not required. Then all 13 of the stations would be eliminated.

5.4 GROUND OPERATIONS

For the purposes of this report, it is assumed that the Satellite Project Operations Control Center (POCC) will be located at Elmendorf AFB, Alaska. During the test and evaluation phase of the mission, the ground stations located at the AFRCC near St. Louis, Missouri, and San Francisco, California, will be used for CONUS coverage. Other ground stations in the maritime region will be built during the operational phase of the mission.

The POCC will be the focal point for all project-unique mission operations beginning with the pre-launch simulations, through launch, and checkout of the spacecraft and the ground terminal network. The ground support concept includes the capability for communications, orbit and attitude determination, spacecraft health and evaluation, and spacecraft command control to be accomplished by the operational meteorological ground network. A description of the proposed system is provided in Appendix F.

5.5 SUMMARY

The satellite system proposed will be essentially capable of satisfying all the system design requirements specified in Section 4, and will solve the problems described in Section 2. Table 5-1 summarizes the extent of the satellite system capabilities to comply with the design requirements. The satellite will be in a low polar orbit in order to provide the ability to see distress incidents at high latitudes and in mountainous regions. In addition, the orbit chosen will provide the only known means of determining position location for the existing ELT/EPIRB's, i.e., doppler tracking.

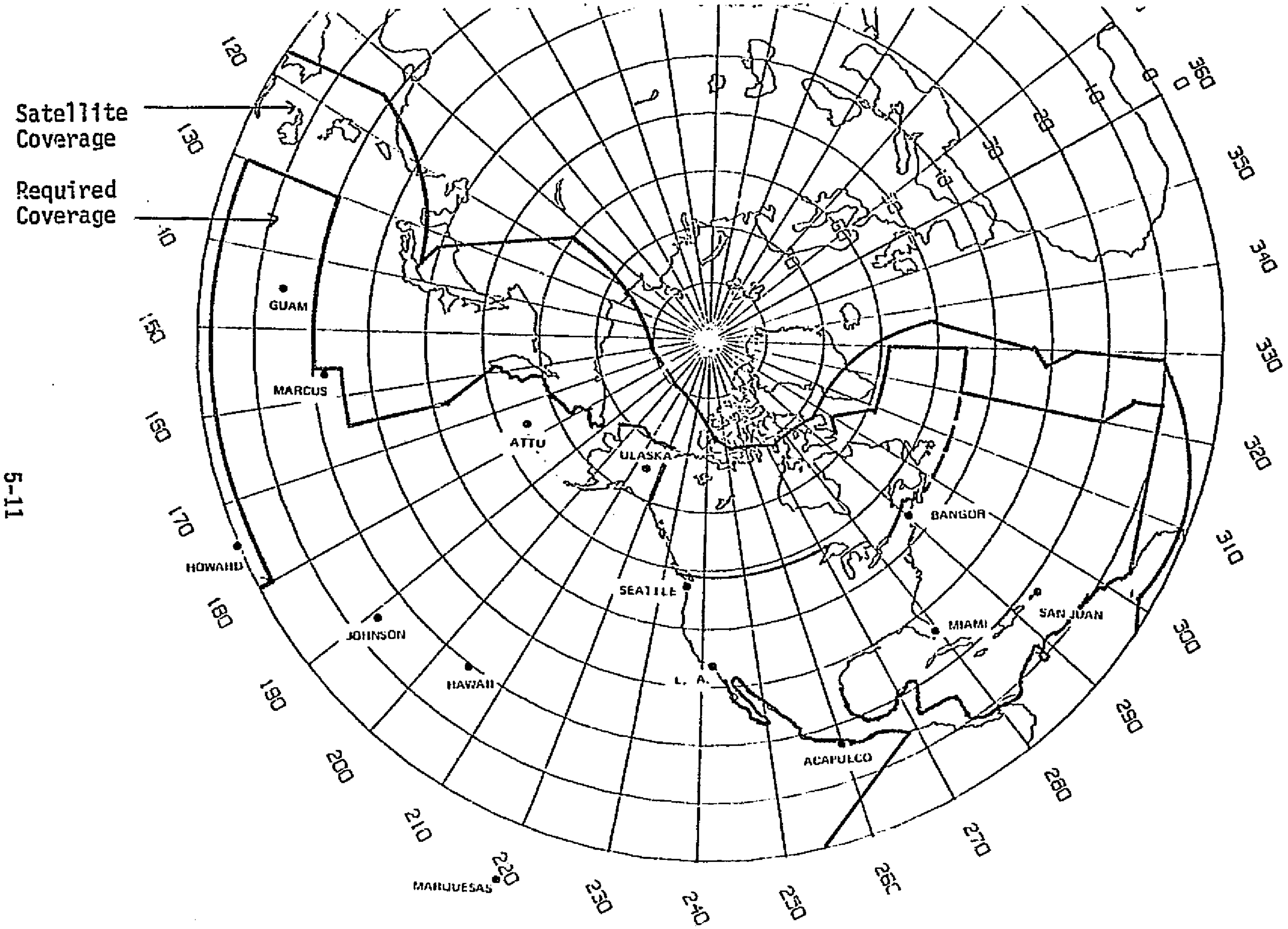


FIGURE 5-6. ELT AND GROUND COVERAGE FOR MARITIME REGION, 700 KM ALTITUDE, 5° ELEVATION ANGLE

TABLE 5-1
SEARCH AND RESCUE SATELLITE COMPLIANCE OF SAR DESIGN REQUIREMENTS

	REQUIREMENT	EXTENT OF COMPLIANCE
1.	Handle 10 simultaneous ELT transmissions	• Handle up to 10 simultaneous ELT transmissions depending on power level and location of ELT signals
2.	Identify ELT/EPIRB and indicate nature of distress (i.e., situation coding)	• Not possible with existing ELT/EPIRB's • Possible with "new" transmitters
3.	Desire 10 km position accuracy	• 10-20 km with existing ELT/EPIRB's • 2-5 km with "new" transmitters
4.	Desire 1 hour waiting time, 4 hours maximum	• 12 hours max (5 hours average for one satellite system) • 2 hours max (1 hour average for five satellite system)
5.	Mandatory coverage for CONUS and Alaska. Maritime coverage	• Coverage for existing ELT/EPIRB's in CONUS and Alaska • Non-real time coverage for Maritime with new ELT/EPIRB's at 406 MHz with on-board satellite storage of data and forward dumping to a ground station.
6.	Growth capability	• New 406 MHz system can handle up to 200 signals simultaneously

6. BENEFITS AND COSTS OF SATELLITE ASSISTED DISTRESS ALERTING AND LOCATING

6.1 INTRODUCTION AND CONCLUSIONS

6.1.1 Introduction

This section estimates the net benefits to society that can be expected to result from a fully operational distress alerting and locating satellite system to assist SAR operations for both aircraft and ships. Determining the net benefits from such a system entails several factors: (a) estimating the cost of the system over a period of time during which the system can be expected to function effectively; (b) estimating the benefits in terms of reduction of resources expended in search of missing persons and property; (c) estimating benefits of expected savings of property and lives during the lifetime of the new system; and (d) comparing the estimates of benefits and costs.

This analysis uses a resources approach to the estimation of benefits and costs. That is, dollars are used as a measure of the real resources (fuel, labor, etc.) they represent, and future price changes are of no interest to the analysis so long as the relative prices among the various goods and services remain constant. Therefore, the entire analysis is performed in constant 1976 dollars. When 1974 and 1975 data are used, they are adjusted by the Department of Labor's Consumer Price Index to 1976 dollars.1/

1/ U.S. Department of Commerce, Survey of Current Business, June 1976.

6.1.2 Conclusions

The conclusions reported in this section are based on a conservative approach to the estimation of costs and potential benefits to the national economy that might result from the implementation of a satellite assisted DAL system.

The major benefit from any satellite assisted DAL system will come from savings of lives. Operational savings from improved equipment and manpower utilization although quite significant, would be smaller relative to the savings of lives. Avoidance of property loss and improved salvage potential have some value for ships, but not for aircraft. When these estimated benefits are compared to estimated life-cycle costs of the system, the result is a benefit cost ratio of 6:1. This ratio was computed by dividing the present value[2/] of total benefits over the life of the system ($200 million) by the present value of the life-cycle costs of the system to the Federal government ($33 million). The annual flow of these benefits and costs are shown in Table 6-1.

Table 6-2 shows further detail of the benefits that are estimated to result from the system. Eighty-one percent of the 1,780 lives expected to be saved by the satellite system during the years 1982 through 2000 are expected to be in GA (inland) accidents, the remainder to occur in commercial and fishing vessels on the high seas. The number of lives saved were converted to a dollar figure ($515.7 million) using a rationale frequently used in cost-benefit analysis that there is a statistical, or economic value of $300,000 placed on a human life.[3/]

[2/] The present value of a dollar for a given future year, n, at a rate of discount i, is $(1+i)^{-n}$. In this study, i = 10 percent as directed by OMB circular number A-94, March 27, 1972.

[3/] "A Survey of Methods for Estimating the Cost Value of a Human Life," prepared for Department of Transportation, March 1, 1976 (to be published), discusses various methodologies for estimating this value. The National Highway Traffic Safety Administration of DOT used a method which produced values in the range of $200,000 to $240,000 in 1972. Accounting for inflation, this comes to $288,000-$346,000 in 1976 dollars.

TABLE 6-1

COMPARISON OF LIFE CYCLE COSTS AND BENEFITS (Millions of 1976 Dollars)

COSTS			BENEFITS[2]	
Year	1976 Dollars	Present[1] Value	1976 Dollars	Present[1] Value
1977	0.7	0.70	0	
1978	7.8	6.76	0	
1979	6.3	4.96	0	
1980	3.1	2.22	0	
1981	1.8	1.71	0	
1982	2.5	1.48	8.1	4.6
1983	3.5	1.35	16.3	8.4
1984	3.5	1.71	24.4	11.4
1985	3.5	1.56	35.9	15.3
1986	2.5	1.01	38.4	14.8
1987	2.5	0.92	39.8	14.0
1988	2.5	0.83	40.7	13.0
1989	2.5	0.76	41.6	12.1
1990	2.5	0.69	42.5	11.2
1991	2.5	0.63	43.4	10.4
1992	2.5	0.57	44.4	9.7
1993	2.5	0.52	45.5	9.0
1994	2.5	0.47	46.5	8.4
1995	2.5	0.43	47.6	7.8
1996	2.5	0.39	48.6	7.2
1997	2.5	0.35	49.8	6.7
1998	2.5	0.32	51.0	6.3
1999	2.5	0.29	52.2	5.8
2000	2.5	0.27	53.4	5.4
	70.20	30.36	770.1[4]	181.5
Infinite[3] Horizon		33.4		200.0

---

[1] 10 percent rate of discount

[2] Includes lives valued at $300,000 per life

[3] Since most of the present value of a stream of benefits and costs of this type are accumulated in the first 24 years, 10 percent is added to the 24 year total to account for future years of operations (to infinity)

[4] Slight error due to rounding

TABLE 6-2
ANNUAL AND CUMULATIVE TOTAL BENEFITS RESULTING FROM SATELLITE-ASSISTED SAR SYSTEM
(In Millions Of 1976 Dollars)

Year	Lives Saved			Dollar Value of Lives	Operational Search Costs And Property Saved			Cumulative Total (w/lives)
	Inland	Maritime	Total		Inland	Maritime	Total (Wo/lives)	
1977	0	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0	0
1982	13.39	4.08	17.44	5.23	1.42	1.46	2.88	8.11
1983	26.90	8.15	35.05	10.52	2.85	2.91	5.76	16.28
1984	40.28	12.23	52.51	15.75	4.28	4.37	8.65	24.40
1985	62.08	16.30	78.38	23.51	6.59	5.82	12.41	35.92
1986	68.12	16.30	84.42	25.33	7.24	5.82	13.06	38.39
1987	71.55	16.30	87.85	26.36	7.61	5.82	13.43	59.79
1988	73.70	16.30	90.00	27.0	7.83	5.82	13.65	40.65
1989	75.95	16.30	92.25	27.68	8.07	5.82	13.89	41.57
1990	78.20	16.30	94.50	28.35	8.31	5.82	14.13	42.48
1991	80.56	16.30	96.86	29.06	8.56	5.82	14.38	43.44
1992	82.94	16.30	99.24	29.77	8.82	5.82	14.64	44.41
1993	85.54	16.30	101.84	30.55	9.09	5.82	14.91	45.46
1994	88.03	16.30	104.33	31.30	9.36	5.82	15.18	46.48
1995	90.75	16.30	107.05	32.12	9.65	5.82	15.47	47.59
1996	93.36	16.30	109.66	32.90	9.92	5.82	15.74	48.64
1997	96.20	16.30	112.50	33.75	10.23	5.82	16.05	49.80
1998	99.05	16.30	115.35	34.61	10.52	5.82	16.34	50.95
1999	102.13	16.30	118.43	35.53	10.85	5.82	16.67	52.20
2000	105.09	16.30	121.39	36.42	11.17	5.82	16.99	53.41
	1,433.82	285.26	1,719.05	515.74	152.37	101.89	254.26	769.97

In addition to the savings of lives, the proposed satellite system would directly benefit the U.S. economy by reducing costs incurred by civilian and military aircraft and ships searching for downed aircraft in the inland region and for distressed ships and people on the high seas. It was also estimated that a significant dollar value of property damage would be avoided through improved rescue and salvage possibilities for commercial ships at sea. The total potential dollar benefits to the U.S. economy from reduction of search costs and property lost is estimated to total $254 million between 1982 and 2000. Sixty percent of this total is in the inland region. Figure 6-1 displays the total dollar benefits another way. It shows the amount of the total ($254 million) that will accrue to the Federal Government ($152 million) and the amount that will accrue to the private sector ($102 million).

6.2 SYSTEM COSTS

This subsection describes the annual and life-cycle costs of the proposed satellite system from program inception to an infinite horizon. The basic data for these cost estimates are taken directly from NASA studies which describe the costs of the major components of the proposed system.4/

6.2.1 Assumptions

Since a satellite-assisted SAR system could take on a number of configurations, each with different cost structures, it is necessary to begin the analysis with a number of assumptions regarding the system definition and operations. The system costed consists of the following assumptions:5/

- The satellite system will use available operational satellites.
- The satellite system will contain four polar orbiting satellites.
- The satellite system starts to become operational in 1981.
- Launches of new or replacement satellites average one per year ($1.5 million per launch).
- R&D costs ($19.7 million) are spread over years 1977-1981. This cost is nonrecurring.

4/ Goddard Space Flight Center, Search and Rescue Orbiting System, Preliminary Execution Phase Project Plan, Greenbelt, Md. September 1976.

5/ All dollar figures used in this section are in constant 1976 dollars.

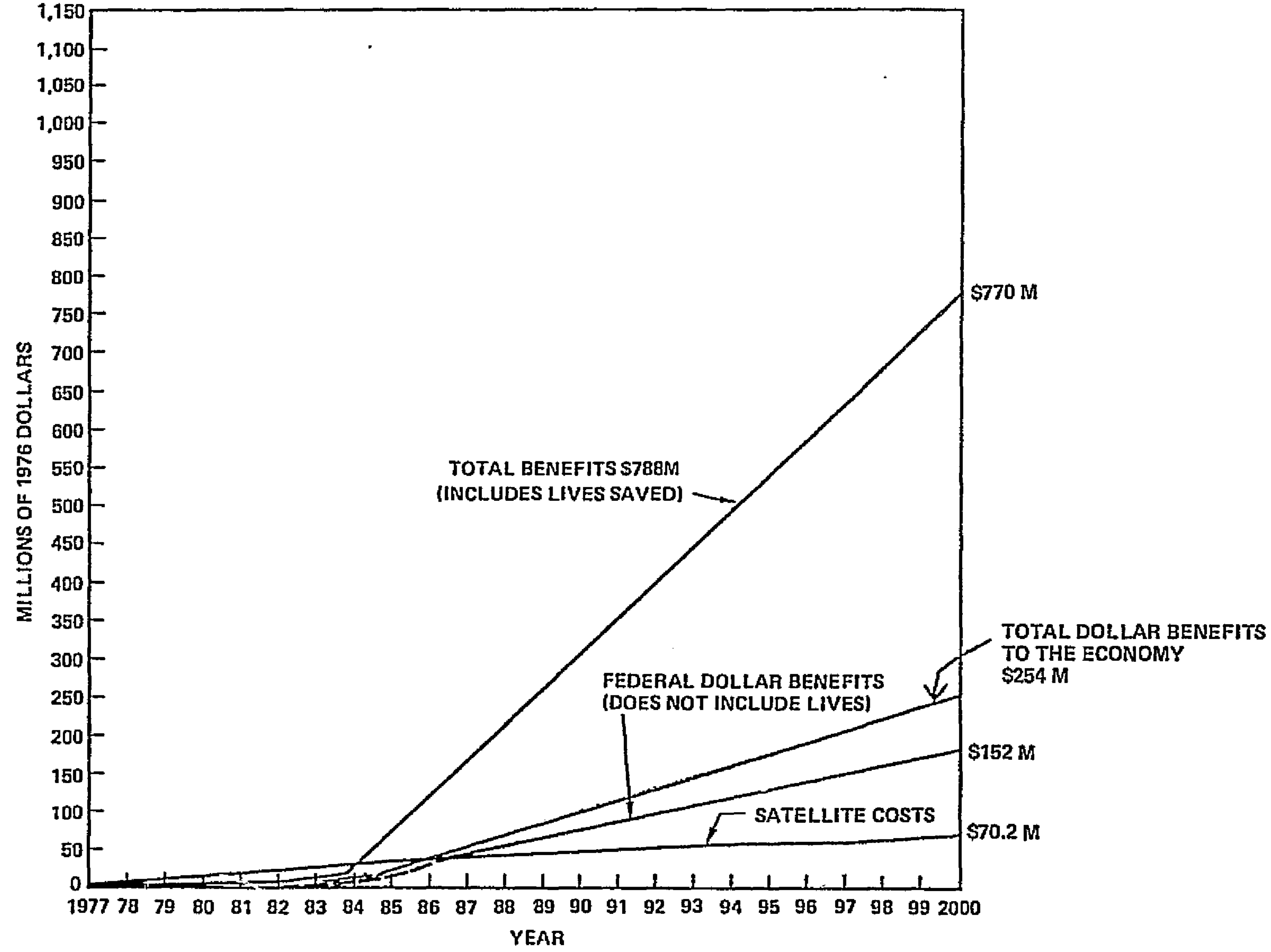


FIGURE 6-1. CUMULATIVE BENEFITS AND COSTS - 1977-2000 (MILLIONS OF 1976 DOLLARS)

- The cost to build additional ground terminals are spread equally over years 1983-1985. This cost is nonrecurring ($3 million).
- Operational costs are $1.0 million per year. This estimate assumes adding personnel at existing facilities.

6.2.2 Life-Cycle Costs

Based on the above assumptions, annual and investment costs for the system are estimated as displayed in Figure 6-2. The assumptions result in a cost pattern which is high in initial years and then drops to a relatively lower and constant level ($2.5 million per year). Total costs of the system on an annual basis from commencement of R&D in 1977 through operations to the year 2000 along with their present values (discounted at 10 percent annually) are presented in Table 6-1. Since about 90 percent of the present value of a cost stream of this sort is incurred during the first 24 years, 10 percent is added to account for all operating costs after the year 2000. Thus, the present value of the entire cost stream is $30.36 million (1977-2000) plus 10 percent, or $33.4 million.

6.3 BENEFITS TO THE INLAND REGION

This subsection discusses the nature and quantity of the benefits which are estimated to result from the operation of the satellite system in the inland region. The operation of the satellite system in the inland region is assumed for this study to apply only to GA aircraft. It excludes potential use of ELT's by lost hikers, canoers, mountain climbers, people residing in remote areas, etc. These groups represent potential sources of future benefits to the proposed system and are not quantified in this analysis.

6.3.1 Methodology and Data Used

The basic approach used in this analysis is to estimate parameters which describe the relationship between the level of GA flying hours on the one hand and the potential reduction in the costs of GA accidents to society (costs of searching operations and lives lost) that an effective satellite system might foster on the other. This approach is made possible by the observation

FLIGHT SYSTEM	77	78	79	80	81	82	83	84	85	EA. YEAR 86 AND ON
NON-RECURRING	.7	6.6	4.5	2.5	1.5	—	—	—	—	—
RECURRING	—	—	—	—	—	1.5	1.5	1.5	1.5	1.5
GROUND SYSTEM										
NON-RECURRING	—	1.2	1.8	.6	.3	—	1.0	1.0	1.0	—
RECURRING	—	—	—	—	—	1.0	1.0	1.0	1.0	1.0

FIGURE 6-2. SATELLITE SYSTEM COST ($1976-M)

that the number of fatalities in GA accidents per million GA hours flown is relatively constant.[6/]

Thus, for a fairly typical year, one can reasonably expect the number of lives lost and the operational search costs to be a direct function of the number of accidents. If one could expect to save a certain proportion of the expected lives lost and search costs, then the expected savings would also be a function of GA hours flown. Thus, potential benefits of the new system can be expressed in terms of activity levels of GA aircraft for the given year and, if forecasts were available of future GA activity levels, meaningful forecasts could be made regarding future benefits.

