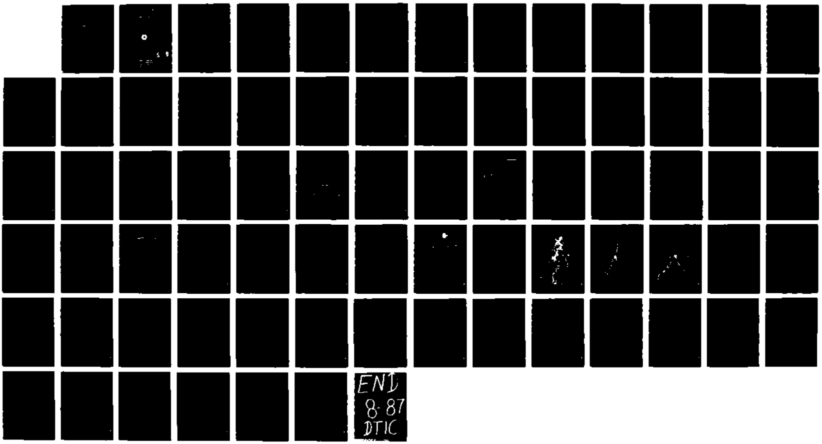
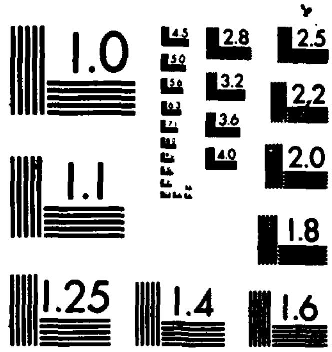
AD-A182 703 HELICOPTER COMMUNICATIONS SYSTEM STUDY(U) ARINC RESEARCH CORP ANNAPOLIS MD M WHITE ET AL. FEB 80 1575-01-2-2162 FAA-RD-80-20 DOT-FA78WAI-939 1/1

UNCLASSIFIED F/G 25/5 NL




1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

Report No. FAA-RD-80-20

HELICOPTER COMMUNICATIONS SYSTEM STUDY

FINAL REPORT

M. White
D. Swann

February 1980

Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

87

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-80-20	ADA182703	

4. Title and Subtitle	5. Report Date
HELICOPTER COMMUNICATIONS SYSTEM STUDY	February 1980
	6. Performing Organization Code
7. Author(s): M. White & D. Swann	8. Performing Organization Report No.: 1575-01-2-2162
9. Performing Organization Name and Address: ARINC Research Corporation, 2551 Riva Road, Annapolis, Maryland 21401	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. DOT-FA78WAI-939/DAAB07-78-A-6606
12. Sponsoring Agency Name and Address: Department of Transportation, Federal Aviation Administration, Washington, D.C. 20591	13. Type of Report and Period Covered: Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report examines the communications requirements of helicopters operating in the National Airspace System in the 1985-1990 time frame. The technical options that exist or are forecast to exist in that time frame are examined for suitability in meeting the requirements, and their pros and cons are discussed. A research plan is formulated for developing the required capabilities. Keywords:

17. Key Words	18. Distribution Statement
helicopter, communication, navigation, surveillance, loran-C.	Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	68	

Form DOT F 1700.7 (8-72)

SUMMARY

The rapid growth of IFR helicopter operations in the Gulf of Mexico has necessitated the expansion of off-shore Air Traffic Control (ATC), in turn creating the need for reliable communications throughout the operational area. Under contract with the FAA, ARINC Research Corporation was tasked to determine the precise requirements for an off-shore communications system in the Gulf, the technical options available, and the optimum configuration for a system that could be installed and commissioned in the near term.

System requirements were gathered from the potential system users, including the helicopter industry, the FAA (ATC), the military, the U.S. Coast Guard, and the Customs Service.

The principal requirement for the helicopter industry was direct pilot-to-controller contact throughout the IFR operational area, which extends from the Galveston area east to the New Orleans area, and off shore 150 miles. An additional requirement was that access to the system be by means of conventional VHF-AM radio, with no additional equipment to be installed in the helicopters.

The FAA Southwest Region set forth its requirements in the form of specific coverage areas and altitudes, involving four off-shore en route sectors with coverage required at 700 feet altitude level, and eight off-shore terminal areas with coverages extending down to a platform height of about 100 feet.