This approach is expressed as follows:

$$\underset{(1974)}{\frac{\text{No. of Accidents}}{\text{GA Hours Flown}}} \times \underset{(1974)}{\frac{\text{No. of Lives Lost}}{\text{No. of Accidents}}} \times \begin{matrix}\text{Percentage of}\\ \text{Losses Savable}\\ (1974)\end{matrix} = \begin{matrix}\text{No. of Lives}\\ \text{Saved per GA}\\ \text{Hours Flown}\\ (1974)\end{matrix} \qquad (1)$$

$$\begin{matrix}\text{No. of Lives}\\ \text{Saved per GA}\\ \text{Hours Flown}\\ (1974)\end{matrix} \times \begin{matrix}\text{No. GA Hours}\\ \text{Flown}\\ (\text{Year N})\end{matrix} = \begin{matrix}\text{No. of Lives}\\ \text{Saved}\\ (\text{Year N})\end{matrix} \qquad (2)$$

The same approach is used for search costs merely by substituting search costs for the "No. of lives lost" and the percentage of search hours savable for "percentage of lives savable." This is shown as follows:

$$\underset{(1974)}{\frac{\text{No. of Accidents}}{\text{GA Hours Flown}}} \times \underset{(1974)}{\frac{\text{No. of Search Hours}}{\text{No. of Accidents}}} \times \begin{matrix}\text{Percentage}\\ \text{of Search Hours}\\ \text{Avoidable}\\ (1974)\end{matrix} = \begin{matrix}\text{No. of Search Hours}\\ \text{Saved per GA Hours}\\ \text{Flown}\\ (1974)\end{matrix} \qquad (3)$$

[6/] National Transportation Safety Board, Annual Review of Aircraft Accident Data, U.S. General Aviation, Calendar Year, 1974, report number NTSB-ARG-76-1, DOT Washington, D.C., January 31, 1976.

$$\begin{matrix}\text{No. of Search Hours}\\ \text{Saved per GA Hours}\\ \text{Flown}\\ \text{(1974)}\end{matrix} \times \begin{matrix}\text{No. of GA}\\ \text{Hours Flown}\\ \text{(Year N)}\end{matrix} \times \begin{matrix}\text{Cost per}\\ \text{Search Hour}\\ \text{(1976 Dollars)}\end{matrix} = \begin{matrix}\text{Dollars}\\ \text{Saved per}\\ \text{Hour Flown}\\ \text{(Year N)}\end{matrix} \tag{4}$$

By using 1976 cost data, all dollar estimates are presented in terms of constant 1976 dollars. These factors are applied to FAA forecasts of GA flying hours to provide forecasts of savings in lives and search costs expected to result from implementation of the system.

Data from the U.S. Air Force Aerospace Rescue and Recovery Service (ARRS) and the National Transportation Safety Board (NTSB) were used to estimate the number of search hours and number of lives that might be saved with the proposed satellite SAR system. The ARRS data base is the only uniform nationwide source of information specializing in aircraft search data. Because the data base contains only incidents reported to the ARRS as a result of organized SAR activity, many accidents were unreported. Accordingly, the benefit for life saving was determined from NTSB data.

A manual analysis of ARRS data for the year 1974 was performed to examine the descriptions of searches involving missing aircraft. From these descriptions, determinations were made regarding the potential saving if a satellite SAR system had been in use. This savings was then expressed as a ratio to total GA aircraft hours flown during the year 1974, as in the equations above. Forecasts of GA aircraft hours flown from 1980 to 2000 were obtained from FAA publications (for the years 1977-1986) and by extrapolation from (1987 to 2000). These forecasts of flying hours were multiplied by the ratio of average search hours saved per GA flying hour to provide an estimate of total search hours saved for a 19 year period. The dollar value was derived by multiplying the number of aircraft hours saved by the cost of operating a typical aircraft used in SAR operations.

In order to determine the potential reduction in the number of lives now lost because of delays in recovering aircraft accident victims, full accident files of 105 of the 121 accidents involving missing aircraft during 1974 were reviewed to determine potential for survival if earlier recovery were possible. Sixteen of the files were not readily accessible. The information in the files reviewed typically contained a field investigation report, photographs of the wreck, autopsy reports, NTSB examiner's analysis, and statements of occupants (if they survived). Most files had autopsy reports only for the pilot. Hence, for these cases, it was assumed that the pilot's condition also represented the condition of other occupants. While most assessments were made on the basis of statements made by the medical examiner, other information in the files occasionally changed the assessment. Most files also contained statements about the presence of and assistance rendered by ELT's.

6.3.2 Benefits From Reduction in Inland Search Time

6.3.2.1 Total Dollar Benefits. It was determined from ARRS data that Civil Air Patrol (CAP) operations accounted for 22,368 aircraft hours flown for SAR purposes in 1974, whereas government operations accounted for 11,289. Examination of the ARRS data indicates that 19,231 of the CAP hours and 4,826 of the military hours flown were in search of downed civilian aircraft. Of these flight hours, 2,260 military and 2,260 civilian hours would probably have been flown for actual command, control and rescue operations, even with a perfectly functioning DAL system. This leaves a potential of 16,971 CAP flight hours and 2,566 military flight hours that could have been avoided with a satellite-aided DAL system. The average cost of operating small to medium sized civilian aircraft was estimated to be $46.00 per hour in 1976 dollars, whereas the cost of operating the typical military aircraft was $2,057 per hour.[7] Thus, the total avoidable costs for 1974 in 1976 dollars are:

	Cost of Flying Hour	x	No. of Flying Hours	=	Cost of Flying SAR for GA	(5)
CAP Cost	$ 46/hr		16,974 hrs		$ .781 million	
Military Cost	$2,057/hr	x	2,566 hrs	=	5.278 million $6.059 million	

These estimates do not include the cost of ground search crews and state and local governments which are usually involved in such incidences.

Not all the potential savings enumerated will be realized because of less than perfect ELT and satellite system effectiveness. It has been

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[7] A derivation of the hourly cost estimates is provided in Appendix G.1.

estimated that between 1982 and 2000, the period of time in which this system would provide benefits, ELT effectiveness will be a minimum of 60 percent and a maximum of 90 percent (see Appendix G.2). Likewise, satellite system effectiveness is very conservatively estimated to be 90 percent. Thus, the potential dollar benefit from Equation (5) is reduced by these percentages as follows:

Maximum Potential Savings	x	ELT Effectiveness	x	Satellite System Effectiveness	=	Dollar Benefit Realized	(6)
$6.059	x	(60 - 90%)	x	90%	=	$3.272-4.908 M	
		Most Probable		(Median)	=	$4.090 M	

6.3.2.2 Benefits to the Federal Government. Most of the avoidable costs in the inland region are presently borne by the Federal Government (USAF). Of the $46.00 per hour estimated cost to operate a civilian aircraft in SAR activities, the USAF reimburses the cost of fuel and oil ($18.00 per hour) whereas the remaining cost ($28.00 per hour) is paid by CAP members and by State governments. Thus, the potential cost savings to the Federal Government in the inland region can be calculated using Equation (5) as follows:

Reimbursable CAP cost	$ 18/hr	x	16,971 hrs	=	$ .305 million
Military cost	$2,057/hr	x	2,566 hrs	=	$5.278 million
					$5.583 million

Using Equation (6), the potential cost savings are reduced as follows:

Maximum Potential Savings	x	ELT Effectiveness	x	Satellite System Effectiveness	=	Dollar Benefit Realized	(6a)
$5.583	x	(60 - 90%)	x	90%	=	$3.015-4.522M	
				Most Probable	=	$3.769 M	

6.3.3 Benefits from Reduction of Lives Lost in the Inland Region

From NTSB accident records, it was determined that of 121 accidents involving 264 people in 1974, 238 died. The assessment was made that 28 people who were recovered dead would almost definitely have survived with a more effective DAL system.

It was determined that another 29 people who died would probably have survived if the DAL time could have been cut from 48 hours (average time for the present system) to 8 hours (projected for the satellite system). This was determined from Figures 6-3 and 6-4, and from ARRS data. Figure 6-3 shows that a system having four satellites would average less than 2½ hours between crash and the location of the crash site in CONUS. Assuming that rescue operations themselves average 5 hours each, the total average rescue time would be less than 8 hours (5 + 2.5 hrs). Figure 6-4 (derived from NTSB data) shows that the survival of individuals is directly related to the time it takes to receive aid. Only 10 percent of injured people in air crashes survive if aid is not provided within 48 hours. However, if this time could be cut to 8 hours, the survival rate would be increased approximately 60 percent, and the number of deaths would be cut in half (60 percent minus 10 percent).

When this reasoning is applied to 1974 NTSB and ARRS data, the incremental number of lives that could have been saved in 1974 can be calculated as follows:

Certain	28 lives
Estimates from NTSB data (58 survivables reduced by NTSB factor on survivability as a function of time. SAR time reduced from 48 to 8 hours	29 lives
Total expected lives saved	57 lives.

The number of lives expected to be saved is reduced as follows:

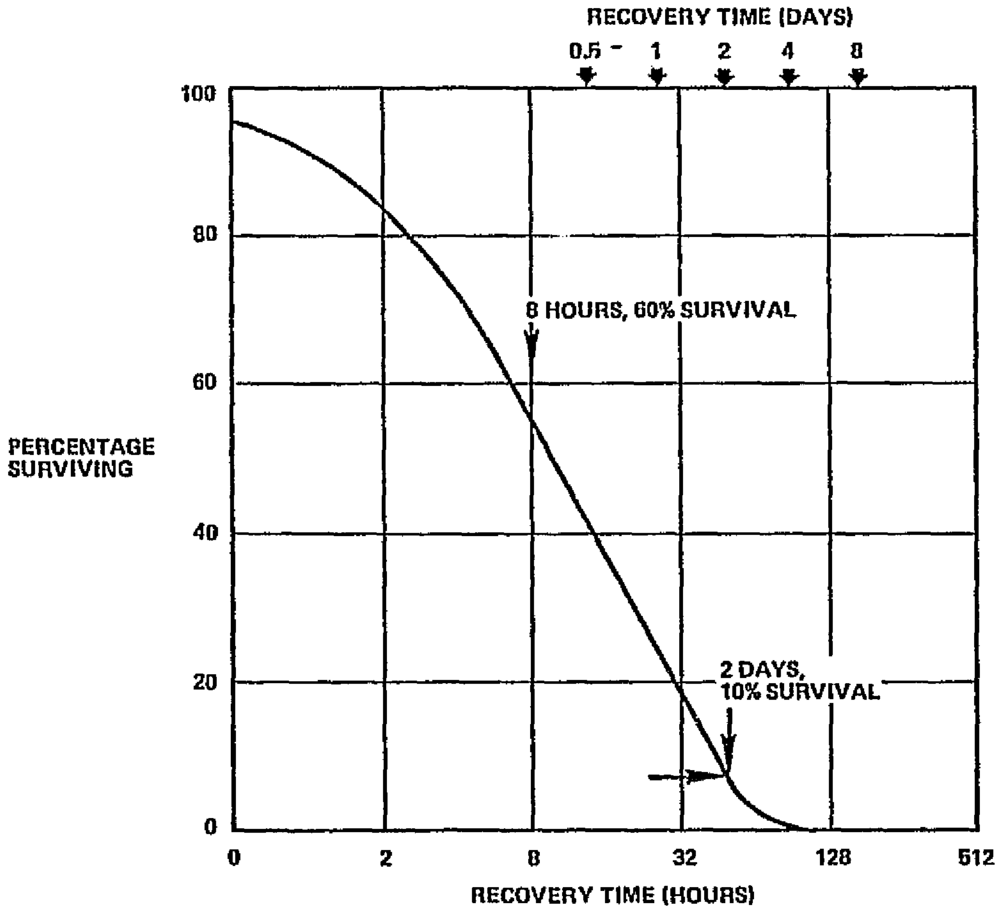
Number Lives Saved		ELT Effectiveness		Satellite System Effectiveness		Number Lives Realized	
	x		x		=		(7)
57	x	(60 - 90%)	x	90%	=	30.78 - 46.17	
				Most Probable (Median)	=	38.48 lives	

NUMBER OF SATELLITES	GLOBAL COVERAGE			REAL TIME		
	1	2	4	1	2	4
CONUS	378* 880 1000	216 660 790	142 390 480	280 630 750	136 390 510	66 180 240
ALASKA	205 580 730	117 370 710	78 290 630	192 540 730	98 350 480	42 90 150
ATLANTIC	514 1000 1140	339 780 910	244 550 620			
PACIFIC	415 1000 1310	269 810 990	218 700 800			

*KEY:

MEAN – 378
90th PERCENTILE – 880
MAXIMUM – 1000

FIGURE 6-3. SEARCH AND RESCUE WAIT TIME SUMMARY (Time in Minutes)



REF: DOD & NSC DATA GIVEN IN C. MUNDO, L. TAMI & G. LARSON, FINAL REPORT PROGRAM PLAN FOR SEARCH & RESCUE ELECTRONICS ALERTING & LOCATING SYSTEM, DOT-TSC-OST-73-42, FEB., 1974.

FIGURE 6-4. SURVIVAL AS A FUNCTION OF RECOVERY TIME

Using the standard value of $300,000 per person as representative of the statistical, or economic value lost to the Nation's economy, the savings in lives would be worth $11.5 million for 1974 (in 1976 dollars).

6.3.4 Forecasts of Future Benefits

Table 6-3 shows estimates of future potential benefits to improved efficiency of inland SAR efforts. It is based upon a forecast of GA flying hours prepared by the FAA and the factors developed from the equations shown above which express the number of lives lost and dollar cost of aircraft sortie time as ratios to GA hours flown. The dollar potential benefits are expressed in constant 1976 dollars. In adjusting 1974 dollars to 1976 dollars, the inflation rates of nine percent for 1975 and five percent for 1976 were used.[8]

These forecasts assume that the first satellite will be launched in 1981, no benefits will accrue in 1981, 25 percent of the potential benefits will be realized in 1982, 50 percent in 1983, 75 percent in 1984, and 100 percent thereafter. The future benefits for the inland region are derived from the dollar savings due to reduced GA flying and the dollar value placed on the savings of lives. The 1974 cost per GA flying hour is computed by dividing the dollar savings owing to reduced GA flying (Equation 6) by the number of GA hours flown in that year (32.474 million) as shown in Equation 7.[9]

$$\frac{\text{Dollars saved}}{\text{GA hrs flown}} = \frac{\$4.090 \times 10^6}{32.474 \times 10^6} = \$0.126 \text{ per GA flying hour} \qquad (8)$$

The 1974 dollar value placed on the savings of lives is computed by dividing the number of lives saved (Equation 7) by the number of GA hours flown in that year as shown in Equation (9).

$$\frac{\text{Lives saved}}{\text{GA hrs flown}} = \frac{38.48}{32.474 \text{ million}} = 1.185 \text{ lives saved per million GA hrs flown} \qquad (9)$$

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[8] U.S. Department of Commerce, Survey of Current Business, June 1966.

[9] FAA, Aviation Forecasts Fiscal Years 1976-1987, FAA-AVP 75-7, September 1975.

TABLE 6-3
FORECAST OF BENEFITS TO GENERAL AVIATION RESULTING FROM SATELLITE ASSISTED SAR OPERATIONS 1981 - 2000

Year	Total A/C[1] Hours $(x10^6)$	x.0126=[2]	Dollar Value[3] Search Hours Saved (millions) 1976 Dollars)	No. of Lives Saved
1981	43.5		0	0
1982	45.3		1.43(3)	13
1983	47.6		2.86(3)	27
1984	49.9		4.28(3)	40
1985	52.4		6.60	62
1986	57.5		7.24	68
1987	60.4		7.60	72
1988	62.2		7.83	74
1989	64.1		8.07	76
1990	6.60		8.31	78
1991	6.80		8.56	81
1992	70.0		8.81	83
1993	72.2		9.09	86
1994	74.3		9.35	88
1995	76.6		9.64	91
1996	78.8		9.92	93
1997	81.2		10.02	96
1998	83.6		10.53	99
1999	86.2		10.85	102
2000	88.7		11.17	105
Total			152.16	1,434

[1] Source: Forecasts for 1976-1987 from Aviation Forecasts Fiscal Years 1976-1987, Federal Aviation Administration, FAA-AVP-75-7, September 1975. Extrapolation for 1988-2000 at 3 percent per year.

[2] From page 6-16.

[3] These figures are adjusted to reflect a learning period as follows: 1982=0, 1982=0.25, 1983=-.50, 1984=0.75 and 1985 onward = 1.0.

Taking the year 2000 as an example of the use of these factors in forecasting benefits for a given future year, the dollar value of inland benefits can be computed. Using the results of Equation (8) and the number of GA hours flown in the year 2000 from Table 6-3, the dollar savings in reduced flying time is:

$$\begin{array}{c}\text{Total GA}\\ \text{Hours Flown}\\ \text{(Year 2000)}\end{array} \quad \text{X} \quad \begin{array}{c}\text{Cost Per}\\ \text{GA flying}\\ \text{hour}\end{array} \quad = \quad \text{Dollars saved} \qquad (10)$$

$$88.7\ \text{M} \quad \text{X} \quad \$0.126 \quad = \quad \$11.17\ \text{M}$$

The number of lives that could be saved can be computed in a similar fashion by using the results of Equation (9) and the number of GA hours flown in the year 2000 from Table 6-3 as follows:

$$\begin{array}{c}\text{Total GA}\\ \text{Hours Flown}\\ \text{(Year 2000)}\end{array} \quad \text{X} \quad \begin{array}{c}\text{Lives saved}\\ \text{per million}\\ \text{GA hours flown}\end{array} \quad = \quad \text{Lives saved} \qquad (11)$$

$$88.7\ \text{M} \quad \text{X} \quad 1.185\ \text{lives} \quad = \quad 105.1\ \text{lives saved}$$

Taking the economic value of a life saved at $300,000, the dollar value for lives saved in the year 2000 is

$$\text{Lives Saved} \quad \text{X} \quad \begin{array}{c}\text{Dollar value}\\ \text{per life saved}\end{array} \quad = \quad \text{Dollars saved} \qquad (12)$$

$$105.1 \quad \text{X} \quad \$300{,}000 \quad = \quad \$31.53\ \text{M}$$

Thus, the total inland benefits for the year 2000 is:

$$\begin{array}{c}\text{Dollars from}\\ \text{reduced flying time}\end{array} \quad + \quad \begin{array}{c}\text{Dollars from}\\ \text{savings of lives}\end{array} \quad = \quad \begin{array}{c}\text{Inland}\\ \text{benefits}\\ \text{(dollars)}\end{array}$$

$$\$11.17\ \text{M} \quad + \quad \$31.53 \quad = \quad \$42.7\ \text{M} \qquad (13)$$

6.4 BENEFITS TO THE MARITIME REGION (HIGH SEAS)

The major benefits to marine activity from a fully operational satellite assisted DAL system will come through the savings of lives, savings in operational search costs, and property damage avoided or mitigated through improved salvage possibilities. Approximately 1,900 U.S. vessels are currently under the mandatory regulations requiring the carrying of EPIRB's.

In addition to these vessels, there are currently another 1,300 small passenger vessels whose routes require the carrying of EPIRB's or who may elect to carry them voluntarily. Initial system planning excludes recreational watercraft for a variety of reasons including saturation of the system through false alarms and the problems involved in requiring ELT's on recreational watercraft.

6.4.1 Methodology and Data Used

The U.S. Coast Guard (USCG) is considered the primary source of data for marine accidents and SAR information for incidents where the proposed initial system would be able to assist distressed vessels and their crews. In 1974, the USCG performed a study about DAL techniques and their impact (SALTTI).[10] Using conclusions drawn from that analysis as well as from additional USCG SAR data for 1974 and 1975, the potential benefits for the base year (1975) were forecasted to the year 2000 based on expected future trends in activity and technological changes in the maritime industry.

6.4.2 Benefits From Reduction in Maritime Search Costs

The USCG spent an estimated $5.8 - $8.8 million in FY 1975 searching for distressed persons or property (excluding time spent for actual rescue operations). The 1974 USCG data (from Appendix G) shows that 15.5 percent of the USCG SAR effort is spent on the high seas and the remainder is spent in the coastal area (within 20 miles). Thus, the maximum potential cost savings with a satellite system is expected to be 0.155 x ($5.8 - $8.8 million) = ($0.899 - $1.365 million), an average of $1.132 million per year.

Using Equation 6, the cost savings are reduced as follows:

Maximum Potential Savings		ELT Effectiveness		Satellite System Effectiveness		Dollar Benefit Realized	(14)
$1.132 M	x	(60 - 90%)	x	90%	=	$0.611-0.917M	
				Most Probable (Median)	=	$0.764 M	

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[10] Telecommunications Management Division, Office of Operations, U.S. Coast Guard Headquarters, Study of Alerting and Locating Techniques and Their Impact (SALTTI), 18 September 1975

6.4.3 Benefits From Reduction of Lives Lost on the High Seas

The USCG SALTTI study reported that about five percent of deaths reported occur on the high seas. The study also concluded that a DAL system would be approximately 45 percent effective in terms of saving life and property within the U.S. maritime region. Additionally, the study stated that one-quarter to one-third of all reported lives lost would not be saved by a satellite system since these lives represent sudden or personal mishaps such as explosions, persons overboard, etc. The rationale for these conclusions is shown in Figure 6-5.

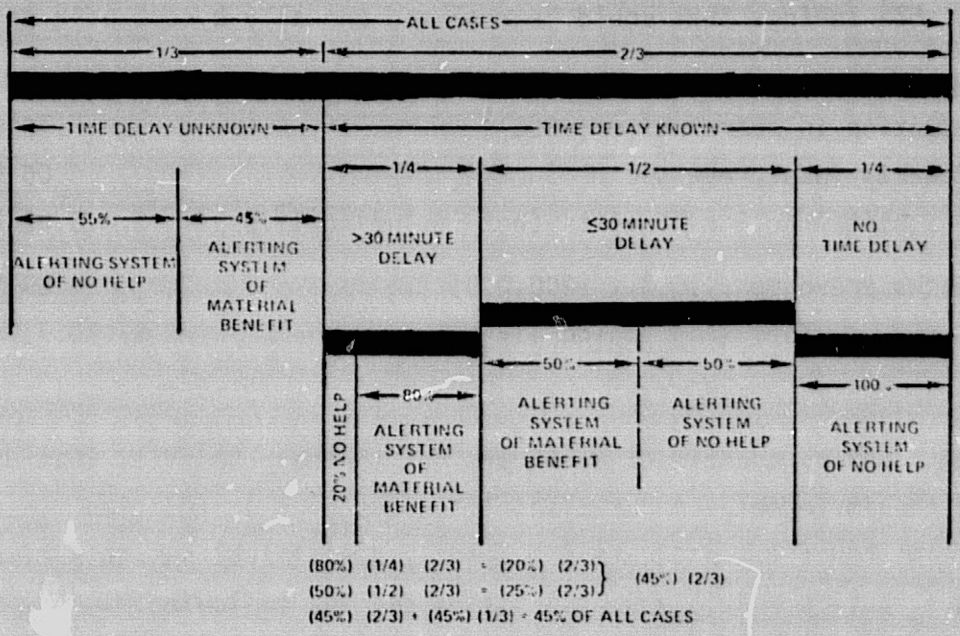
The estimated 45 percent ELT effectiveness used by the USCG is lower than the estimate of 60 percent derived in Appendix G. However, since the aim of this analysis is to take a conservative approach, the lower estimate (45 percent) is used in this portion of the analysis.

Applying these figures yields an estimated benefit of 22 lives that could be saved per year. Owing to the length of time it takes to complete a maritime rescue operation after a distress alert notice has been received, the actual effectiveness, based upon historical data, in the saving of lives is 82.5%[11/] Multiplying the lives that could be saved (22) by the USCG rescue effectiveness (82.5%) and the satellite system effectiveness (90%) yields 16.3 lives saved per year.

6.4.4 Benefits From Reduction of Lost Property

The property lost in SAR incidents is not a reportable statistic. However, the USCG estimate of preventable property loss in FY 1975 was $306.8 million. That is, assuming a system effectiveness similar to that for saving lives yields an estimated $113.5 million of property lost in FY 1975. If only two-thirds was saved, and the satellite system was 45 percent effective for SAR cases as discussed earlier, $34.2 - $38.2 million would be the property loss which could have been saved in the U.S. maritime region.

[11/] Personal communication with Cmdr. A. Miller, USCG Hq., Washington, D.C., October 1976.



Source: Telecommunications Management Division, Office of Operations, U.S. Coast Guard Headquarters, "Study of Alerting and Locating Techniques and Their Impact (SALTTI)."

FIGURE 6-5. ESTIMATE OF ALERTING SYSTEM EFFECTIVENESS FOR COAST GUARD SAR CASES

Using the 15.5 percent of the USCG SAR effort on the high seas (see 6.4.2), the maximum potential cost savings is expected to be 0.155 x ($34.2 - $38.3 million) = $5.13 - 5.75 million, an average of $5.62 million. Multiplying this figure by satellite system effectiveness (0.9) yields $5 million per year as the expected benefit.

6.4.5 Total Maritime Benefits

Adding the above three sources of benefits yields the following maximum quantifiable savings that could be realized annually by use of a satellite system.

Reduction in search time (USCG)	$ .76 M
Property loss prevented	5.06 M
Subtotal dollar benefits (not including lives)	$ 5.82 M
Deaths prevented (16.3 x $300,000)	4.89 M
Total (including lives)	$ 10.71 M

6.4.6 Other Maritime Benefits

The benefits quantified above are not the only benefits that would result from the implementation of a satellite system. In addition, there are significant benefits which are not readily quantifiable at this time. These include, but certainly are not limited to, the following:

- Costs of diverting commercial and Naval vessels for search efforts
- SAR problems in international waters
- Coastal and Inland waters.

6.4.7 Forecast of Maritime Benefits

USCG projections show traffic to be increasing. However, ships are becoming more sophisticated and are expected, by some people, to have fewer accidents. Technological enhancements in navigation, communications and automatic warnings of impending malfunctions would seem to make alerting and locating less of a problem. On the other hand, if ships become larger and more sophisticated, the losses that do occur could be more costly per incident. A detailed analysis of these countervailing economic and technological trends would require considerable examination of a major portion of the maritime industry. Such a study was beyond the scope of this effort. Relying on the judgment of the SALTTI Study Review of April 1974, which also showed mixed trends, but a slight upward trend of the SAR workload in the high seas area, it was assumed that there will be no growth in future benefits to the maritime region. That is, the annual level of future benefits will be constant at the 1975 level (10.7 million per year). Thus, the total maritime benefits for the period 1982 - 2000 would be $187 million including the saving of 285 lives.

7. SATELLITE SYSTEM COSTS

7.1 RESEARCH AND DEVELOPMENT (R&D) COSTS

Research and development (R&D) costs for a SAR orbiting satellite system fall into four major areas. These are: space segment, ground segment, system evaluation, and ELT/EPIRB. Upon completion of the test and evaluation phase, the system would be declared semioperational and modified with additional capability deemed necessary. The satellite-aided SAR system would become fully operational upon successful launch and check-out of the complete complement of satellites and ground stations in the system. The satellite system costs are shown in Table 7-1 and explained in subsequent paragraphs.

TABLE 7-1

SATELLITE SYSTEM R&D COSTS (1976 $'s)

PARAMETER	AMOUNT ($M)
Spacecraft	$ 7.1 - 15.8
Launch Vehicle	2.0 - 0.0
Ground Terminals (2)	2.0 - 2.9
Test and Evaluation	0.3 - 0.5
ELT Development	0.3 - 0.5
TOTAL	$ 11.7 - 19.7

7.1.1 Satellite R&D Costs

It is anticipated that the satellite development costs can be kept low by using one of the now existing or under development spacecraft buses such as a NASA Applications Explorer Mission (AEM) or a Navy TRANSIT, or by building an instrument package to be placed on board an available satellite. The development costs for the satellite would be for a new instrument package such as the one shown in Figure 7-1. The figure assumes a design capability for transponding all three uplink frequencies (121.5, 243, and 406 MHz) to the ground stations. Note that for the 406 MHz link, a capability is provided for on-board storage of the ELT/EPIRB position location data for subsequent dumping of the data to a ground station (assumes the ground station is not in view of the satellite when the satellite receives the ELT/EPIRB signal). Additionally, all three uplink frequencies can be transponded immediately to a ground station that is in the field of view of the satellite.

7.1.2 Launch Vehicle Costs

If the SAR instrument package is not launched as part of another satellite, either as an instrument package or as a total secondary payload, then the package integrated into one of the spacecraft buses (described in Section 7.1.1) will need its own launch vehicle. The appropriate launch vehicle will be of the Scout class.

7.1.3 Ground Terminal R&D Costs

As stated in Section 5.4, there will be two ground stations for the test and evaluation phase of the mission. The control center will be located at Elmendorf AFB, in Anchorage, Alaska, and at the AFRCC near St. Louis, Missouri. Other ground stations in CONUS will be built during the operational phase of the mission.

7.1.4 Test and Evaluation Phase

The purpose of the test and evaluation phase is to prove the suitability of space technology to detect and locate the existing low powered ELT/EPIRB hardware and to demonstrate the effectiveness of satellite-aided SAR. During this phase, ELT/EPIRB's will be purposely activated to exercise, in a test environment, all the hardware and software of the system including communication

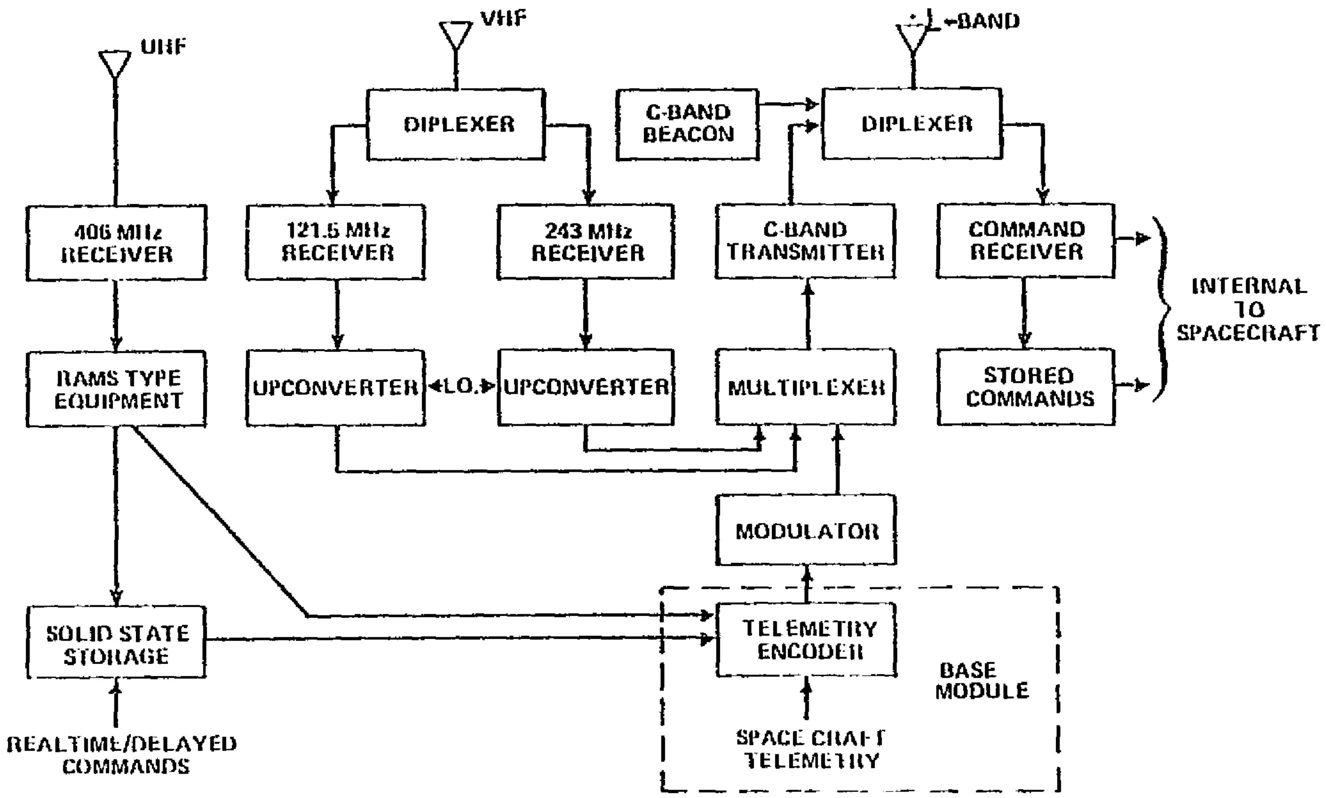


FIGURE 7-1. SEARCH AND RESCUE SATELLITE INSTRUMENT MODULE BLOCK DIAGRAM

coordination with the regional coordination centers. This test and evaluation phase will last approximately one year. Upon successful completion of the test and evaluation phase, the operational system may be implemented by responsible operating agencies.

7.1.5 ELT/EPIRB Costs

The new ELT/EPIRB unit would be designed to operate on the International Telecommunication Union (ITU) approved earth-to-satellite frequency band for mobile SAR users at 406 MHz. Operation at this frequency will provide a clearer channel with fewer interfering sources. With the incorporation of identification coding, the new ELT characteristics will aid SAR efforts. Additionally, burst transmission techniques will allow higher EIRP (effective isotropic radiated power) with the same power source as well as a vast improvement in multiple access capability. The basic cost of a new ELT/EPIRB operating at 406 MHz and one compatible with satellite operations is estimated to cost less than $200 for production quantities. This price is within the range of present 121.5/243 MHz units. If situation coding is added, the cost could increase by a factor of two.

7.2 OPERATIONAL COSTS

The operational system will consist of a constellation of five polar orbiting satellites to guarantee coverage at least once every two hours. Additional ground stations will be built to provide complete coverage for CONUS. The SAR mission agency will be responsible for operating the ground stations, including operational support for the satellites. Table 7-2 lists the costs for the operational system.

TABLE 7-2

10 YEAR SATELLITE SYSTEM OPERATIONAL COSTS (1976 $'s)

PARAMETER	AMOUNT ($M)
Spacecraft and Launch Vehicle	13 - 60
Ground Terminal	3 - 5
Operations	10 - 24
Total	26 - 89

7.2.1 Satellite and Launch Vehicle Operational Cost

As stated in the previous section, the satellite cost would be between $10-20 million for the first satellite. Considering the satellite system proposed, follow-on spacecraft would probably cost $1.5-10 million per spacecraft including launch.

7.2.2 Ground Terminal Operational Costs

The cost to build additional ground stations to monitor ELT/EPIRB signals such as the one at St. Louis, would cost around $250,000 each.

7.2.3 Operational Costs

Assuming about a three-man shift operation at the ground command and control stations and four shifts per week, the total complement of personnel directly assigned to SAR operations would be 12 men full-time. Assuming a cost of $13,000 per man year,[1] the total cost per ground station would be $156,000 annually. Only one man per shift would be required at receive only Local User Terminals for a cost of $52,000 annually per ground station Savings can be obtained by colocation of ground command and control stations at existing military installations. The range of total operations cost per year is $1.0-2.5 million.

7.2.4 SAR Instruments on Operational Meteorological Satellites

An approach to implementing the SAR satellite mission, which is currently under study, would be to utilize the NOAA and USAF operational meteorological satellites to carry a SAR instrument and associated antennas. This approach would perform the same function that would be accomplished by a dedicated satellite. Also, this approach is reflected in the high range of the R&D costs of Table 7-1 (19.7 million) and the low range of the operational costs of Table 7-2 ($28 million). This approach is discussed in Appendix F.

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[1] USCG uses $13,000 per man year for planning purposes. U.S. Air Force (AF Reg. 173-10) uses $10,000 per man year.

8. CONCLUSIONS

Section 1 gave the background of the ELT/EPIRB units and typical SAR missions. Section 2 identified the main problem with the existing use of ELT/EPIRB's in the field - a lack of an effective monitoring and locating system. Overwater alerting of shipboard EPIRB's is predicated on aircraft making long overwater flights monitoring the 121.5 MHz channel in accordance with regulations of the International Civil Aviation Organization (ICAO). Unlike the oceanic case, there are no mandatory guard requirements for monitoring the 121.5 MHz channel when overland. Military aircraft are only required to monitor 243 MHz while airborne. FAA and USAF ground stations required to monitor ELT signals are sparsely located, inadequately equipped with DF equipment, and are limited to short-range (20 km) radius due to line-of-sight reception. Moreover, no ground stations (civil or military) are required to be equipped with portable hand-held DF devices to home in some signal sources. FAA airport facilities are becoming equipped with portable DF units.

Section 4 discussed the system design requirements based upon the analysis performed in evaluating the various advanced concepts to improve DAL discussed in Section 3. Section 5 provided a potential low orbiting satellite system that satisfies the requirements mentioned in Section 4. The operational reasons for choosing a low orbiting satellite system are:

a. Difficult to immediately effect user change
b. Large existing investment in user devices (ELT/EPIRB's)
c. Greatest immediate impact upon the serious problem in CONUS and Alaska
d. Consistent with rescue unit DF capability.

Based upon the material presented in this report, the following conclusions can be drawn:

- There presently does not exist a reliable monitoring system for aircraft-equipped ELT's and ship-equipped EPIRB's during all distress situations.
- A system that would provide the position location of present day transmitting ELT's and EPIRB's to within 10 km (5.4 nmi) would be a great aid for SAR operations.
- A space system appears to be the optimum, near-term method for effectively providing DAL for present day and improved ELT and EPIRB (in the high seas area) equipped vehicles.
- A low-altitude polar satellite system, employing the doppler measurement technique, is the optimum space technique for near-term aids to SAR in CONUS and Alaska.
- A satellite system employing add-on SAR packages to planned and approved operational satellites appears to be an effective, low-cost method for DAL.
- Geosynchronous altitude satellite systems can provide near-term aid for DAL through use of on-board satellite communications, but they cannot operate with existing ELT/EPIRB's. Further, in the case of ELT's, they do not provide coverage over the extreme north or south latitudes or in mountainous terrain.
- The most immediate need and benefit for satellite-aided SAR will be the general aviation community within the continental United States and Alaska.

- DAL on the high seas will benefit from a satellite-aided SAR system.
- In the maritime region, there is an operational requirement for EPIRB identification and situation coding to facilitate SAR.
- Improvements in SAR techniques by better DAL methods will reduce the risk, time and cost to search units.
- EPIRB-equipped ships transmitting in the coastal zone (within 20 miles of U.S. coast) could benefit from a satellite-aided SAR system.
- Experience with a single satellite would be useful to prove the operational practicality and cost-effective advantages of a satellite-aided SAR system.
- Although the near-term solution for DAL points to the use of low-orbiting satellites, a geosynchronous satellite would provide continuous and instantaneous coverage for detection and notification of an emergency, and therefore holds great promise for the maritime area.
- Based upon the preliminary benefits and costs study, it has been determined that a benefit cost ratio of 6:1 can be achieved over a 20-year period by employing the low altitude doppler measurement satellite system.

9. RECOMMENDATIONS

The ICSAR ad hoc working group on satellites for search and rescue makes the following recommendations:

- Demonstration of a satellite-aided search and rescue system capable of monitoring and locating existing ELT and EPIRB equipped vehicles should be implemented immediately to provide operational experience and cost-benefit data to user organizations.
- Development of an advanced distress ELT/EPIRB at the internationally accepted 406 MHz frequency for use on aircraft and ships and designed for operations with a satellite system should be implemented.
- The advanced EPIRB should contain identification and situation coding which would be an optional feature for ELT's.
- Since the international aspects of a SARSAT have been recognized with the possibility of reducing SAR costs, foreign participation is encouraged in any demonstration satellite system in order to promote international acceptance.

- Any satellite system proposed should be outlined to ICAO and IMCO to ensure international participation and a uniform worldwide system.
- The aviation and maritime communities and government agencies should support and actively participate in any satellite demonstrations.
- Government and civilian organizations should study the management, cost, and operations aspects of implementing an operational SARSAT system, including international participation.
- Continued development of techniques for the use of future satellite systems such as INMARSAT, AEROSAT, and others, for SAR (DAL as well as SAR coordination) should be encouraged.

APPENDIX A

FULL TEXT OF SELECTED REFERENCES

Reference 1

AMENDMENT TO THE OCCUPATIONAL SAFETY AND HEALTH ACT OF 1970 (P.L. 91-596)

EMERGENCY LOCATOR BEACONS

Sec. 31. Section 601 of the Federal Aviation Act of 1958 is amended by inserting at the end thereof a new subsection as follows:

"EMERGENCY LOCATOR BEACONS

"(d)(1) Except with respect to aircraft described in paragraph (2) of this subsection, minimum standards pursuant to this section shall include a requirement that emergency locator beacons shall be installed ——

"(A) on any fixed-wing, powered aircraft for use in air commerce the manufacture of which is completed, or which is imported into the United States, after one year following the date of enactment of this subsection; and

"(B) on any fixed-wing, powered aircraft used in air commerce after three years following such date.

"(2) The provisions of this subsection shall not apply to jet-powered aircraft; aircraft used in air transportation (other than air taxis and charter aircraft); military aircraft; aircraft used solely for training purposes not involving flights more than twenty miles from its base; and aircraft used for the aerial application of chemicals."