Each of the four military services indicated that it had no requirement for any additional communication capability in the Gulf. Either they had all required facilities or they had no Gulf flight operations.

The Coast Guard stated essentially the same requirement as industry operators, i.e., direct pilot-controller contact over the entire operational area. They also indicated that VHF access is acceptable to them; i.e., no UHF is required.

The Customs Service supports the Drug Enforcement Agency with flight operations directed against narcotics smuggling. Customs representatives indicated that while they have no specific requirement for a communication system, they would probably be a "light" user of such a system if it were available.

In determining how the system requirements could best be met in the short term, all means of over-the-horizon communications were examined for suitability. Table S-1 lists the options considered and their estimated costs and relative-value ratings. The options fall into two categories -- direct and relay -- reflecting the two basic ways in which an off-shore helicopter at low altitude can contact shore-based facilities. Direct methods permit VHF contact with the aircraft directly from shore-based facilities, while relay methods employ off-shore relay stations of one kind or another.

Table S-1. COMMUNICATIONS OPTIONS

Option	Approximate Costs ($ Thousands)		Voice Quality	Link Reliability
	Initial	Recurring		
Direct (Over the Horizon)				
Direct VHF	930	6/month	Good	Good
Direct HF	N/A	N/A	N/A	N/A
Relay*				
Troposcatter	1,290	16/month	Good	Good
HF Link	448	16/month	Fair	Poor
Buoy Repeaters	2,000	2,000/year	Fair	Good
Balloon-Borne Repeaters	5,000 to 10,000	150/year	Very good	Good
Meteor-Scatter	50	16/year	Poor	Poor
Relay Aircraft	2,000	8,000/year	Very good	Good
Satellites	37/month lease, 1,350 purchase	25/month	Very good	Very good
Microwave	0	10	Very good	Very good

*The costs shown for the relay modes are in addition to the VHF terminal cost, which is estimated to be about $14,000 per terminal to acquire and about $2,000 per month to maintain. The microwave option in general requires no additional off-shore equipment.

Direct contact between shore and aircraft via High Frequency (HF) was considered. HF has been used for this purpose with only limited success. HF is a capricious medium given to fading and static interference. Its low reliability makes it a poor choice for ATC communication. In addition, most aircraft engaged in Gulf operations are not equipped for HF. HF equipment, especially antennas, has proved to be difficult to install on helicopters. Finally, this option would not be responsive to the industry requirement that no equipment be added to the aircraft. These considerations make direct HF a generally unacceptable option. The other direct means of VHF over-the-horizon communication examined was the use of very tall towers and high-gain antennas located on shore close to the shoreline. Such installations require extensive equipment complements and provide only marginal coverage at the distances of interest.

Relay modes employ a remote VHF outlet linked to shore by some means. It was assumed that the outlet would consist of RCAG-type transmitters, receivers, control circuits, and antennas, and would be placed on either floating platforms (e.g., buoys) with omni-directional antennas or on rigid platforms (e.g., off-shore oil platforms) with directional antennas.

The troposcatter would provide fairly reliable communications (in fact, such links are currently used on rigs in the North Sea). However, extensive installations at each off-shore area would be required, including two 30-foot dish antennas. A shore facility would have to be established with two 30-foot antennas for each link (2 per site are required for diversity to reduce the effects of fading). In addition, antenna alignment is critical, necessitating the use of rigid platforms.

HF radio links are not suitable for direct contact, as mentioned above. HF was also considered as a means of linking a remote outlet to shore. HF equipment is relatively cheap and easy to install; however, it is not very reliable. HF is given to fading and static interference and is dependent on such factors as time of day and year and sunspot activity. Despite attempts to forecast its performance, HF remains a somewhat capricious medium not well suited to the real-time, 24-hour-per-day requirements of ATC communications.

The use of floating buoys to support remote VHF outlets has been proposed. Buoys of the type required for this application are used by NOAA for oceanographic data collection and transmission. The unstable nature of the buoys dictates the use of omni-directional antennas, which, together with a maximum antenna height of about 40 feet, places a limit on the range of such a system. Numerous buoys would be required to provide line-of-sight relays over the 150-mile-long routes. It is estimated that some 20 such buoys, costing $100,000 each for acquisition and installation, would be required, with maintenance and support costs of about $100,000 per year per buoy. The performance of such buoy-mounted repeaters and outlets would be degraded in heavy seas by antenna motion and wave shielding.