SEPARABILITY

Sec. 32. If any provision of this Act, or the application of such provision to any person or circumstance, shall be held invalid, the remainder of this Act, or the application of such provision to persons of circumstances other than those as to which it held invalid, shall not be affected thereby.

APPROPRIATIONS

Sec. 33. There are authorized to be appropriated to carry out this Act for each fiscal year such sums as the Congress shall deem necessary.

EFFECTIVE DATE

Sec. 34. This Act shall take effect one hundred and twenty days after the date of its enactment.

Approved December 29, 1970.

Maj Doherty/4927/16 Sep 75/js

FILE 13N
70

AFRCC/Stop 600

23 SEP 1975

Emergency Locator Transmitter Satellite Monitoring

MAC/DO/Stop 101

1. In accordance with the National Search and Rescue Plan, the Air Force is the responsible agency for coordinating search and rescue (SAR) activities with the Inland Region (48 contiguous states). The Chief of Staff, United States Air Force, has designated the Commander, Aerospace Rescue and Recovery Service (ARRS), as his executive agent to implement this plan. The Air Force Rescue Coordination Center (AFRCC) has been established, within my headquarters, to carry out the responsibility of coordinating SAR operations. The AFRCC works with federal, state, county, local government agencies, and volunteer organizations to develop a cooperative national SAR network.

2. Because of its extensive responsibilities to civil and military aviation, the Federal Aviation Administration (FAA) is the most frequently contacted federal organization. Through its Air Route Traffic Control Centers and Flight Service Stations, aircraft filing flight plans are monitored and flight-followed. Normally, FAA is the first agency to alert the AFRCC of an overdue or missing aircraft.

3. With the recent enactment of federal law requiring most aircraft to be equipped with an Emergency Locator Transmitter (ELT), the ability to locate a downed aircraft is enhanced. The ELT is activated manually or by "G" forces upon impact. It then transmits an emergency signal on 121.5 or 243.0 mhz. FAA communication facilities and en route aircraft monitoring these emergency frequencies will receive the signal. The activation reports are forwarded to the AFRCC through FAA channels to be investigated as a probable distress signal. Of the 2913 ELT reports received by the AFRCC, from 1 Jan to 30 Jun 1975, only 28, or 1%, were actually distress cases.

4. Two major deficiencies exist in the present ELT system, transmitter malfunctions/misuse and receiver coverage. The initial problem can be

overcome by educating the operator and by improving the equipment; however, the latter is a far greater problem. Due to low power output and line of sight transmission limitation, remote areas of the United States are not monitored by existing receiver stations. A high percentage of airplane crashes occur in the remote, rugged terrain areas, thus reducing the effectiveness of the ELT. A downed aircraft with survivors, in this environment, may not be located because the ELT signal could not be heard by ground stations or over flying aircraft. The National Search and Rescue Manual, AFM 64-2, states "that the life expectancy of injured survivors decreases as much as 90 percent the first 24 hours following an accident." Thus the requirement for immediate notification and dispatch of rescue forces is paramount. The ELT unit can provide this capability, if it is detected immediately after the incident occurs.

5. Today there exists the means by which to monitor ELT signals for the entire area of the United States. One low orbiting polar satellite system would provide coverage at any point in the world having an average scan interval of 5 hours. Presently, the National Aeronautics and Space Administration (NASA) is studying the capabilities of satellites to monitor ELT transmissions. Preliminary findings are encouraging. The Aerospace Rescue and Recovery Service (ARRS) supports the initiative and concepts of NASA and concurs with the recommendations of the Search and Rescue Panel, conducted in May 1975, at Easton, MD (atch 1).

6. I strongly recommend indorsement by the Interagency Committee for Search and Rescue (ICSAR).

7. Request the Military Airlift Command (MAC) support the concepts of NASA and that this proposal be forwarded to the appropriate Air Staff offices for review.

RALPH S. SAUNDERS, Major General, USAF
Commander

1 Atch
Extract (Satellite-Aided Search and Rescue)

Cy to: Mr. Bernard Trudell

AMENDMENT TO THE CODE OF FEDERAL REGULATIONS, CHAPTER 1, TITLE 46

PART 33-LIFE SAVING EQUIPMENT

Subpart 33.60-1 Emergency Position Indicating Radiobeacon (EPIRB) T/OC

(a) Each vessel in ocean and coastwise service must have an approved Class A emergency position indicating radiobeacon (EPIRB) that is--

(1) Operative;

(2) Stowed where it is readily accessible for testing and use; and

(3) Stowed in a manner so that it will float free if the vessel sinks.

(b) Compliance with this section is not required for a coastwise vessel--

(1) That carries a VHF radiotelephone that complies with the FCC requirements; and

(2) Whose Certificate of Inspection is endorsed for a route which does not extend more than 20 miles from a harbon or safe refuge.

Reference 4

AOPA

AIRCRAFT OWNERS AND PILOTS ASSOCIATION/WASHINGTON, D.C. 20014/Tel: (301) 654-0500/cable address: AOPA, Washington, D.C

July 9, 1975

Admiral Owen W. Siler, Commandant
United States Coast Guard
400 7th Street, S. W.
Washington, D. C. 20590

Dear Admiral Siler:

It is our understanding that the Interagency Committee on Search and Rescue was to be reviewed on June 30, 1975 to determine if it should be continued, realigned or terminated. The Aircraft Owners and Pilots Association offers these comments for your consideration in preparing your recommendations.

AOPA has become increasingly concerned about the civil aviation search and rescue (SAR) situation. The division of the responsibility in this area between different agencies, coupled with what we believe to be an occasional lack of coordination between these agencies has caused a deterioration of any SAR system we now have. Examples of these problems include various responsibilities of the FAA flight service stations, the lack of coordination on existing emergency locator transmitter (ELT) problems and lack of interest by some agencies in developing an ELT monitoring system.

AOPA believes there are two underlying problems that must be solved. First, there is no organized forum through which civil aircraft operators can discuss SAR with all responsible government agencies as a group to resolve mutual problems. While the Radio Technical Commission for Aeronautics (RTCA) has had a number of special committees working on SAR-related problems, the terms of reference have always been limited. Special Committee 127 currently working on improved Minimum Performance Standards for emergency locator transmitters (ELT) is a perfect example. The Committee is limited to discussing standards for the airborne equipment. Outside of RTCA, separate aviation users must deal with separate SAR agencies. This has not been very effective in the past.

The second problem is the documented inadequacies in the existing SAR alerting system. These inadequacies include the VFR flight plan and ELT systems. FAA has said that 10-15% of itinerant VFR flights file flight plans with the FAA. In calendar year 1974 of the 191 SAR missions coordinated by the SAR forces for the contiguous states, only 67 missions (35%) were initiated by FAA flight service stations for aircraft on VFR flight plans. The remaining SAR missions were initiated by: family concern, lost radio/radar contact, law enforcement agencies, FBO's and base operations, visual sightings and ELT's.

Further, there is no effective ELT monitoring system in the United States. When the requirement for ELT carriage went into effect, the monitoring system was considered to be those ground stations monitoring the emergency frequency and a voluntary program of airborne monitoring by pilots. Those pilots who chose to monitor for ELT's were soon discouraged from doing so by the attitude of personnel at the facilities they reported signals to, specifically FAA facilities. In the original ELT regulation adopted on September 14, 1971, FAA commented that monitoring capability was adequate for that time. AOPA and many others disagreed. It was determined that additional rule making would be undertaken when it was deemed necessary. In the period since ELT implementation, it has been clearly demonstrated that ELT monitoring is inadequate. AOPA and others have highlighted this fact on numerous occasions, however, we are not aware of any resulting improvement in the situation.

Based on the foregoing discussion, AOPA makes the following recommendations:

1. The Interagency Committee on Search and Rescue (IACSAR) be made an advisory committee and that nongovernment aviation representatives be invited to serve on the committee. Failing this, some mechanism should be established for nongovernmental interests in SAR to be consulted with or through which these interests can make recommendations to IACSAR.

2. IACSAR recommend and actively support a program to develop a SAR satellite monitoring system. Much work has already been done in this area by the National Aeronautics and Space Administration (NASA). At a recent NASA workshop on the subject, aviation users spoke in favor of a satellite test.

3. IACSAR recommend to appropriate agencies that an adequate airborne monitoring system be established. This system should be developed and implemented as soon as possible and could include ELT monitoring by the air carriers. Further, this system could serve in the interim until satellite monitoring becomes operational.

It should be apparent from these recommendations that the issue of an adequate SAR alerting network is of deep concern to the Aircraft Owners and Pilots Association as the representative of our 180,000 members. AOPA stands ready to assist in the development and implementation of any responsive program that you establish.

Cordially,

Robert T. Warner

Robert T. Warner
Special Projects Assistant
Policy and Technical Planning

cc: National Association of Search and Rescue Coordinators
Air Force Rescue Coordination Center
RTCA Special Committee 127
New Mexico Department of Aviation
✓NASA/GSFC
Don Downie, AOPA Western Representative

AOPA
AIRCRAFT OWNERS AND PILOTS ASSOCIATION/WASHINGTON, D.C. 20014/Tel: (301) 654-0500/cable address: AOPA, Washington,

June 21, 1976

Dr. James C. Fletcher, Administrator
National Aeronautics and Space Administration
Fourth and Maryland Avenue, S. W.
Washington, D. C. 20546

Dear Dr. Fletcher:

As you may know, Public Law 91-596, enacted December 29, 1970, required most of the civil aircraft fleet to install Emergency Locator Transmitters (ELTs). There are now approximately 135,000 ELTs in use. Unfortunately, an effective monitoring system to detect ELT signals does not exist.

AOPA has for some time urged that a system be established to adequately monitor for ELT signals. In 1972, AOPA together with the New Mexico Department of Aviation, recommended to NASA and the FAA that an experiment be conducted to determine the feasibility of monitoring for ELT signals by satellite. AOPA currently is participating in the Working Group of the Interagency Committee on Search and Rescue (ICSAR), which has a draft report on this subject.

In answer to a query from us, Mr. Eugene Ehrlich, NASA Office of Applications, in a letter dated June 15, 1976, indicated that through tests and studies conducted by NASA, it has been determined that present-day ELT signals can be received and position of the ELT located by low orbital satellites.

It would appear that the next step would be for NASA, on behalf of the U.S. Government, to develop and launch as soon as practical a prototype satellite to demonstrate the capabilities of a satellite ELT monitoring and location system. We understand that the Canadians also have shown interest in the project, since they have a similar problem.

Your comments will be appreciated.

Sincerely,

Victor J. Kayne, Senior Vice President
Policy and Technical Planning

Member: International Council of Aircraft Owner and Pilot Associations

Reference 5

NATIONAL ASSOCIATION OF SEARCH AND RESCUE COORDINATORS

P. O. BOX 8100 SALT LAKE CITY, UTAH 84108

BLAIR E. NILSSON
Colorado SAR Coordinator
President

JOHN H. OLSON
Oregon SAR Coordinator
1st Vice President

JEFF F. MONROE
North Dakota SAR Coordinator
2nd Vice President

PAUL H. KOENIG
Utah SAR Coordinator
Secretary/Treasurer

January 27, 1976

Dr. James C. Fletcher, Administrator
National Aeronautics and Space Administration
Washington, D. C. 20546

Dear Dr. Fletcher:

I, and other members of NASARC, met with Mr. Eugene Ehrlich and Mr. Bernie Trudell of NASA at the FAA-sponsored ELT Symposium in Oklahoma City on October 1-2, 1975, and at the NASARC Annual Conference in Denver on December 4-7, 1975. We are very impressed with NASA ideas and proposals for a satellite monitoring system for the aviation emergency frequencies.

Because of its extensive involvement in SAR operations for victims of aviation accidents, NASARC heartily endorses the promotion of an effective Emergency Locator Transmitter (ELT) Program. This device has greatly improved the SAR community's ability to rapidly locate an accident site and provide resources appropriate to the terrain and weather. However, the ELT program currently is being frustrated by problems of two types: first, the high incidence of malfunction or inadvertently caused signals; and, secondly, the lack of an effective monitoring system covering the entire area of United States for detecting and fixing the source of the signal.

Due to low power output of ELT's, and the line of sight transmission characteristics, many of our more remote and rugged areas of America are not monitored by receivers at all, or very infrequently by overflying high altitude aircraft at best. Therefore, there is a serious gap in present day monitoring capabilities by aircraft and ground stations. Prompt detection of ELT signals and accurate fixing of the signal source geographically could well mean the difference between life and death or an expensive search for a non-distress signal activation.

NASARC, for these reasons, most heartily supports and encourages NASA initiatives and concepts for the development of a satellite monitoring system. NASARC agrees with the recommendations of the NASA Search and Rescue Panel held at Easton, Maryland in May 1975. We consider the development and launching of such a system to be a giant step forward in humanitarian

"That Others May Live"

Reference 5

concern for our fellow citizens. NASARC, at its Annual Conference, has forthwith elected to endorse the concept of such a system as described by your organization. We are appreciative of efforts by NASA in applying its advanced technological expertise to "everyday" living in the interest of humanitarian concern.

Sincerely,

Blair E. Nilsson

Blair E. Nilsson
President NASARC

BEN:hb

cc: Ryland R. Dreibelbis, Colonel, USAF
Director, Inland SAR
Headquarters AFRCC
Scott Air Force Base, Ill. 62225

Reference 6

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AEROSPACE RESCUE AND RECOVERY SERVICE (MAC)
SCOTT AIR FORCE BASE, ILLINOIS 62225

REPLY TO ATTN OF: AFRCC (Colonel Dreibelbis/4927) 20 May 1976

SUBJECT: Successful ELT Missions

TO: SEE DISTRIBUTION

1. It is becoming increasingly apparent to the Air Force Rescue Coordination Center (AFRCC) that Emergency Locator Transmitters (ELTs) are working better and are contributing to quicker finds of aircraft crashes, the saving of lives, and a reduction of flying hours necessary for search missions.

2. From 1 January 1976 through 30 April 1976, the AFRCC has coordinated air or ground searches for 54 civil aircraft. Twenty (37%) of these aircraft were located by operating ELT equipment; nineteen people survived these accidents, and hundreds of search hours were avoided. This is a significant improvement over previous ELT experience and may indicate a turning point in equipment reliability. This success rate, if continued, should increase pilot confidence in the system and motivate increased ELT reporting throughout the aviation spectrum.

3. Attached are brief summaries of the 20 successful ELT associated missions. For further information concerning these missions, contact Headquarters ARRS/AFRCC, Scott AFB, IL 62225.

FOR THE COMMANDER

RYLAND R. DREIBELBIS, Colonel, USAF
Director, Inland SAR

2 Atch
1. Distribution List
2. Successful ELT Missions

Reference 7

Air Transport Association ata OF AMERICA

1709 New York Avenue, N.W.
Washington, D. C. 20006
Phone (202) 872-4000

December 4, 1975

ATA Statement Regarding Regulatory Proposal 446, FAR 121.313,

Subject - ELT Alerting Devices

The FAA proposal to amend 121.313 by adding a subparagraph (j) to require a radio sensing device to be installed aboard air carrier aircraft to detect an ELT and automatically warn an air carrier flight crew, is opposed. As our formal comments already indicate, we have offered to monitor the emergency frequency 121.5 MHz when requested by a responsible agency as a part of a lost aircraft event. We would like to comment at this time on what we believe to be the lack of maturity of the subject of determining the most cost effective means of ELT monitoring.

FAA data, reported at the third meeting of RTCA SC-127, indicated that during the first six months of 1975 there were 2,917 reports of ELT activation and 2,683 during the last six months of 1975 (to mid-September).

Of these 5,600 reports, 88 per cent of the ELT operations (all inadvertant) result from ELT devices located on airports. Recent discussions with FAA indicate that inadvertant operation continues at the level of 300 - 400 per month. These data would seem to indicate that drastic action must be taken to reduce significantly the number of false activations before monitoring by any organization might produce meaningful data to alert rescue operations.

A number of suggestions have been offered concerning potentially useful methods of monitoring ELTs:

1. Require air carrier aircraft to be equipped (per regulatory proposal being discussed today). With this proposal, at least two methods have been offered as to ways of advising FAA that the ELT has been detected:

    a) Require the pilot in command to notify an appropriate ground station (as provided by FAA proposal to amend 121.564).

    b) Interconnect the alerting device with the transponder code selector to change the code to one that would alert ATC.

2. Install automatic detecting device (perhaps including an automatic direction finder) on high terrain or a tall tower near the most appropriate locations. The detector could have an automatic telephone dialing unit associated with it to report to the appropriate facility.

3. Use low altitudes orbiting or synchronous satellites to detect ELT signals. (May involve changes to ELT.)

We are not aware of any authorative cost versus benefit studies that have been made which would indicate the most effective and lowest cost method of providing for monitoring of ELTs. It is rather obvious that utilizing any of the three foregoing methods has significant costs related to it.

It seems completely unreasonable that the FAA should, at this time, make a regulatory proposal without providing meaningful data on the cost of at least the most obvious alternatives.

We have made some preliminary estimates as to what an automatic ELT alerting device might cost to buy, install and maintain on 2500 air carrier aircraft. Our best judgment at this early date is that the cost of providing this sort of service by 2500 air carrier aircraft would not be less than $12.5 million to buy and install the equipment and $3.75 million per year to maintain it. Without some assurance of being reimbursed, airlines would be reluctant, if not opposed, to make an investment of this magnitude.

One further item should be noted. It would take not less than 18 months and more likely 24 months to write characteristics, procure and install the equipment on a very expeditous basis in 2500 air carrier aircraft. This suggests that if it could be shown that monitoring by air carrier aircraft might be the most cost effective method, and assuming the government is willing to pay the bill, in our view, an interim solution, such as installing alerting equipment on promontories near major airports may be an interim, perhaps even long term, useful solution and deserves very careful consideration.

ATA comments on regulatory proposal 446 inadvertantly omitted from FAA published version.

Proposal No. 446 FAR 121.313

ATA opposes this proposal. Automatic monitoring of any distress frequency by airline aircraft operating over the United States would require a new VHF receiving function not useable for other purposes along with an auto-alarm capability, another warning device in the cockpit. No "simple" monitor is possible using existing equipment. Implementation of such new equipment to automatically monitor crash locator beacons triggered primarily by general aviation aircraft is not justifiable. Though the proposal lacks essential detail and justification, it is apparent that the primary benefit would be to general aviation, and no benefit to the airlines carrying the device. Costs are unknown, but from initial calculations, the economic impact on the airlines to perform this search and rescue function primarily for general aviation aircraft would be substantial. Separate antenna would be costly, adding drag and weight. In this connection, parallel connection to existing antenna would degrade performance of each receiver. Providing monitoring devices for ELT transmission is an expense that should not be made applicable to air carriers. Further, the present rate of false alarms would make monitoring and reporting an impossible and unacceptable burden. The objective of the proposal in the broad morality context is a worthy one, but it would impose a substantial economic burden on the air carriers with nothing received in return. On the other hand, the airlines have repeatedly pledged their readiness to offer Good Samaritan service whenever requested by a responsible agency during a specific lost aircraft event by monitoring the emergency frequency 121.5 MHz and relaying any resulting information to appropriate agencies.

APPENDIX B
AIRCRAFT OPERATORS AND PILOTS COMMENTS ON FAR PART 121

In late 1975, the Federal Aviation Administration (FAA) proposed a requirement for FAR Part 121 operators (air carriers) to carry an ELT monitor device by July 1977. This device would include a visual indication to the pilot that an ELT signal was radiating. Currently, this is the only known plan to improve DAL utilizing aircraft. The geographical coverage to be provided by such a system was developed by a study of the Department of Transportation's Transportation System Center. In its report (DOT-TSC-OST-73-42), the Center concluded that "one can expect once a day coverage over 90% of the Continental U.S."

The FAA proposal was commented on by aircraft operators and pilots in a public forum in December 1975. The following comments were made:

Aircraft Owners and Pilots Association: "We feel that the ELT system in the United States will not exist until such time as we have airborne monitoring. The ELT cannot approach its intended purpose as a useful search and rescue tool until that time. In brief, we strongly support the proposal made by FAA."

Air Transport Association: "ATA agrees with the objective of the proposal. However, we oppose this particular item as a way of satisfying that objective. Number one, because of the poor reliability of the current

ELT equipment aboard aircraft. Number two, it will adversely affect airline safety because justification has not been properly analyzed - whether it is considered as the potential impact on the loss of an airline aircraft. The economic investment to the carriers currently is projected at $12.5 million for procurement and installation; and slightly less than $4 million annually to maintain.

"We would suggest, however, that inasmuch as this objective is certainly a worthwhile one, that alternative measures should be pursued in order to determine a better way of satisfying this particular requirement."

Air Line Pilots Association: "We agree with the concept of the FAA proposal since this is one more part in the proposed worldwide emergency communications system. We would, however, like to stipulate that this device should not be a no-go item. It should be capable of deactivating when necessary."