Tethered balloon systems designed to carry communications relay equipment to altitudes up to 15,000 feet are available. They could be used either on shore of off shore to extend communication range. These balloons, however, cost from $5 million to $10 million each and are susceptible to damage from storms and high winds; they must be reeled in during heavy weather, at just the time when their communications services may be needed the most. An additional problem is the balloon's tether and, in fact, the balloon itself, which represents a large potential obstacle for aircraft.

Meteor-scatter communication exploits the ion trails left by the many thousands of micro-meteors that strike the earth's atmosphere each day to reflect VHF signals in the 70 to 80 MHz band over paths up to 1,500 miles. But this mode is highly intermittent, characterized by lapses up to 10 minutes between usable reflection paths. This factor makes the meteor-scatter mode a poor choice for a real-time voice application.

Relay aircraft are sometimes used to extend communication range. This method does provide fairly high-quality communications but is expensive to implement and operate, and the aircraft are subject to the same limitations associated with storms and heavy weather as the balloons discussed earlier.

The use of geo-synchronous satellite links provides high-quality, high-reliability communications that could be used to link the remote VHF outlets to shore. The scheme involves rather extensive off-shore equipment installation, including 15-foot dish antennas. The attractiveness of this option is diminished for the short term because of the expense and lead time involved in the installation of the off-shore equipment.

Many of the off-shore oil rigs in the Gulf are linked to shore by means of a private microwave system, which provides telephone service, as well as remote control and telemetry from unmanned rigs. These microwave circuits could be used to link remote VHF outlets. Many of the companies that operate these microwave systems have indicated that channels could be made available. Such an approach permits establishing a system with a minimum of off-shore equipment installation. The circuits provided by these systems offer high-quality, high-reliability links consistent with the requirements of ATC communications.

On the basis of these considerations, it is recommended that the FAA employ off-shore VHF outlets located on oil rigs, linked to shore via the petroleum microwave service. Table S-2 lists the elements of such a system -- eight installations located in or near the off-shore areas, supplemented by on-shore facilities.

It is recommended that surveillance be accomplished by means of voice position reports based on on-board navigation, usually Omega or LORAN. As a refinement at a later date, the position reporting could be automated by means of data-link transfer of position information.

Table S-2. SYSTEM LOCATIONS

Off-Shore Locations
High Island 582
East High Island 323
West Cameron 585
West Cameron 509
Vermilion 245
Eugene Island 330
Ship Shoal 154
South Timbalier 190
On-Shore Locations
Galveston, Texas
Sabine Pass, Texas
Cameron, Louisiana
Pilotown, Louisiana

CONTENTS

	Page
FOREWORD	iii
ABSTRACT	v
SUMMARY	vii
CHAPTER ONE: INTRODUCTION	1-1
1.1 Background	1-1
1.2 Objectives	1-2
1.3 Approach	1-2
1.4 Report Organization	1-3
CHAPTER TWO: REQUIREMENT DEFINITION	2-1
2.1 Industry Requirements	2-1
2.2 FAA Requirements	2-3
2.3 Military Requirements	2-4
2.4 Other Requirements	2-4
2.4.1 Coast Guard	2-4
2.4.2 Customs Service	2-6
CHAPTER THREE: TECHNICAL OPTIONS	3-1
3.1 Radio Propagation	3-1
3.2 Communications Options	3-7
3.2.1 Direct Modes	3-7
3.2.2 Relay Modes	3-10
3.3 Option Summary	3-39
CHAPTER FOUR: RECOMMENDED SYSTEM CONFIGURATION	4-1
4.1 Off-Shore Installations	4-1
4.2 System Example	4-6
4.2.1 Off-Shore Facilities	4-6
4.2.2 On-Shore Facilities	4-7

CONTENTS (continued)

		Page
4.3	Costs	4-7
	4.3.1 Off-Shore Equipment	4-7
	4.3.2 On-Shore Facilities	4-8
	4.3.3 Recurring Costs	4-8
	4.3.4 Discussion	4-9
4.4	Implementation	4-10
CHAPTER FIVE:	SURVEILLANCE	5-1
CHAPTER SIX:	CONCLUSIONS	6-1

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Off-shore oil drilling platforms are operated by many oil companies and in many areas of the world. One of the largest concentrations of these platforms is in the Gulf of Mexico. Reliable transportation between these platforms and the shore is required for a variety of purposes: crew changes, material deliveries, medical evacuations, and inspections. Helicopters, with their unique ability to take off and land vertically, have long been used to meet this requirement. Historically, off-shore helicopter operations have been limited to daylight, Visual Flight Rules (VFR) conditions. Recently, however, with the advent of the so-called "third generation" helicopter, some flights are being made under night and Instrument Flight Rules (IFR) conditions. This development makes it necessary to extend Air Traffic Control (ATC) services to off-shore locations, in turn creating the requirement for reliable communications throughout the IFR operational area.

At present, IFR operations are quite limited. For example, less than 50 of the approximately 500 helicopters engaged in Gulf* operations are equipped for IFR flight. Interviews with petroleum industry representatives indicate, however, that many helicopter operators plan to expand their IFR operations in the next few years. The goal of this expansion is to allow virtually all-weather, day-night crew changes and MEDEVAC service.

Under its Helicopter Operation Development Plan, the Federal Aviation Administration (FAA) has set out to determine ways and means of extending communication to pilots operating in the off-shore area.

Off-shore IFR helicopter flights are characterized by minimums of about 400-foot ceilings and 1/2-mile visibility, with en route altitudes usually below 5,000 feet. The route structure in the Gulf features approximately a dozen routes, all terminating in "point in space" approaches, from which the helicopter then proceeds VFR to his destination. Most of these flights are made in support of crew-change operations, with a smaller number involved in material delivery and medical evacuation. Currently, these

*Throughout this report, the term "Gulf" will be used to denote the Gulf of Mexico.

flights proceed under more or less normal IFR circumstances until radio and radar contact is lost, usually just after the aircraft crosses the beach. From that time, the aircraft is on what amounts to a void-time clearance for landing on the platform, discharging and boarding passengers or cargo, taking off, and returning along the route until contact is reestablished. During the time the aircraft is out of contact, it is difficult or impossible for the shore-based controller to clear another aircraft along the same route. The resulting delays can cause serious problems for the operators, not only in lost revenue but in safety-of-life situations that can occur if weather prohibits or delays a MEDEVAC flight.

The loss of contact is, of course, related to ranges and altitudes. At the low altitudes the helicopters use, radio line-of-sight, and hence VHF range, is about 50 to 75 miles. Because many of the present oil platforms are more than 120 miles off shore, and exploration is carried out far beyond that distance, the aircraft is simply out of the range of normal communications. Radar contact, with its higher operating frequencies, is even more susceptible to range limitations.

In addressing this problem, the FAA contracted with ARINC Research Corporation to perform a multi-task study of off-shore operations and communications requirements and to develop an interim system plan for establishing communications in a designated off-shore area. The study also includes the development of an R&D plan for the development of a long-term solution to the low-altitude aircraft communication and surveillance problem, not only in the off-shore area but anywhere in the National Airspace System (NAS).

1.2 OBJECTIVES

The objectives of this study are as follows:

1. To study the requirements for and the various means of achieving extended ATC communications in the Gulf of Mexico and to recommend the most cost-effective means of extending at least minimal ATC communications into the Gulf in the near term (one to three years).

2. To develop a detailed R&D plan for the development of a long-term solution to the low-altitude communication and surveillance problem, not only off-shore but anywhere in the NAS.

1.3 APPROACH

This project is divided into two phases. Phase I involves the development of a detailed communications and surveillance plan that will permit extending at least minimal ATC services in designated off-shore areas. Phase II involves the preparation of a detailed R&D plan for the development of a long-term solution to the low-altitude communication and surveillance problem in the NAS, including the off-shore area.