ALPA suggested that since this is a part of a worldwide system, that federal funding be available for installation of these devices.

This proposal, if implemented, would only serve as the initial alert of an ELT signal activation. If an air carrier pilot were to follow-up by monitoring the emergency frequency, he might be able to provide some additional information using the fade-and-build technique. However, there might still be a requirement for additional airborne search, depending on the situation, to obtain a more precise location. There are no known plans to improve this portion of the airborne search capability. Existing airborne DF capabilities include: the Air Force, the Coast Guard, FAA Flight Inspection Aircraft, the Civil Air Patrol (CAP) and SAR organizations and agencies. Air Force and FAA capabilities are limited and both agencies have priority duties above ELT searching. Coast Guard capabilities are primarily responsible for the maritime SAR region. As of January 1976, AFRCC records indicate that the CAP has 266 DF equipped aircraft in the nation. Only 90 of these are capable of instrument flight.

APPENDIX C

RADIATING POSITION LOCATION SYSTEMS

C.0 INTRODUCTION

Radiating position location systems are derived from two classes of stations: fixed and satellite systems. This appendix discusses the four types of fixed stations (LORAN-A, LORAN-C, OMEGA, and DECCA) and two types of satellite systems (TRANSIT and GPS). Table C-1 presents comparative characteristics of the radiating position location systems described in this appendix.

TABLE C -1
COMPARATIVE CHARACTERISTICS OF RADIATING POSITION LOCATION SYSTEMS

POSITION LOCATION TECHNIQUE	DAYTIME RANGE (N.M.)	FREQ. 1	ACCURACY (N.M.)	ADVANTAGES	DISADVANTAGES
LORAN-A	600	1.75 — 1.95 MHz	1.0	o passive, all weather o low cost package	o Short range o multipath error o complex equipment
LORAN-C	1200	90- 110 KHz	0.25	o medium accuracy o medium long range o passive, all weather	o high receiver cost o complex equipment o multipath error
OMEGA	6000	10- 14 KHz	1.0	o worldwide coverage o all weather	o high user cost o significant ambiguities o moderately complex equipment
DECCA	500	70- 130 KHz	2.0	o low power	o range limited o multipath error o complex equipment
TRANSIT	World-wide	150 MHz, 400 MHz	0.1	o worldwide coverage o all weather o hourly coverage	o complex equipment
GPS	World-wide	L-Band	0.01	o worldwide coverage o all weather o instantaneous coverage	o complex equipment

C.1 LORAN NAVIGATION SYSTEM

The LORAN Navigation Sytem is in use throughout most of the world, particularly along the densely populated coastlines and by maritime and naval shipping users. The method used to determine position locations is to define two or more lines of position (LOP) or range lines from pairs of transmitting radio stations. Ranges from known radio stations are measured by comparing the time of arrival difference of the signals from each of two stations. Each pair of stations provides a hyperbolic curve on the surface of the earth. The intersection of the curves defines the position location as shown in Figure C-1.

C.1.1 LORAN-A

The LORAN-A system is considered an all-weather navigational system up to a range of from 1100-1600 km (600-900 nmi) in the daytime using groundwaves. The accuracy of LORAN-A is largely dependent on the correct timing and synchronization of the transmitted signals. In each local area, one station is considered to be the master station which assures a precisely spaced series of transmitted pulses. The various other stations are considered to be "slave" stations. The slave station transmits a correponding series of pulses upon receipt of the master transmission.

Distances beyond groundwave coverage areas can be received with reduced accuracy up to 2600 km (1400 nmi) usually at night, by skywaves which are reflected from the ionosphere one or more times.

C.1.2 LORAN-C

The LORAN-C, like LORAN-A, is a pulsed, hyperbolic navigational system which uses the time of arrival difference of RF signals from three stations of known location to establish a position location. A phase-difference measurement system is used which provides a greater accuracy than is available by the pulse-difference method alone. Since the LORAN-C system uses a lower frequency than the LORAN-A system, groundwave coverage can be extended out to approximately 2200-2600 km (1200-1400 nmi).

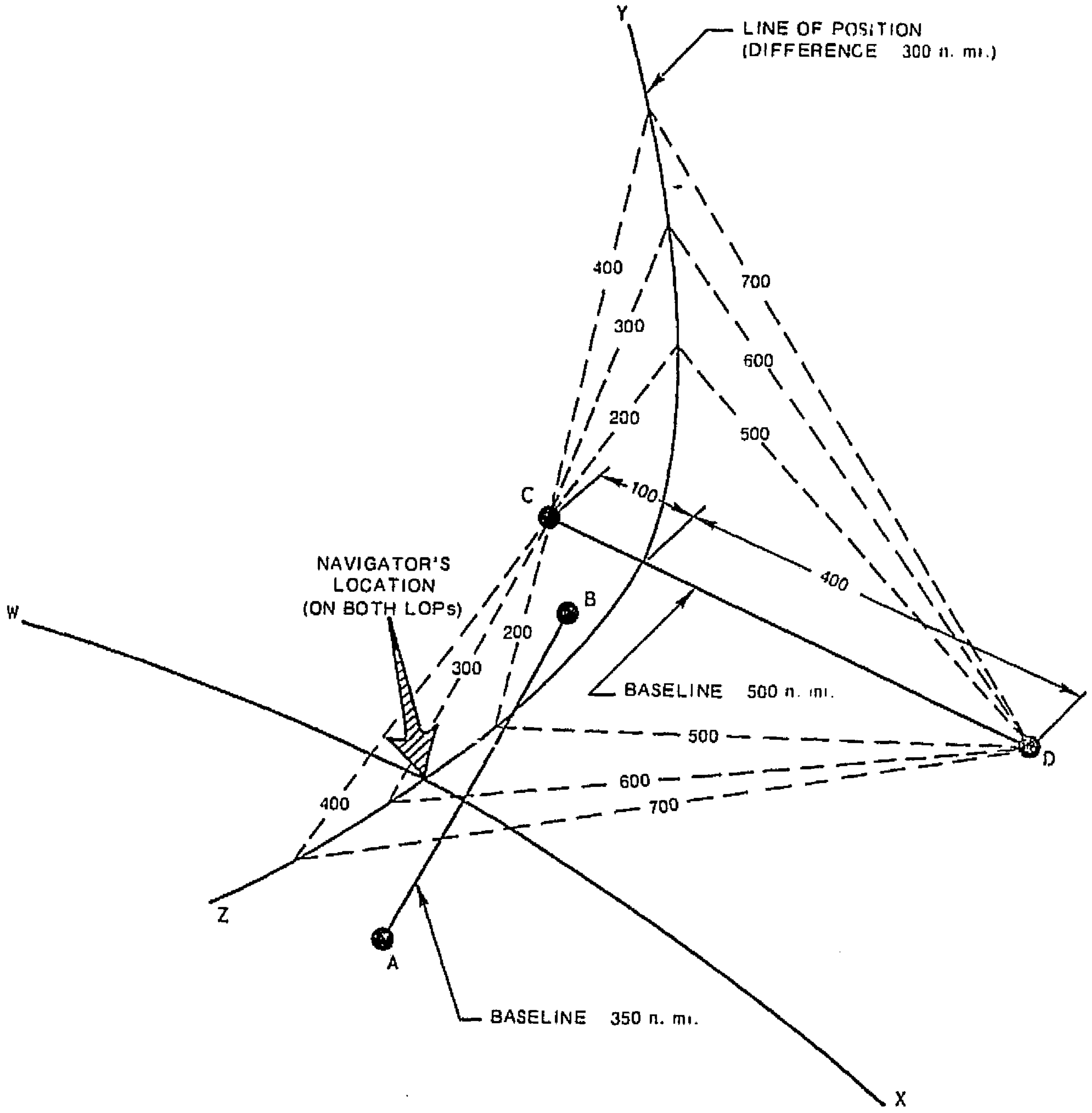

FIGURE C-1. LORAN LINE OF POSITION AND LOCATION DETERMINATION

C.2 OMEGA

The OMEGA system consists of a network of eight VLF (10-14 KHz) radio stations, strategically located, for complete worldwide coverage to provide position location to an accuracy of 1 nmi.

Each of the eight stations transmits a 10.2 KHz continuous wave signal for one second in turn, every 10 sec, with all transmissions phase-locked to a common standard time. Since the transmissions are phase-locked, the signal field phase is everywhere stationary; and the relative phase angle of a particular pair of signals observed at any given point depends solely upon how much further it is to one of the stations supplying the pair of signals from the other. Furthermore, the same phase angle will be observed at all points which have the same difference in the distances from the two stations. The locus of such points is a contour of constant phase (isophase contour) fixed on the surface with respect to the locations of the corresponding pair of transmitters.

Thus, the relative radio frequency phase of every pair of signals observed at any point on earth defines a known isophase contour (hyperbolic line of position) containing that point, and the intersection of two such contours established by different pairs of stations defines the location of the point.

C.3 DECCA

The DECCA navigation system is an operational range difference navigation system. Position fixes are determined by measuring phase differences in received continuous-wave signals. The DECCA system's range is limited to approximately 460-925 km (250-500 nmi). The system requires a tuneable receiver since there is no fixed operating frequency for its different areas of coverage.

C.4 TRANSIT

The Navy Navigation Satellite System (TRANSIT or NNSS) has provided a worldwide, all-weather navigation system that can provide a navigational fix to an accuracy of 0.19 km (0.1 nmi) at intervals of approximately 2 hours or less. The system is shown schematically in Figure C-2 and consists of near-earth satellites, tracking stations, injection stations, a computing center, and shipboard navigation equipment.

Timing signals transmitted from the satellites of the system are synchronized with universal time code (UTC) to within 200 microseconds. The system employs the doppler effect for both satellite position determination and navigation. In the former, four tracking stations in precisely known locations observe the doppler shift of the ultrastable radio signals generated by the satellite transmitter as the satellite approaches and recedes from the stations. This doppler information is translated into satellite positions as a function of time by the computing center. From this information and with the knowledge that the motion of the satellite is governed by Newton's laws of motion, the position of the satellite as a function of time can be predicted. These predictions become the ephemeris of the satellite for the predicted duration (16 hours) and are stored in the memory of the satellite by the injection station. As the satellite orbits the earth, it continually reads out data from which its position can be computed together with precision time. This transmission is continually updated by the satellite by discarding obsolete data and drawing more timely data from its memory. To determine his position, a navigator equipped with shipboard navigation equipment need only observe the doppler shift in the satellite signals, obtain the data on the satellite position, and perform the necessary computations. The navigator remains completely passive; i.e., no interrogation of the satellite is necessary.

The ground support system consists of tracking stations to receive, record, and digitize doppler signals from the satellites; a computing center where future orbits, orbital parameters, and time corrections are computed; and an injection station to transmit these new orbital parameters and time corrections to the satellite. In addition, the satellite time signals are compared with

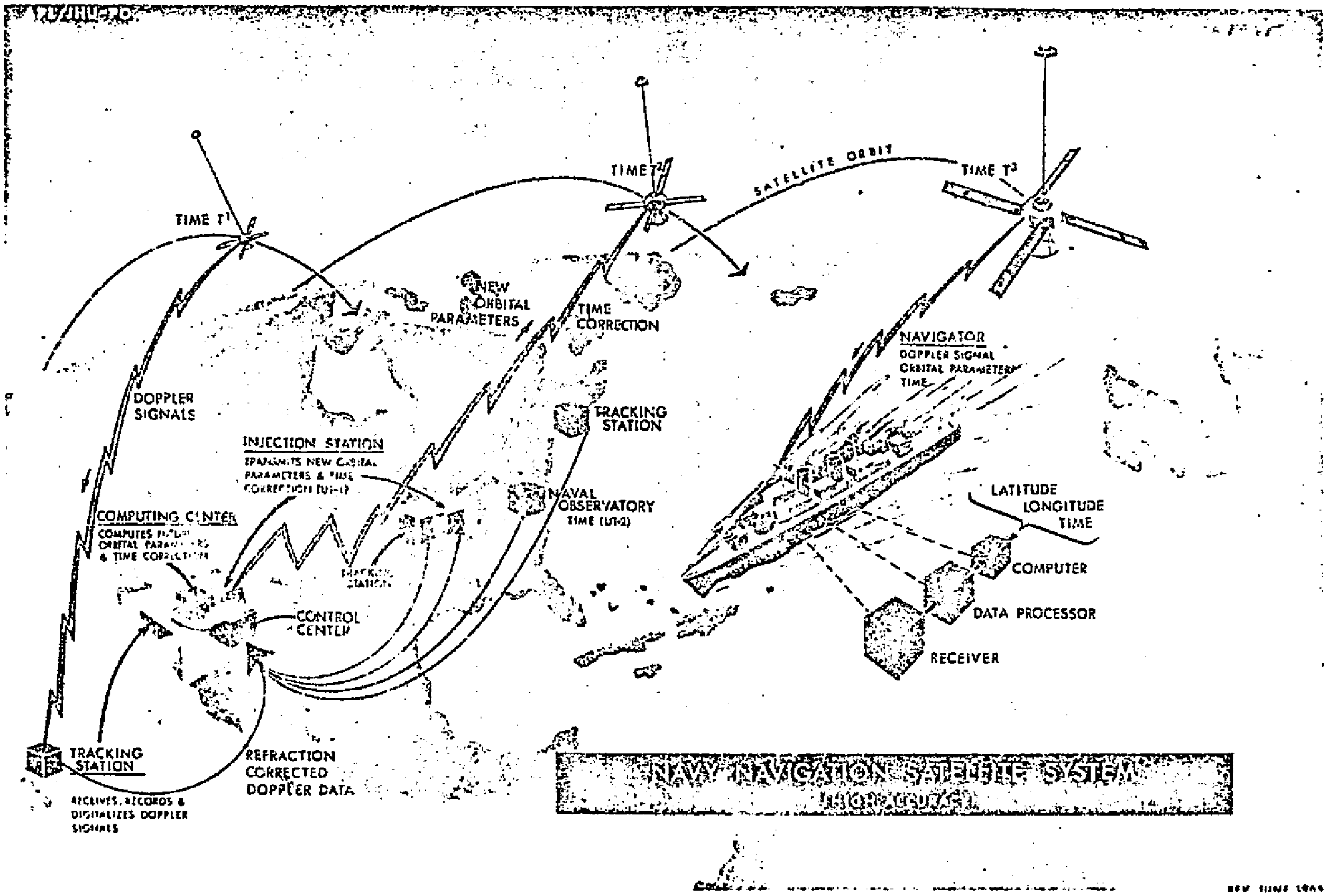

FIGURE C -2. NAVY NAVIGATION SATELLITE SYSTEM universal time. This information is used in the computing center for the time correction computations. The U.S. Navy Astronautics Group, with headquarters at Point Mugu, California, is responsible for operating the system.

C.5 GLOBAL POSITIONING SYSTEM (GPS)

The NAVSTAR (Navigation System Using Time and Ranging) global positioning system (GPS) will provide a worldwide, highly accurate, and instantaneous three-dimensional location by air, sea, and surface vehicles equipped with GPS receivers. The global operational system consists of 24 satellites orbiting the earth at an 18,500 km (10,000 nmi) altitude in three orbital planes with eight satellites in each plane. The satellites would provide continuous signals under all weather conditions. When these signals are received by the GPS user equipment, they are translated into longitude, latitude, altitude, and velocity readings accurate to within tens of meters.

APPENDIX D
CURRENT FREQUENCY ALLOCATIONS

D.1 TERRESTRIAL MODE

International radio regulations provide the following frequency bands for possible use in connection with distress, safety, and emergency communications:

Frequency	
500 kHz	The international distress safety and calling frequency used by ship, aircraft and survival craft stations.
2182 kHz	International distress, safety and calling frequency used for distress purposes by ship, aircraft, survival craft and EPIRB's.
2670 kHz	USCG emergency coordinations.
3023.5 kHz	This frequency may be used for intercommunication between mobile stations when engaged in coordination SAR operations, including communication between these stations and participating land stations.
4335 kHz	AF crash boats, general.
4383.8 kHz	Alaska emergency frequency.

4236.3 kHz and 6204 kHz	If a distress message has not been acknowledged on 2182 kHz, these frequencies may be used south of latitude 15°N in Regions 1 and 2 and latitude 25°N in Region 3. Frequencies will change to 4125 kHz and 6215.5 kHz on January 1, 1978.
5680 kHz	This frequency may be used for intercommunication between mobile stations when engaged in coordinated SAR operations, including communication between these stations and participating land stations.
8364 kHz	Designated for use by survival craft stations for SAR purposes.
121.5 MHz	This is the aeronautical emergency frequency in this band; mobile stations of the maritime mobile service may communicate on this frequency for safety purposes with stations of the aeronautical mobile service. ELT/EPIRB's also use this frequency.
156.8 MHz	This is the international distress, safety and calling frequency for radiotelephony for stations of the maritime mobile service when using frequencies in the authorized bands between 156 and 174 MHz. It is used for the distress signal and call and distress traffic, for the urgency signal, urgency traffic and the safety signal.
121.6 MHz	Canada/U.S. scene of action
123.1 MHz	NATO/ICAO scene of action
138.45 MHz	ARRS scene of action
138.78 MHz	Scene of action
243 MHz	This frequency is used by military emergency survival craft stations and equipment. ELT/EPIRB's also use this frequency.
282.8 MHz	International scene of action SAR

D.2 SATELLITE MODE

International radio regulations provide the following frequency bands for possible use in connection with distress, safety, and emergency communications:

Frequency	Present Allocation for Emergency Communications
406 - 406.1 MHz	This band is reserved solely for the use and development of low-power (not to exceed 5W) EPIRB systems using space techniques.
1542.5 and 1543.5 MHz	Suitable for Emergency Communications* Use of this band is limited to transmissions from space to earth stations in the aeronautical mobile-satellite (R) and maritime mobile-satellite services for communication and/or radio-determination purposes. Transmissions from land stations directly to mobile stations, or between mobile stations, of the aeronautical mobile (R) and maritime mobile services, are also authorized. Utilization of this band is subject to prior operational coordination between the two services.

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[*] Although these bands are not allocated exclusively for distress, safety and emergency communications, they are shared between aeronautical and maritime mobile-satellite services and such uses are likely as operational mobile-satellite systems develop. Provision also exists for terrestrial use. The adequacy of these frequency allocations for any DAL system depends upon the design requirements of such a system. When design requirements are fixed, the adequacy of frequency allocations may be appropriately addressed.

1644 - 1645 MHz	Use of this band is limited to transmissions from earth to space stations in the aeronautical mobile-satellite (R) and maritime mobile-satellite services for communication and/or radio-determination purposes. Transmissions from mobile stations directly to land stations, or between mobile stations, of the aeronautical mobile (R) and maritime mobile services, are also authorized. Utilization of this band is subject to prior operational coordination between the two services.

APPENDIX E
SATELLITE COVERAGE OF ELT/EPIRB's

Section 5 discussed the satellite-ground coverage for 700 and 1000 km altitudes for Alaska, CONUS, and the maritime regions. This appendix discusses, parametrically, the effect of satellite-ELT/EPIRB coverage due to satellite altitude and the ELT/EPIRB latitude and local elevation (horizon) angle.

In order to acquire an accurate position location fix on an ELT/EPIRB signal, it is necessary to "track" the signal from the satellite for a sufficiently long period of time. From past studies, this length of time has been determined to be about 4 minutes.

As a satellite moves along its trajectory, it traces out a swath on the earth's surface. This swath width is the instantaneous cross track view to a ground observer (ELT/EPIRB) for a particular local elevation angle. For a polar orbiting satellite, the earth rotates (precesses) a fixed angle every satellite revolution. If this swath width is exactly equal to the earth precession angle, then adjacent satellite swaths would just intersect at the equator and overlap for all other latitudes. For swath widths less than the earth precession angle, the adjacent satellites track swath would intersect at some latitude other than at the equator. Below this latitude, the coverage interval could be greater than 12 hours.

Figure E-1 shows the latitude above which a 4 minute satellite-ELT/EPIRB coverage, can be guaranteed every 12 hours. As an example, for an ELT/EPIRB with an elevation of 20° and a satellite altitude of 700 km, the limiting lower latitude for overlapping coverage for adjacent orbits is 38°. In contrast, a satellite with an altitude of 1000 km can provide coverage for the same ELT/EPIRB down to the equator. Or, stated another way, a satellite with an altitude of 1000 km can provide coverage for ELT/EPIRB's with elevation angles up to 27° at a latitude of 38°. Figure E-1 also shows that coverage can be extended by increasing the time (24 hours) allowed for a satellite to come within 4 minutes of visibility with an ELT. Figure E-2 expands the range of the parameters shown in Figure E-1.