The activities to be performed during the two phases are grouped into the following tasks:

- Phase I: Short-Term Solution in the Gulf
  - Task 1: Requirement Definition
  - Task 2: Technical Option Definition and Trade-off Study
  - Task 3: Plan Preparation
- Phase II: Long-Term R&D Plan
  - Task 1: Extension of Requirement Definition
  - Task 2: Technology Forecast and Option-List Expansion
  - Task 3: Plan Preparation

This report addresses Phase I of the study. The approaches to the Phase I tasks are summarized as follows:

- Task 1. The requirements for a communication system were determined by interviewing potential system users. Their needs and preferences concerning system capabilities and configuration were noted, and the degree to which they planned to use the proposed systems was discussed. Potential users from various groups, including industry, Government, and the military, were included in this task.
- Task 2. All the technical means of communicating over the distances involved were examined for suitability. Factors such as effectiveness, cost, and ease of installation and maintenance were considered in judging suitability. This task also addressed the "resources" existing in the Gulf, e.g., microwave system, off-shore platforms, etc.
- Task 3. Technical options identified in Task 2 that best meet the requirements set forth in Task 1 were selected as the preferred means. A plan based on these means was formulated, and an example of how some of the available resources in the Gulf could be organized into a working system was developed. Other resources and alternatives were also considered.

1.4 REPORT ORGANIZATION

The remaining chapters of this report are organized as follows:

- Chapter Two: Requirement Definition - The potential users of the communication system are identified and their requirements catalogued.
- Chapter Three: Technical Options - The various means of meeting the requirement developed in Chapter Two are discussed in terms of their advantages and disadvantages. Platform and link resources are also discussed.

- Chapter Four: Recommended System Configuration - The recommended system configuration for implementation in one to three years is described.
- Chapter Five: Surveillance - Surveillance options as they apply to the Gulf are discussed, and the recommended means are identified.
- Chapter Six: Conclusions - The findings of the study are summarized.

CHAPTER TWO

REQUIREMENT DEFINITION

For a communication system to be successful it must be responsive to the requirements of its users. Therefore, the first step in the study was to identify the potential users of the system and their requirements. These potential users fell into four categories: industry, FAA, military, and other, including the U.S. Coast Guard and the U.S. Customs Service. Industry users included both petroleum companies that operate their own aircraft and helicopter contractors such as Petroleum Helicopters Inc. (PHI). The FAA users included the Southwest Region Air Traffic Service, which has responsibility for the region of the Gulf subject to intense helicopter traffic. Potential military users included all four services, since each has some helicopter operations. Other users included the Coast Guard, because of its important Search and Rescue helicopter activities in the Gulf; and the Customs Service, engaged in border patrol for drug-enforcement purposes. These potential users are discussed in the following sections.

2.1 INDUSTRY REQUIREMENTS

As the first step in its study, ARINC Research surveyed the petroleum and helicopter operations industries to identify their requirements and preferences for a communication system in terms of the capabilities and services desired. The communication subcommittee of the Helicopter Safety Advisory Committee of the Off-Shore Drillers Association provided valuable insights and introductions to representatives of the helicopter and petroleum industries. Through discussion with these key representatives, the requirements for a communication system were identified.

The primary requirement cited by both helicopter pilots and petroleum company representatives was for direct communication between the pilot and the controller over the entire operational region. This region extends approximately from the Galveston, Texas area to the Venice, Louisiana area, and out to a range of about 150 miles for existing drilling operations and up to 200 miles for a few exploratory rigs. The helicopter pilots and operators interviewed indicated a need for such contact at all points along the route, up to and including touchdown on the pad. The helicopter pilots also addressed the need for contact with Flight Service Stations for the purpose of filing, amending, and canceling flight plans.

In addition, it was stated that communication should be by means of standard VHF aircraft radio, with no requirement for additional equipment on the aircraft.

Several other requirements not dealing directly with communications were identified. These may have a bearing on the ultimate choice of system parameters and are therefore included here for completeness. The helicopter industry informed ARINC Research that the bulk of their flight operations are, and will continue to be, daylight VFR. The industry is generally not willing to accept any interference with or control of these flights. It is feared that the delays and roundabout routing inherent in any controlled airspace will make the cost of these already expensive and difficult operations prohibitive. One oil company chief pilot expressed his opinion as follows: "We would rather do without the FAA's help in IFR if it meant giving up uncontrolled VFR flights."

Another area of concern is military flight operations in the Gulf. There are several Olive-Branch (formerly Oil-Burner) routes that traverse the gulf at low altitudes. There have been a number of near misses between SAC B-52s and helicopters, with miss distances less than 1,000 feet. The industry considers better coordination with the military necessary in this area.

A final concern is the use of LORAN-C, Omega, and radar. These navigation aids are working very well in the Gulf and have been found to be operationally reliable. The industry would like to have these certified as approach aids for their off-shore operations.