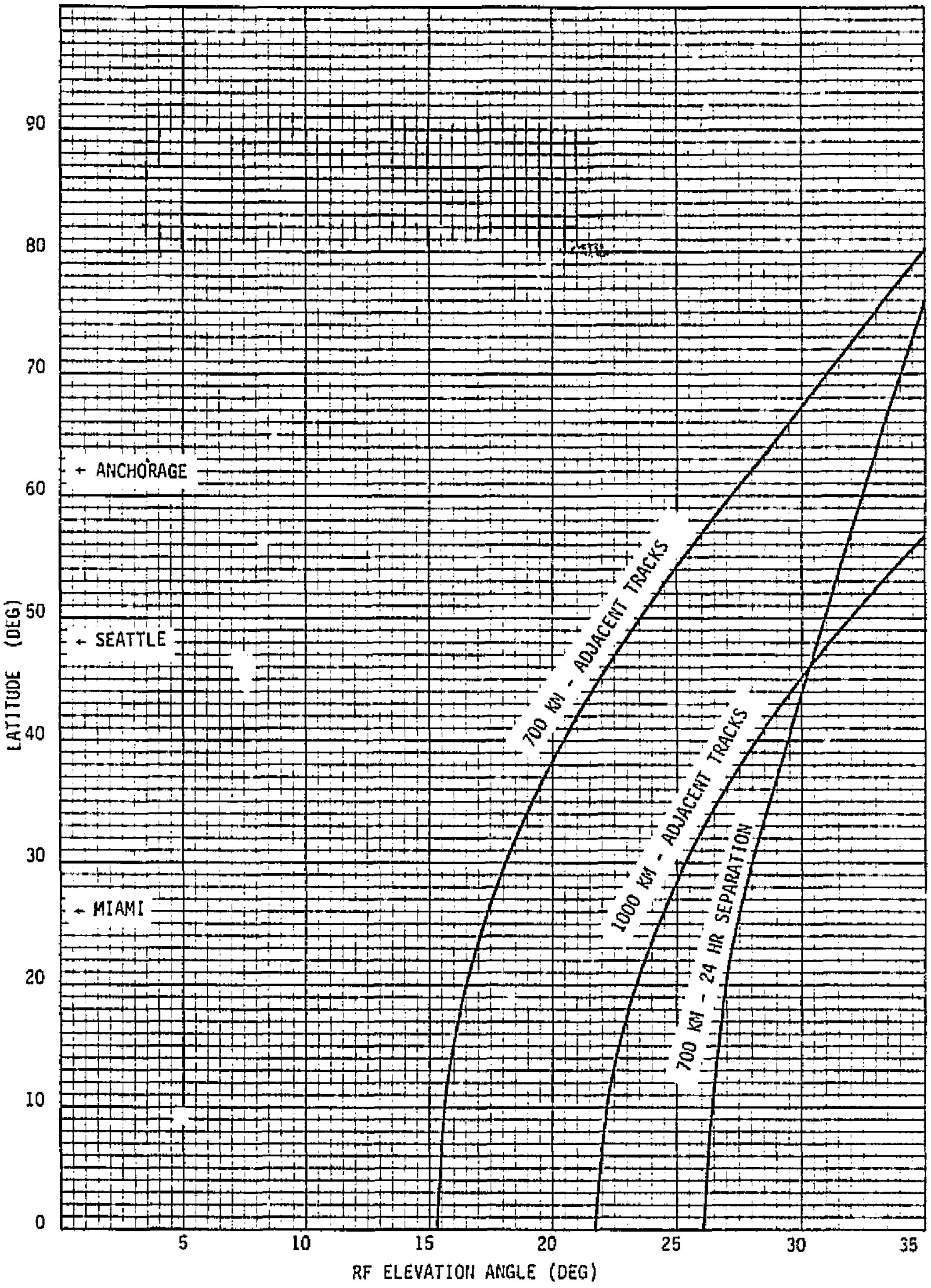


FIGURE E-1. SATELLITE GROUND TRACK CROSS OVER POINT FOR 4 MINUTE MINIMUM CONTACT TIME

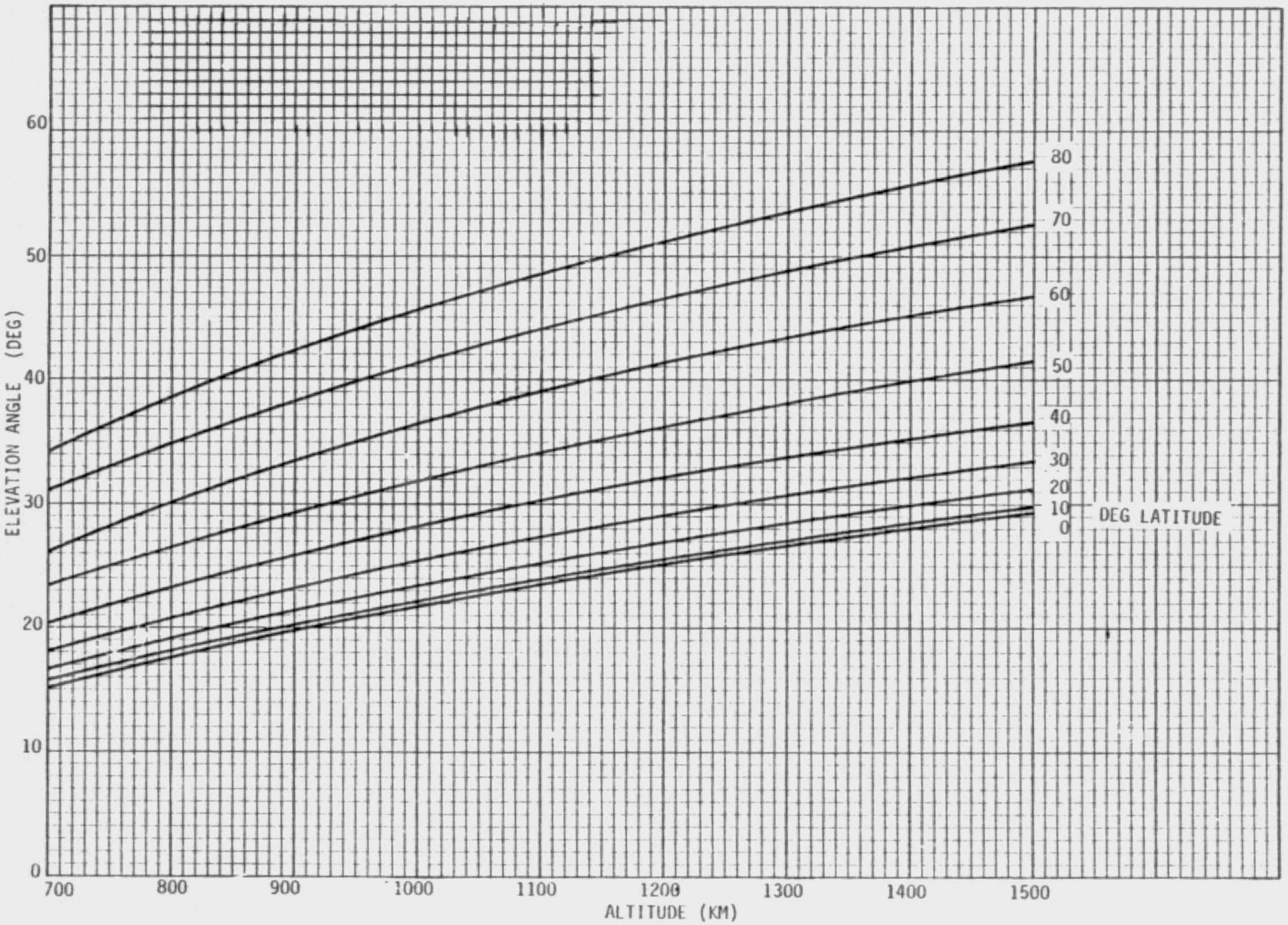


FIGURE E-2. SATELLITE GROUND TRACK CROSS OVER POINT FOR 4 MINUTE MINIMUM CONTACT TIME

APPENDIX F
SEARCH AND RESCUE ORBITING SYSTEM (S.O.S.)

F.1 MISSION CHARACTERISTICS

The use of satellites to detect and locate existing ELT's and EPIRB's requires signal acquisition and processing techniques with emphasis on the current problems of low signal strength, poor frequency stability, and the variety of modulation techniques being employed. The operational system proposed, as shown in Figure 5-3, is to use satellite-aided detection and location to fulfill the needs for alerting and locating "distress incidents" for the SAR user community.

The ELT's and EPIRB's will transmit their signals to the orbiting spacecraft. The spacecraft will relay the signals, in real time, to an earth station which will detect the signal using phase-locked loop techniques and process the doppler information to determine position location. This data will then be relayed to the nearest rescue coordination center where the SAR forces will be alerted and deployed. These SAR forces can then use the same emergency transmitting signal for final location of the distress. The position location capability of the satellite-aided system will give a distress situation location to an accuracy of about 10-20 km which is well within the SAR force search range.

The satellite system under consideration would be capable of detecting and locating ELT/EPIRB's operating at 121.5 and 243 MHz, as well as improved/new ELT's operating on the 406 MHz frequency authorized for ground-to-satellite SAR use. The baseline concept envisions launching the S.O.S. modules as instruments on the NASA/NOAA and USAF operational weather satellites at approximately 850 km in near polar orbits. Each spacecraft will provide a minimum of two daily overpasses for SAR operations. The instrument modules will also be designed to be compatible with the NAVY TRANSIT "gap-filling" SCOUT-D launches as necessary.

F.2 SYSTEM DESCRIPTION

The satellite-aided SAR system consists of the ELT's and EPIRB's, the spacecraft S.O.S. payload, the ground stations, data processing, and the SAR forces. The interface relationship among the various segments of the total S.O.S. system is shown in Figure F-1. The spacecraft command and control center will be the existing NOAA CDA station located in Alaska, providing maximum contact with the S.O.S. instrument in near polar orbit. The operational demonstration phase will utilize three local user terminals (LUT's). NASA will develop the LUT's and processing software and will provide two terminals. It is assumed that the USAF will provide one terminal. The ELT/EPIRB location data will be sent from the S.O.S. local user terminals to the appropriate rescue coordination centers.

F.2.1 Coverage

The location of the ground stations to provide the coverage for the U.S. (CONUS and Alaska) shown in Figure F-2 are: (1) Elmendorf AFB, Alaska, (2) San Francisco, California, and (3) St. Louis, Missouri. The coverage shown in Figure F-2 assumes a mutual visibility time of at least four minutes between any incident in the area of coverage and the selected ground stations at least once every 12 hours by each satellite carrying the S.O.S. instrument provided that the ELT local elevation angle is 20 deg or less (the coverage contours assumes a ground station elevation angle to the satellite of at least 5 deg from the horizon). The waiting time for a person in distress is shown in Table F-1 as a function of the mode of operation

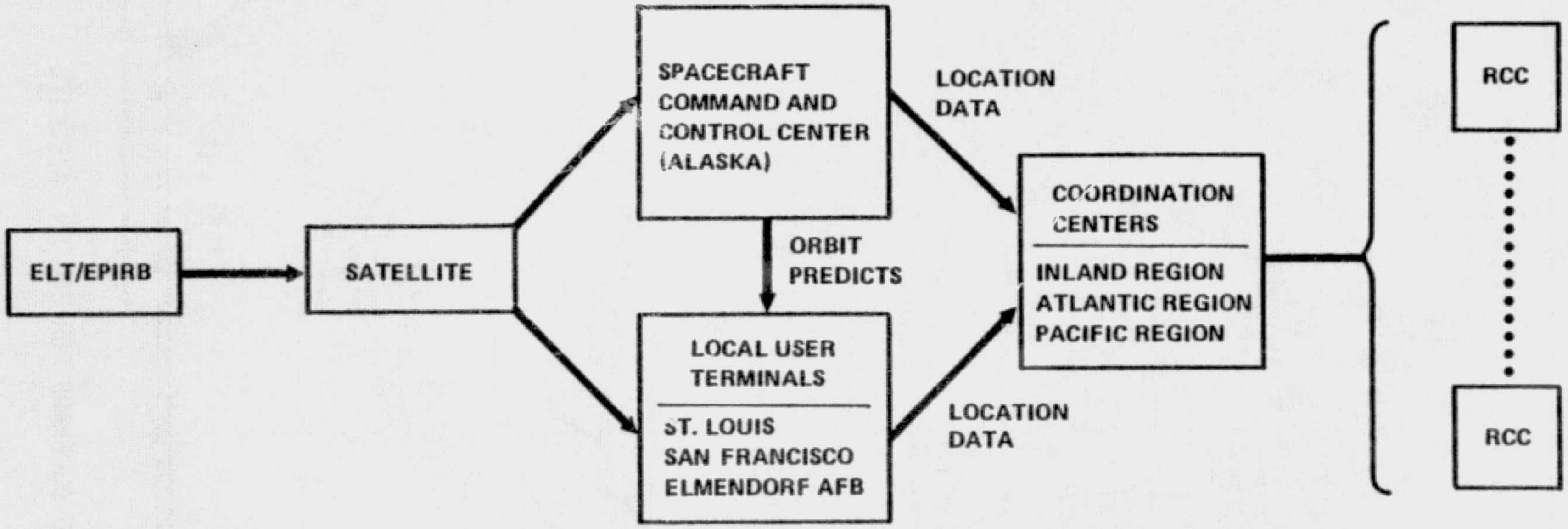


FIGURE F-1. S.O.S. SYSTEM BLOCK DIAGRAM

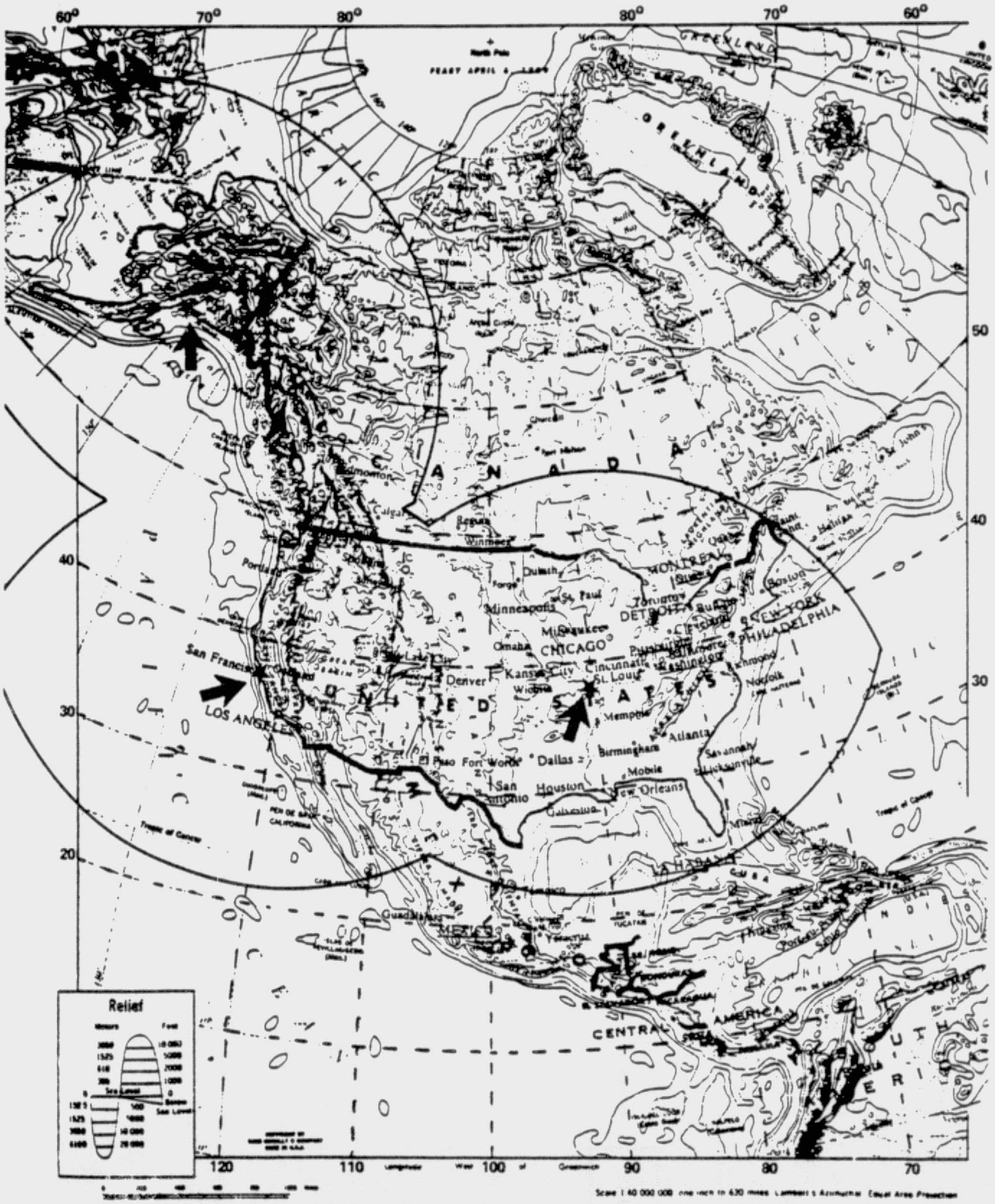


FIGURE F-2. GROUND COVERAGE FOR 850 KM SATELLITE

TABLE F-1
SEARCH AND RESCUE WAITING TIME SUMMARY
(TIME IN MINUTES)

NUMBER OF SATELLITES	GLOBAL COVERAGE			BENT – PIPE		
	1	2	4	1	2	4
CONUS	378* 880 1000	216 660 790	142 390 480	280 630 750	136 390 510	66 180 240
ALASKA	205 580 730	117 370 710	78 290 630	192 540 730	98 350 480	42 90 150
ATLANTIC	514 1000 1140	339 780 910	244 550 620			
PACIFIC	415 1000 1310	269 810 990	218 700 800			

*KEY:

MEAN – 378
90th PERCENTILE – 880
MAXIMUM – 1000

and the number of S.O.S. instruments in orbit. Figure F-3 shows a polar projection of the four meteorological satellites shown in Table F-1. Table F-2 provides the assumptions used in producing Figure F-3 and Table F-1. The "global" mode utilizes the on-board processing and storage capability of the new 406 MHz ELT/EPIRB's to provide a location of a distress incident anywhere on the earth with readout when the spacecraft is over the Elmendorf, Alaska, station. The "bent-pipe" mode provides coverage in real-time only. Additional coverage to reduce the waiting times shown in Table F-1 could be provided by launch of an S.O.S. instrument on a dedicated spacecraft using a TRANSIT spacecraft bus.

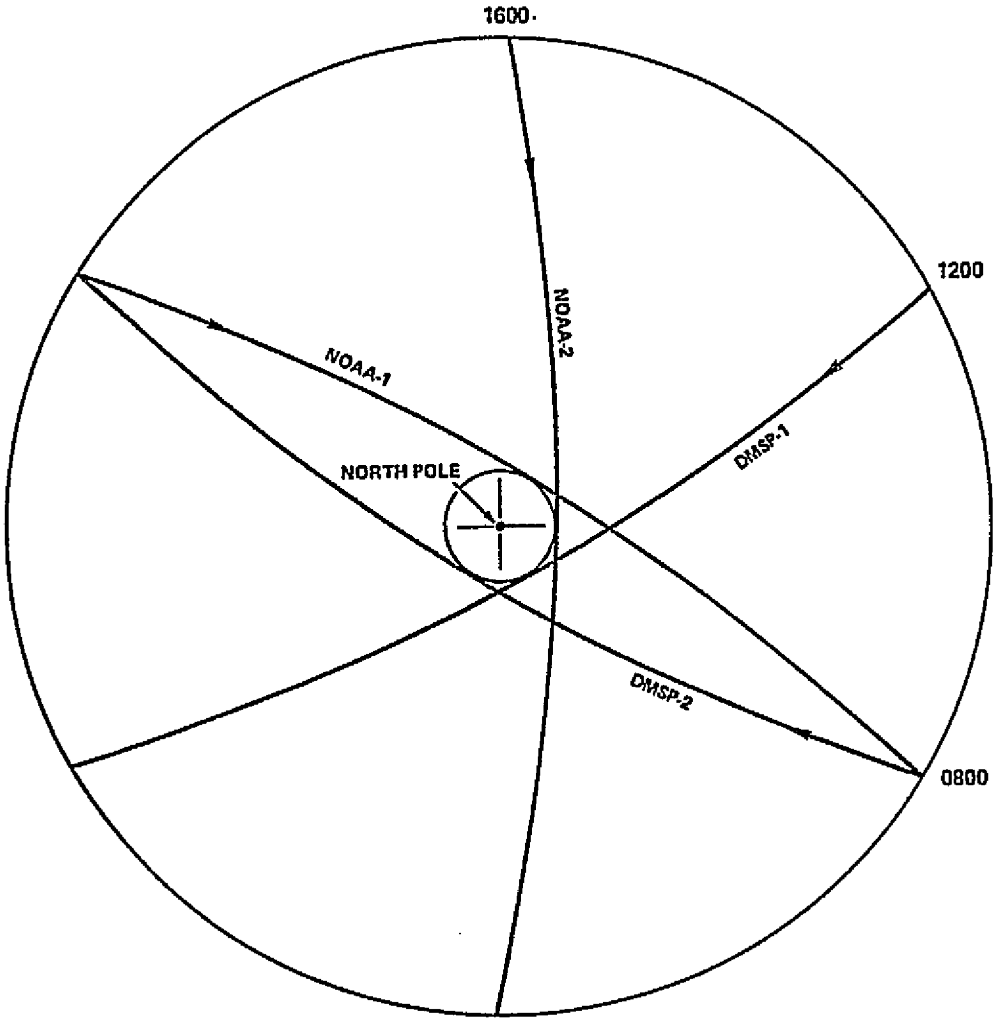
F.2.2 Communication Requirements

The S.O.S. transponder will retransmit the signals received at 121.5, 243 and 406 MHz through a common downlink to a ground station. The overall requirement on the S.O.S. instrument is to repeat the received signals without significantly degrading the overall signal quality of the received signals. Typical engineering design utilizes a signal-to-noise ratio in the satellite-to-ground downlink at least 10 dB higher than the ELT/EPIRB-satellite uplink. An even more conservative assumption is to design the dynamic range in the downlink to handle an emergency voice broadcast appearing in either the 121.5 or 243 MHz band without degrading a weak ELT also operating in either of these frequency bands.

The uplink calculations for S.O.S. are presented in Tables F-3 and F-4 showing worst case and nominal operation. The worst case conditions include major degradation due to man-made noise, lowest usable elevation angle and weakest ELT signal levels.

The nominal performance is expected to represent the performance of the system for a large percentage of ELT transmissions.

An interference calculation is made for an aircraft transmitting at 121.5 MHz, a typical power of 25 W into a stub antenna. The aircraft is assumed directly under the satellite. The result of this calculation is shown in Table F-5. Although this signal may be considered interference, such a call might also constitute a legitimate distress alert and could be received at the ground terminals.



*DMSP - Defense Meteorological Satellite Program

FIGURE F-3. FOUR METEOROLOGICAL SATELLITE CONFIGURATION

TABLE F-2

NOAA AND USAF DMSP* ORBITAL PARAMETERS

(MEAN, ST. DEV)

	NOAA-1	NOAA-2	DMSP-1	DMSP-2
Eccentricity	0., .001	0.,.001	0.,.001	0.,.001
Argument of Perigee	0.,0.	0.,0.	0.,0.	0.,0.
Right Ascension	60,.01	120,.01	300,.01	0.,.01
Inclination	99,.01	99,.01	99,.01	99,.01
Altitude (km)	(450 nmi) 834,2	834,2	834,2	834,2
Mean Anomaly	Randomly chosen between 0° & 360°			

GROUND STATION PARAMETERS

	Lat.	Long.	Alt. (m)	Min. Elev. Angle
Configuration A				
Anchorage	61.12N	149.48W	400	10°
Configuration B				
Anchorage	61.12N	149.98W	400	5°
St. Louis	38.39N	90.15W	0	5°
San Francisco	37.45N	122.26W	0	5°

Assumptions:

1. Earth is randomly positioned at beginning of simulation.
2. Statistics are based on 100 samples at each ELT position.
3. Minimum elevation angle for visibility of the ELT from a satellite is 10°.

*DMSP - Defense Meteorological Satellite Program

TABLE F-3
S.O.S. UPLINK (WORST CASE)

Frequency	121.5 MHz	243 MHz
ELT EPIRB (75 mwatts)	-11.2 dBW	-11.2 dBW
Modulation Loss	4.8 dB	4.8 dB
Ionospheric Loss	1.0 dB	0.3 dB
Polarization Loss	4.0 dB	4.0 dB
Path Loss at 10° Elevation	142.0 dB	148.0 dB
Satellite Antenna Gain	2.0 dB	2.0 dB
Received Carrier Power	-161.0 dBW	-166.3 dBW
Satellite System Temperature	10,000° K	2,500° K
Satellite Noise Density	-188.6 dBW/Hz	-194.6 dBW/Hz
Received Carrier to Noise Density	27.6 dB-Hz	28.3 dB-Hz
Required C/N_0	26.0 dB-Hz	26.0 dB-Hz
Margin	1.2 dB	2.3 dB

TABLE F-4
S.O.S. UPLINK (NOMINAL)

Frequency	121.5 MHz	243 MHz
ELT/EPIRB (75 mwatts)	-11.2 dBW	-11.2 dBW
Modulation Loss	4.8 dB	4.8 dB
Ionospheric Loss	1.0 dB	0.3 dB
Polarization Loss	4.0 dB	4.0 dB
Path Loss at 20° Elevation	139.5 dB	-145.5 dB
Satellite Antenna Gain	3.0 dB	3.0 dB
Received Carrier Power	-167.5 dBW	-162.8 dBW
Satellite System Temperature	1,400° K	650° K
Satellite Noise Density	-197.1 dBW/Hz	-200.5 dBW/Hz
Received Carrier to Noise Density	39.6 dB-Hz	37.7 dB-Hz
Required C/N_0	26.0 dB-Hz	26.0 dB-Hz
Margin	13.6 dB	11.7 dB

TABLE F-5
INTERFERENCE UPLINK CALCULATION

Frequency	121.5 MHz
Transmitter Power (25 W)	14.0 dBW
Antenna Gain (90° elevation)	-3.0 dB
Path Loss (90° elevation)	132.7 dB
Polarization Loss	3.0 dB
Satellite Antenna Gain	3.0 dB
Received Carrier Power	-121.7 dBW
Satellite Antenna Temperature (same as is assumed for weak ELT)	10,000° K
Received Noise Power	-188.6 dBW
Received Carrier-to-Noise Density	66.9 dB-Hz

TABLE F-6
S.O.S. DOWNLINK (WORST CASE)

Satellite Downlink Power (10 W)	10.0 dBW
Degradation for Two Analog Channels and Telemetry Downlink	4.0 dB
Satellite Downlink Antenna Gain	3.0 dB
Path Loss (1543 MHz) at 5° Elevation	164.5 dB
Polarization Loss	1.0 dB
Ground Receiver Antenna Gain (10 ft. diam.)	31.0 dB
Received Signal Level	-125.5 dBW
Receiver Noise Temperature	1,000° K
Receiver Noise Power Density	-198.6 dB/Hz
Downlink Carrier to Noise Density	73.1 dB-Hz
ELT Uplink C/N_0 (worst case)	27.6 dB-Hz
Interference Uplink (25 W transmitter)	66.9 dB-Hz
Interference Signal-to-Noise Ratio (25 kHz bandwidth)	22.9 dB
ELT Downlink C/N_0	33.8 dB-Hz
Overall ELT Total C/N_0	26.7 dB-Hz
Required C/N_0	26.0 dB-Hz
Margin	0.7 dB

The downlink calculation for S.O.S. is shown in Table F-6 including degradation for the 25 W voice signal. The nominal downlink frequency selected for this satellite is 1543 MHz, which is a frequency allocated for emergency space communications for ships and aircraft.

F.3 SPACECRAFT SUBSYSTEM DESCRIPTION

F.3.1 Instrument Description

The S.O.S. instrument module on the NOAA meteorological spacecraft as shown in Figure F-4 consists of a VHF/UHF to L-band transponder and an appropriate solid-state storage device for the 406 MHz digital signal. The module is estimated to weigh 25 Kg (see Table F-7) and require 50 W of power. The three uplink ELT/EPIRB signal frequencies are multiplexed, after on-board signal processing, onto an L-band downlink carrier.

The interface with the spacecraft occurs at the output of the telemetry encoder. It is envisioned that the 406 MHz ELT signal would be encoded and sampled along with the instrument telemetry and the composite signal multiplexed with the spacecraft telemetry. The 121.5 MHz and 243 MHz signals are relayed to a ground station using only the "bent-pipe" approach. The 406 MHz signal can be relayed using the bent-pipe approach or a store-and-forward technique for dumping the data when the satellite cannot provide real-time coverage to the ground station. The decoding of commands for the instrument module would be accomplished by a command decoder which receives a serial command word from the meteorological spacecraft command system.

The 406 MHz uplink signal is received on a separate UHF antenna followed by a low noise receiver. Processing of the 406 MHz ELT signal is accomplished by equipment that will be similar to that used by the NIMBUS-6 RAMS experiment. The processing equipment will format the doppler data for: (1) on-board storage in the solid state storage device; and (2) buffering to the telemetry encoder for insertion into the telemetry bit stream for real-time transmission to the ground.

The 121.5 MHz and 243 MHz uplink signals are received by VHF antennas and processed by separate receivers. The analog ELT/EPIRB signals are then upconverted and multiplexed onto an L-band downlink transmitter over the L-band antenna. An L-band beacon is provided as an aid to ground stations for

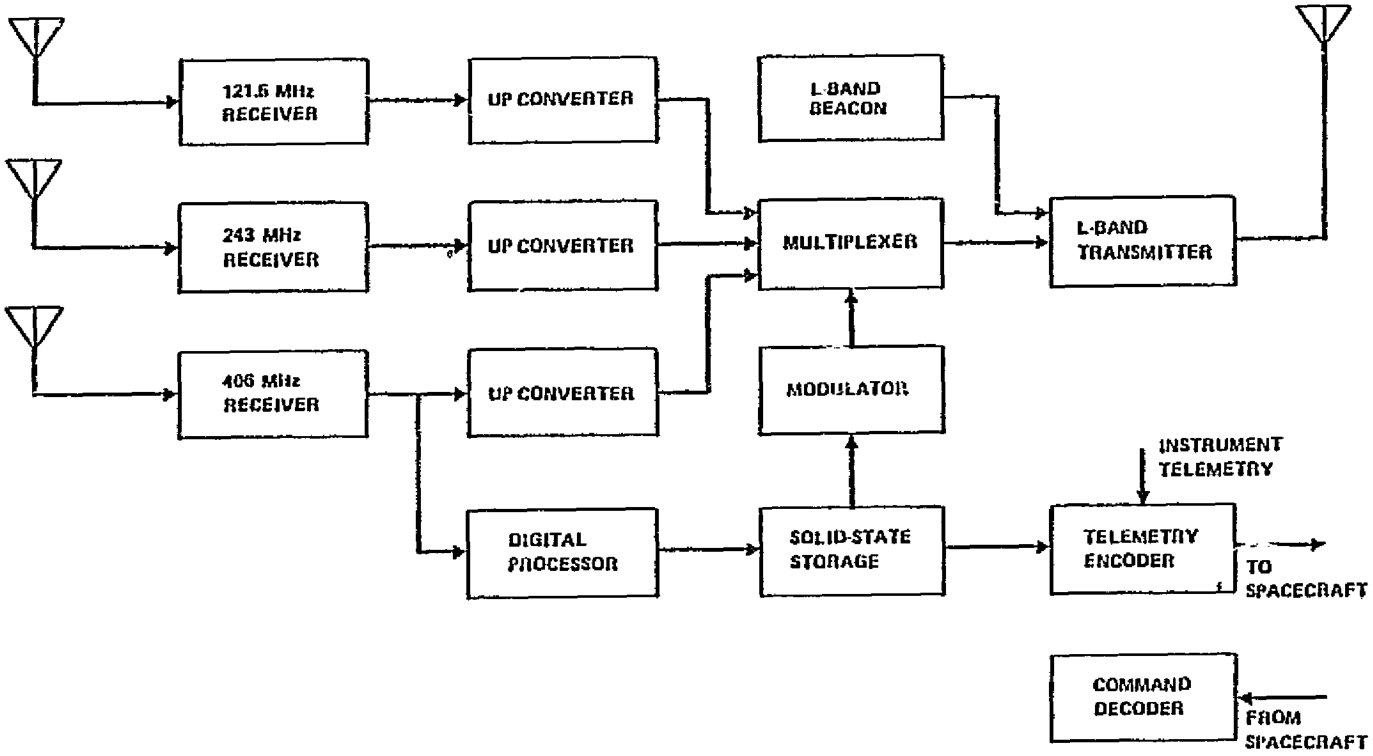


FIGURE F-4. S.O.S. INSTRUMENT MODULE BLOCK DIAGRAM tracking the spacecraft carrying the S.O.S. instrument module and for use in removing downlink doppler.

TABLE F-7

S.O.S. INSTRUMENT MODULE WEIGHT BUDGET

Instrument Module	Weight (Kg)
Structure, Thermal and Harness	5.0
Receivers	1.5
Transmitter	2.0
Antennas	4.0
I.F.'s	1.5
Synthesizer and M.O.	1.5
On-board Processor and Command Decoder	4.0
Uncertainty	5.5
TOTAL	25.0

F.4 GROUND SUBSYSTEM

The ground support concept during the operational phase requires the capability for communications, orbit and attitude determination by NOAA and the USAF; spacecraft command and control is to be accomplished independently of the S.O.S. local user terminals. The S.O.S. local user terminals located in CONUS will be able to receive transponded SAR data and compute locations for the distress incidents. Figure F-5 is a block diagram of this type of ground station. During the operational phase the USAF ground terminals will be augmented to provide for processing the SAR data.

The received L-band downlink composite signal is demultiplexed at the local user terminal. Each signal is individually processed to extract the appropriate segment containing position location information before being fed to a minicomputer called the Doppler Position Processor. The location data is then displayed at the ground station control console and forwarded to the appropriate rescue coordination center.

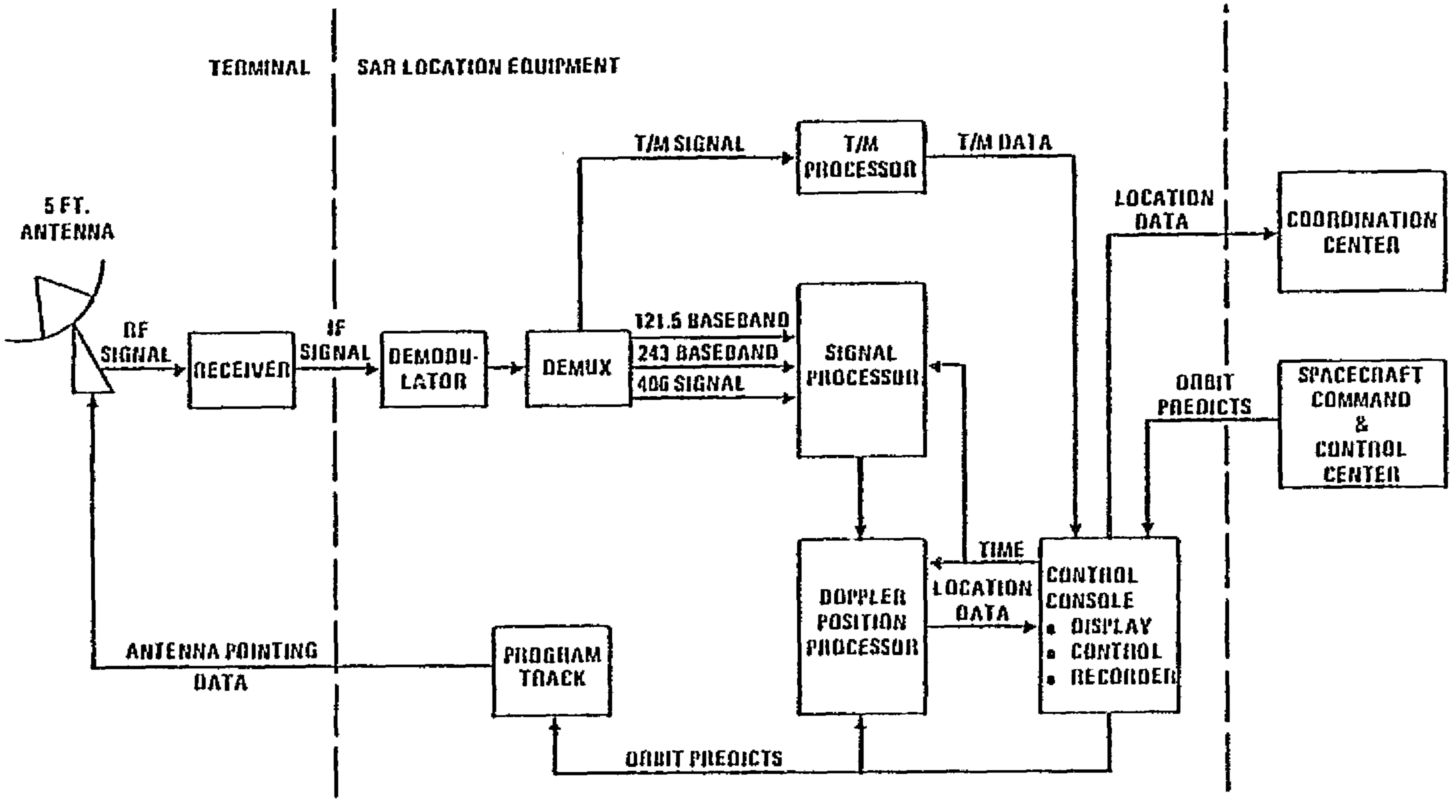


FIGURE F.5. S.O.S. LOCAL USER TERMINAL

APPENDIX G

BACKUP MATERIAL FOR BENEFIT COST ANALYSIS

G.1 COST OF OPERATING AIRCRAFT USED IN INLAND SAR OPERATIONS

The estimates of hourly operating costs for typical military and civilian aircraft engaged in SAR activities are given in the discussion that follows.

G.1.1 USAF Operating Costs

The most frequently used aircraft in SAR operations by the USAF are the HC-130 and the HH-53. The HH-53 costs about 30 percent more per flight-hour than the HC-130, but an effort is made to restrict its use to the later stages of the SAR missions, after initial locations are determined. Accordingly, the costs used in this analysis represent those of HC-130's, as follows:

Operating cost per flying hours[1]	$ 891.00
Crew (nine crew members, 1.316 hours spent per flight hour and assume $10 per hour)[2]	118.40
AFRCC	6.50
Misc. (10% of labor cost above)	12.40
Subtotal	1028.30
Overhead (Assumption	1028.30
Total cost per hour	$ 2056.60

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[1] Col. R. Dreibelbis, Personal communication with Air Force Rescue Coordination Center, Scott Air Force Base, Illinois, August 1976.

[2] ARCC data showed that crew members on representative SAR missions worked an average of 0.316 hours on the ground for each hour spent in flight.

G.1.2 Civilian Operating Costs

The CAP uses a variety of small and medium size aircraft in SAR operations. The costs of operation are approximated by the rental charges plus cost of crew and ground rescue coordination as follows:

Hourly cost of renting C-182 is $25.00[3]	
Hourly cost of renting C-172 is $19.00[3]	
Average hourly cost	$ 22.00
Crew time (assume $10.00 per person)	20.00
Ground rescue coordination[3] (assume one-third of military rate)	2.00
Misc. (10 percent of above labor costs)	2.00
Total	$ 46.00

G.2 ELT EFFECTIVENESS

Section 6 of this report estimated 60 - 90% of ELT effectiveness for the period after 1982. These estimates are derived in this subsection.

ELT effectiveness improved from 24 percent in 1974 to 33 percent in the first half of 1976. The primary reason for failure was mechanical. These failures have caused many false alarms with a resultant loss of credibility among some potential listeners for ELT signals. Since the reliability of ELT is improving and since additional development promises significant further improvements, it is reasonable to expect the upper bound of the effectiveness estimate to approach 90 percent during the 1980's. In order to project a lower bound for these estimates, a survey of key experts and responsible individuals in the field was conducted with the following results:

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[3] Col. R. Dreibelbis, op cit.

USAF	Col. Ryland Dreibelbis, Director Rescue Coordination Center, Scott AFB	65-70%
RTCA	CDR. Robert Wehr (USCG) Chairman RTCA Special Committee No. 127	70%
AOPA	Victor Kayne, Senior Vice President Policy and Technical Planning, AOPA	60-70%

There is insufficient data upon which to draw conclusions regarding EPIRB effectiveness. However, the USCG Office of R&D believes that EPIRB effectiveness should be at least as good as that of ELT's[4].

G.3 FURTHER DETAIL OF BENEFITS ESTIMATES

Section 6 of this report presented the conclusions of the cost-benefit analysis of a satellite system. The benefits were reported as follows:

Reduction of Federal Government operational costs	$152 Million
Other dollars savings to the economy	102
Lives saved ($300,000 per life)	516
Total	$770 Million

Further details on the sources and nature of these benefits are presented in the paragraphs that follow.

G.3.1 Savings to Federal Government

Figure G-1 displays the present value (discounted at 10 percent per year) of the annual costs and benefits which accrue in terms of operational cost savings to the Federal Government (USCG and USAF). The period 1977-1981 represents R&D and initial launches of spacecraft. The period after 1981 represents operational costs including ground station operations and one launch

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[4] Mr. John Carros, EPIRB Project Office, Marine Safety and Technology Division, USCG Office of Research and Development.

per year for replacements. Figure G-2 shows this same data cumulated from 1977 onward. It can be seen from this data that the reduction in Federal operational costs will be greater than the cost of the system.