ARINC Research conducted a survey of those helicopter operators and oil company representatives present at the Helicopter Safety Advisory Committee meetings. Survey participants are listed in Table 1. The survey covered eight helicopter operators and four major oil companies, 450 of the estimated 500 helicopters operational in the Gulf, and operators flying more than 25,000 flights per week. Petroleum Helicopters, Inc. (PHI) and Air Logistics, which account for more than 95 percent of the flight operations and aircraft in the Gulf, provided significant quantities of data to ARINC Research for this study. At present, PHI is the only operator carrying out IFR flights on a routine basis.

One of the more interesting results of the survey was the amount of flight time actually spent in instrument meteorological conditions (IMC). PHI records indicate that in an 18-month period, a total of only 35 actual flight hours were spent in IMC, and most of this was in penetrating the fog bank that often forms along the Gulf coast. Only "a few" flights were made entirely in IMC conditions.

Another finding of the survey is that there is virtually total agreement within the industry on the need for the FAA to establish communication and control of IFR aircraft in the Gulf. The only reservations expressed concern the possibility of control of VFR aircraft, as discussed earlier.

Table 1. SURVEY PARTICIPANTS

Helicopter Operators	
Petroleum Helicopters, Inc. (PHI)	
Air Logistics	
Evergreen Helicopters	
Southern Natural Gas	
Transcontinental Gas Pipeline Co.	
Omniflight Helicopters	
ERA Helicopters	
Helicopter Medical Evacuation, Inc.	
Oil Companies	
Shell	Mobil
Tenneco	Texaco

2.2 FAA REQUIREMENTS

ARINC Research surveyed representatives of the FAA, in particular the Southwest Region, to determine their requirements for a helicopter communication system. The Southwest Region has already entered into discussions with the helicopter industry as to communications, navigation, and IFR procedures in the Gulf. A broad set of requirements was developed as a result of these meetings; this was refined and extended during meetings between ARINC Research and the Southwest Region.

Basically, the FAA's requirement was the same as that of industry: direct pilot-controller contact over the entire IFR operational area during all phases of the flight. This general requirement is expressed specifically as follows:

- On-Shore coverage
  - •• From 500 feet MSL to 6,000 feet MSL within 25 nautical miles (nm) of Scholes VORTAC (Galveston) from the 090° radial clockwise through the 190° radial
  - •• From 500 feet MSL to 6,000 feet MSL within 20 nm of Sabine Pass
  - •• From 500 feet MSL to 6,000 feet MSL within 20 nm of Cameron Heliport
  - •• From 500 feet MSL through 7,000 feet MSL within 40 nm of Morgan City
  - •• From 500 feet MSL through 7,000 feet MSL within 30 nm of Houma
- En Route Coverage - over each sector from 700 feet MSL through FL 240

- Off-Shore - from platform height to 10,000 feet MSL within 25 nm of the following off-shore areas: High Island Blocks 323 and 582, West Cameron Blocks 509 and 587, Vermilion Block 245, Eugene Island Block 330, Ship Shoal Block 154, and South Timbalier Block 190.

These areas, as well as the extent of the various off-shore sectors, are shown in Figure 1.

These requirements were forwarded by the Air Traffic branch of the Southwest Region with the understanding that they were the total requirement for present and projected IFR operations, and that not all of these areas would or could be covered in the first phases of a system implementation. It was expected that the system would evolve into one that would meet all these requirements over a period of years.

2.3 MILITARY REQUIREMENTS

Representatives of the Army, Navy, Air Force, and Marine Corps were interviewed to determine the requirements of these services for IFR communications in the Gulf.

The Air Force indicated that there were Olive-Branch low-altitude routes in the Gulf but that they had no requirement for any additional communication capabilities in that area.

The Navy performs carrier-qualification landing operations aboard the USS Lexington in the area around Corpus Christi, Texas. However, the representative interviewed stated that these operations were carried out usually under VFR conditions and that, in any event, air traffic control was provided by the carrier on military UHF channels; no additional communications were required.

Both the Army and the Marine Corps indicated that they have no requirement at all for any additional communications capabilities in the Gulf.

In summary, the military indicated that they have no requirement for additional communications capabilities in the Gulf and would not use them extensively even if they were available (this is without regard to the question of VHF versus UHF frequencies).