G.3.2 Dollar Benefits to the National Economy

The estimated annual dollar benefits to the national economy is displayed by source of benefit in Figure G.3. Sixty percent of these benefits accrue to the inland region. A cumulation of these benefits showing the upper and lower estimates is shown in Figure G.4. The present value of these dollar benefits over an infinite time horizon is cumulated in Figure G-5 and compared to the cumulated present worth of the cost of the system. Thus, without considering lives saved, the dollar benefits are more than twice the cost of the system. Adding the value of lives ($300,000 per life) the benefits increase by a factor of 3 as shown in Figure G.6.

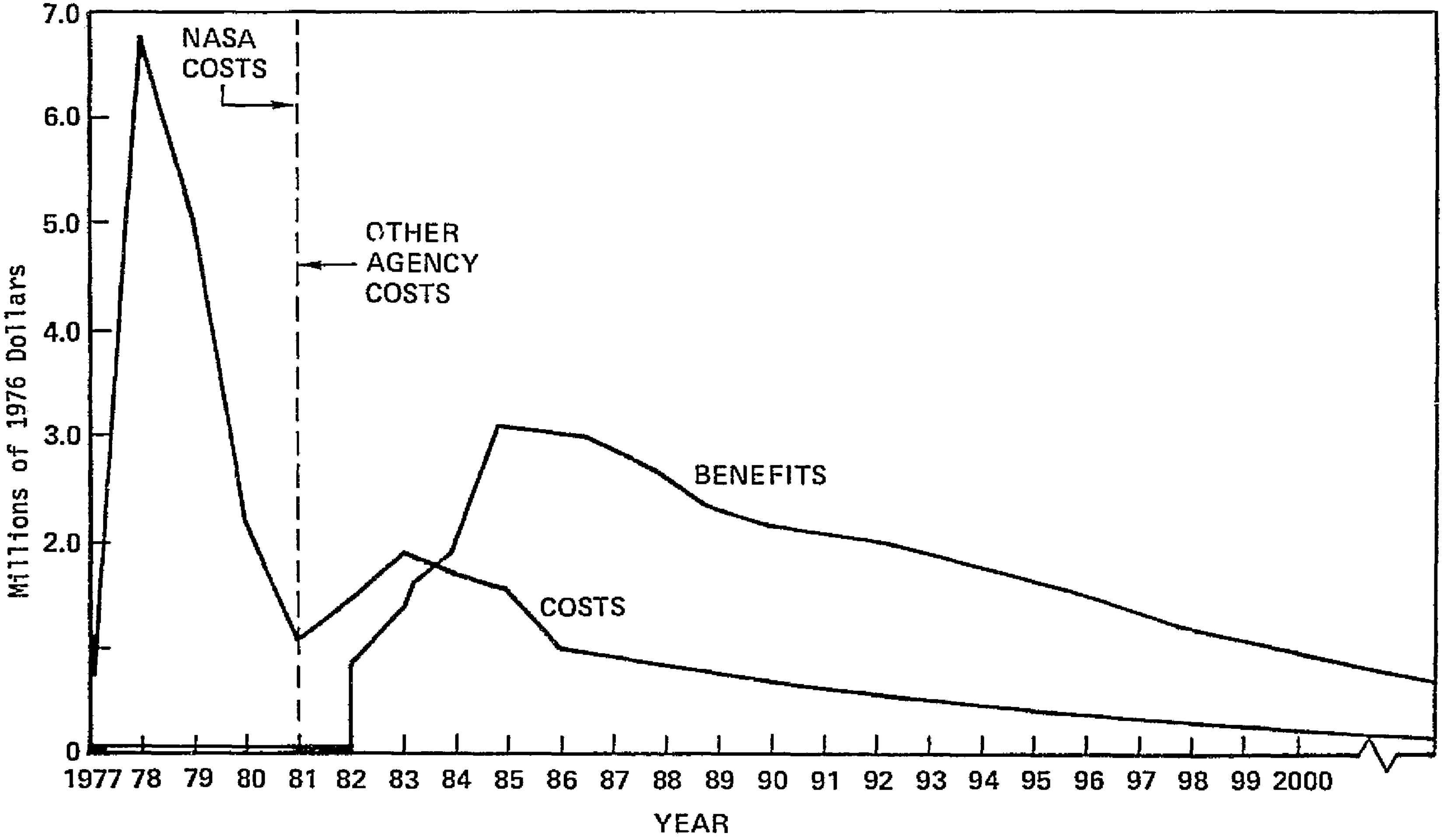

FIGURE G-1 COMPARISON OF PRESENT VALUE OF LIFE COSTS AND FEDERAL GOVERNMENT OPERATIONAL SAVINGS

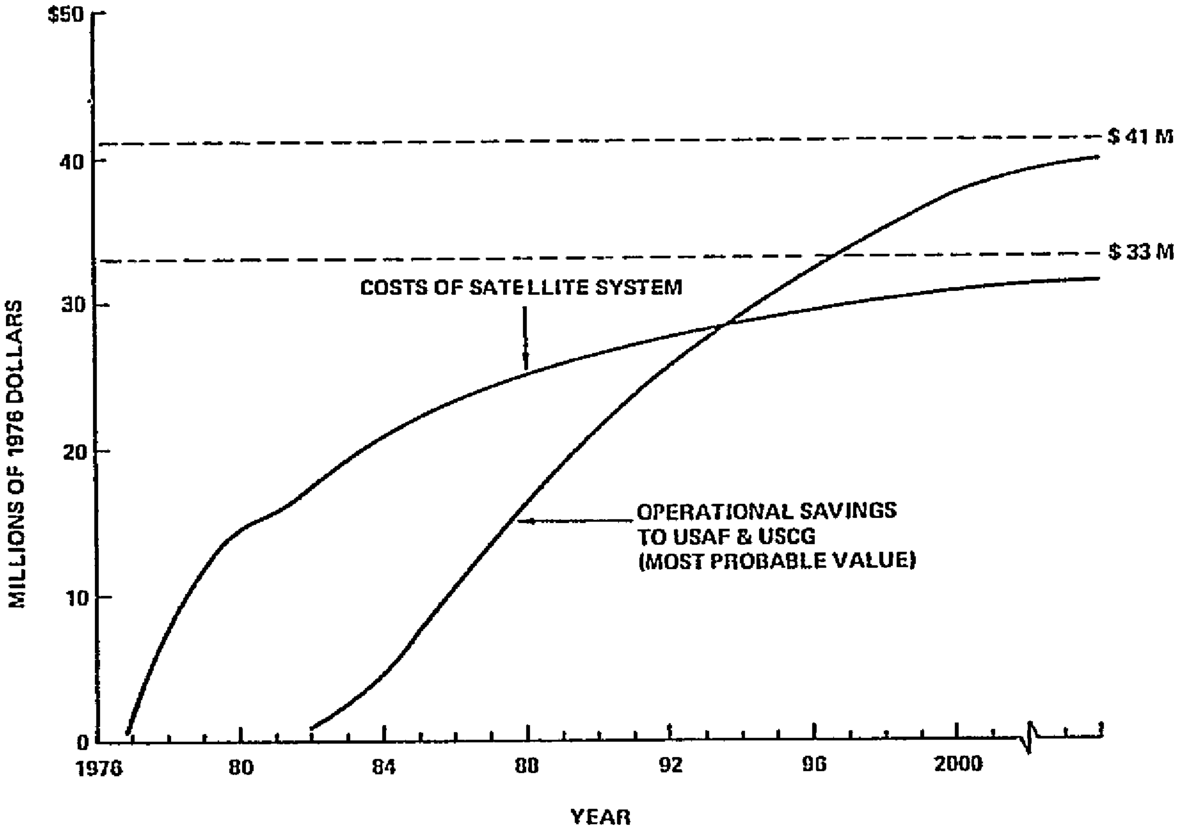

FIGURE G-2. COST OF SATELLITE SYSTEM AND DIRECT FEDERAL OPERATIONAL SAVINGS (PRESENT VALUE, CUMULATED)

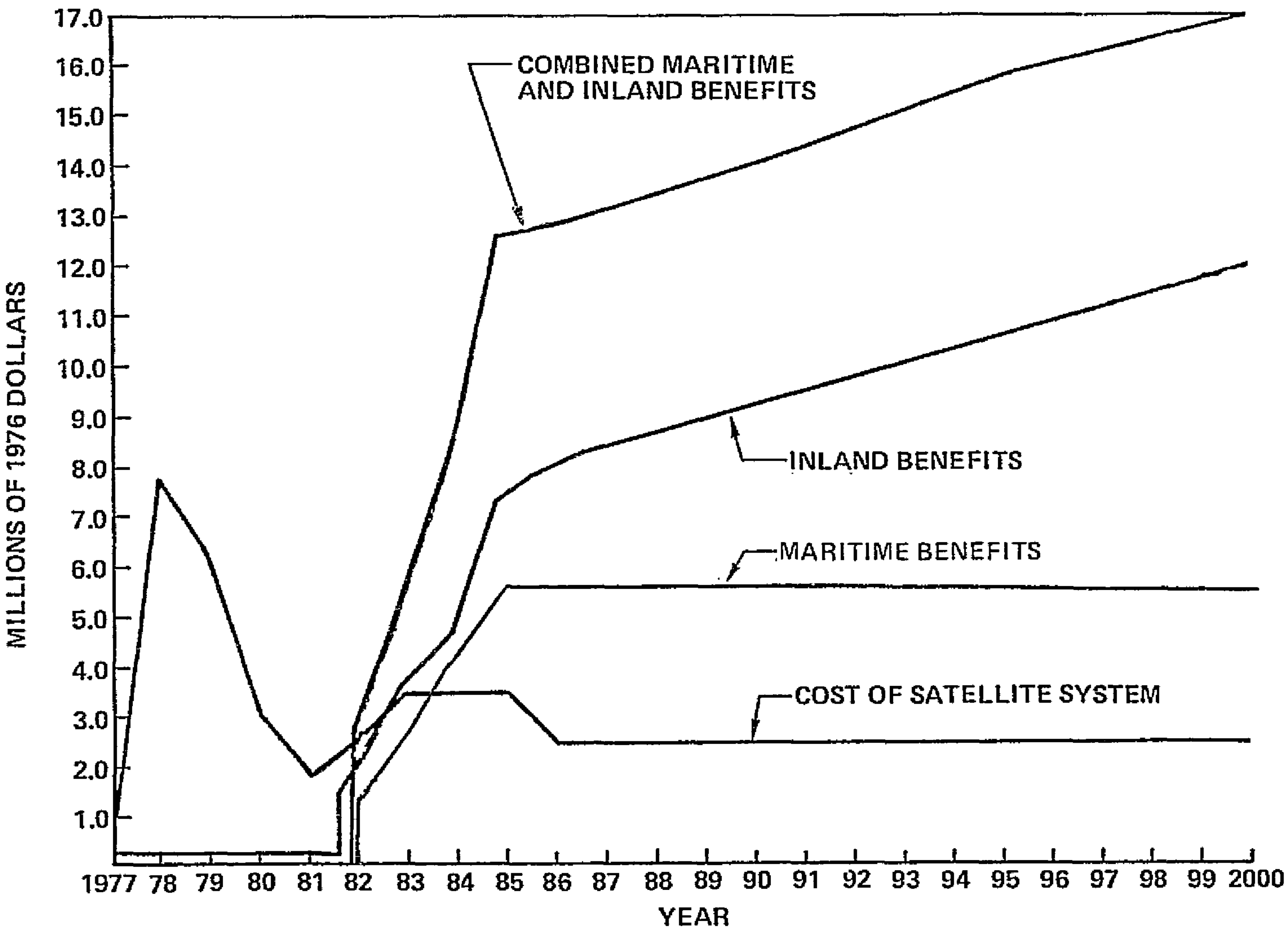

FIGURE G-3. DOLLAR BENEFITS AND COSTS OF SATELLITE SAR 1977- 2000 (LIVES NOT INCLUDED)

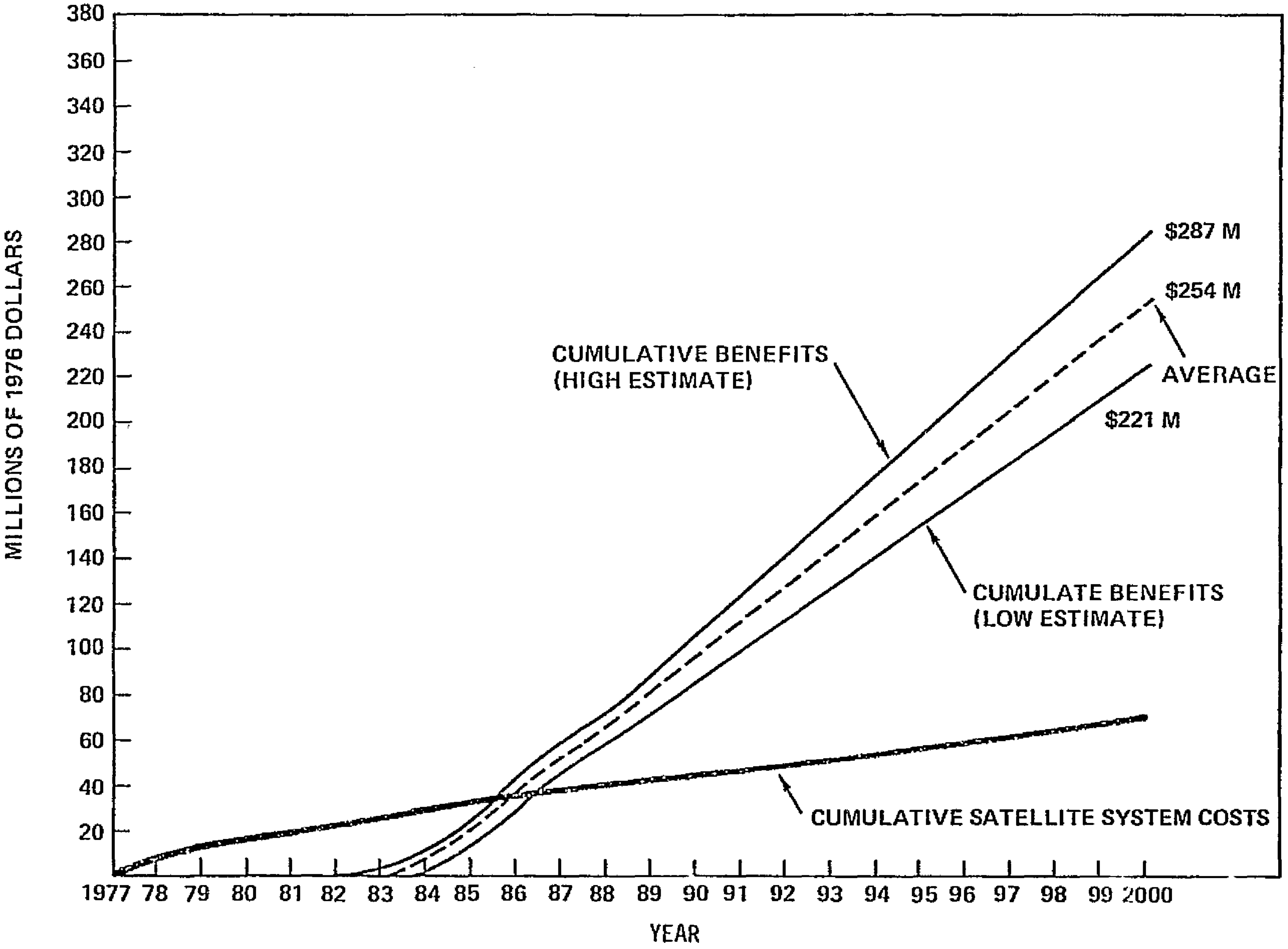

FIGURE G-4. CUMULATIVE CONSTANT DOLLAR BENEFITS RESULTING FROM SATELLITE SAR 1977-2000 (LIVES SAVED NOT INCLUDED)

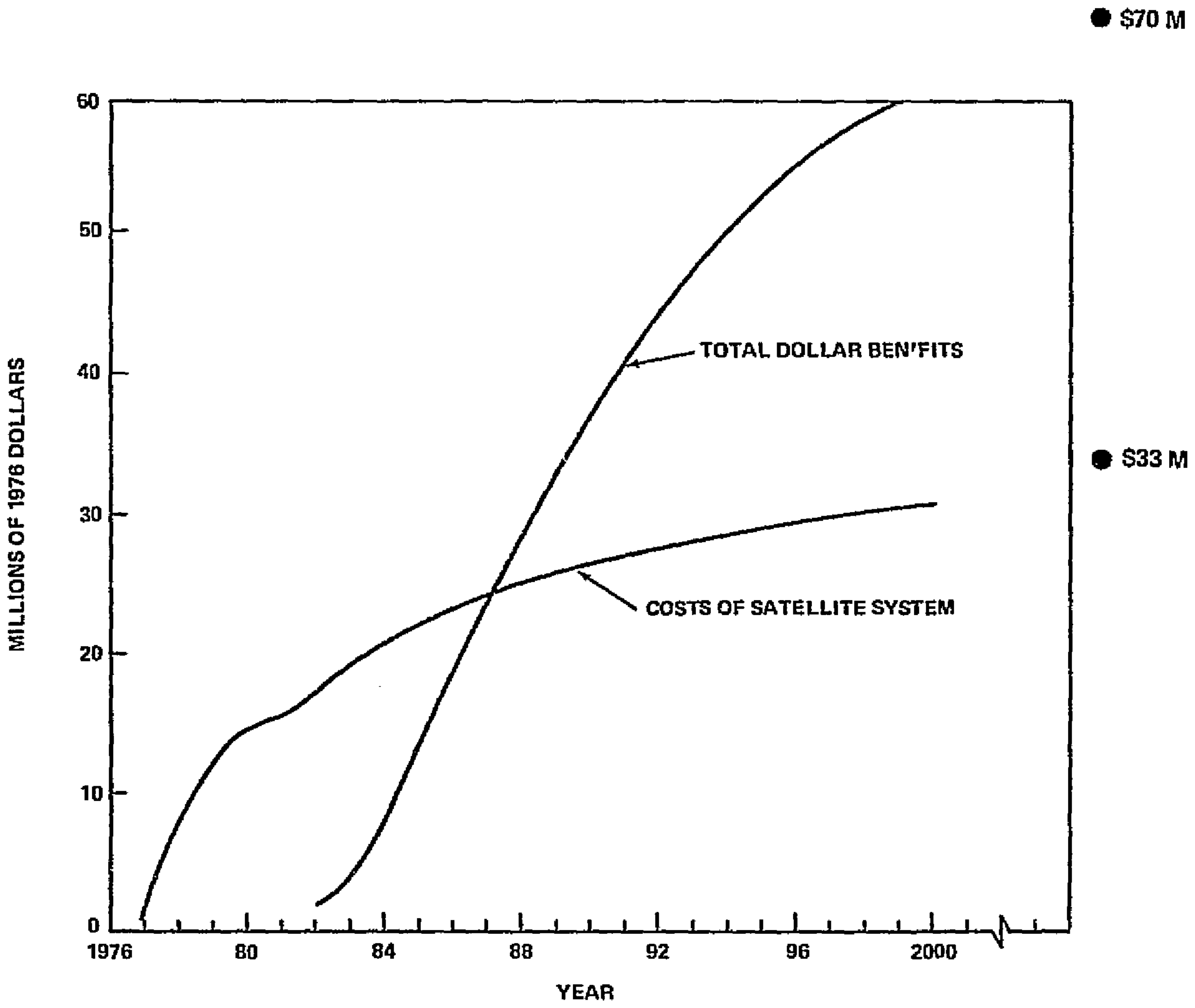

FIGURE G-5. COMPARISION OF PRESENT VALUES OF LIFE CYCLE COSTS AND BENEFITS CUMULATIVE, 1977 ONWARD

APPENDIX H

GLOSSARY OF TERMS

Attitude	The position or orientation of a spacecraft between its axes and some fixed system of reference axes.
Axis	One of a set of reference lines for a coordinate system.
Doppler Shift	The magnitude of the doppler effect measured in cycles per second
Interferometer	An apparatus used to produce and measure interference from two or more coherent wave trains from the same source.
Geosynchronous Satellite	Special case of a synchronous satellite where the satellite remains at a fixed point over the equator.
Multiplexing	The simultaneous transmission of two or more signals within a single channel.
Orbital Period	The interval between successive passage of a satellite through the same point in its orbit.
Polar Satellite	A satellite orbiting the earth with an inclination with respect to the equator of 90^{0} such that it passes over the poles once each orbit.

Satellite	A manmade object that revolves about a spatial body.
Synchronous Satellite	A satellite orbiting the earth at an altitude of approximately 35,900 km. At which altitude it makes one revolution in 24 hours, synchronous with the earth's rotation.