2.4 OTHER REQUIREMENTS

2.4.1 Coast Guard

The U.S. Coast Guard operates 10 helicopters and 8 fixed-wing aircraft in support of search and rescue operations in the Gulf area. All of these are equipped for IFR flight, and IFR operations are routinely carried out with methods similar to those used by private operators. Representatives of the Coast Guard were interviewed to determine their requirement for an

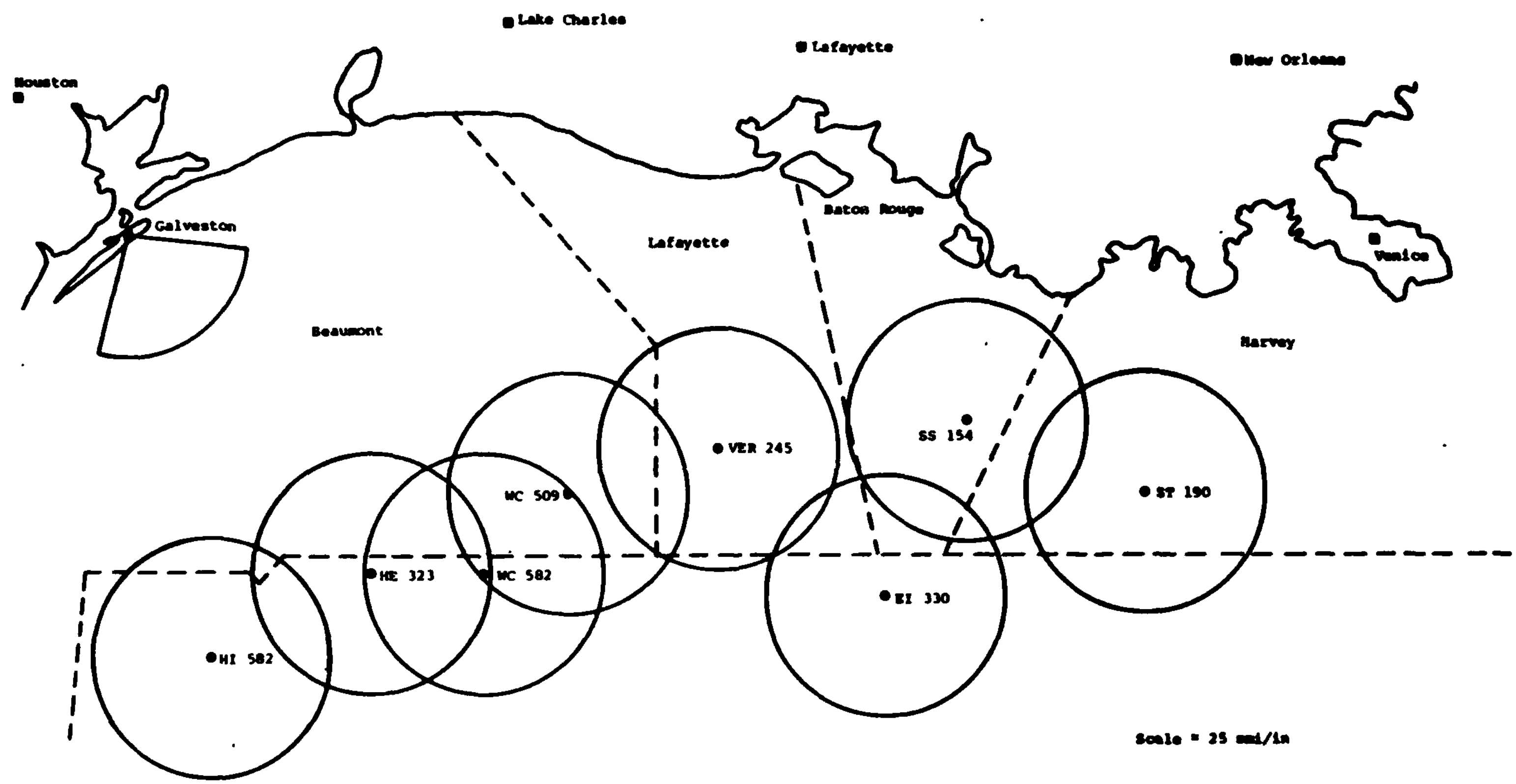


Figure 1. OFF-SHORE SEGMENTS OF FAA REQUIREMENTS

IFR communication system in the Gulf. They said that they had the same requirement for communications as the private operators -- that is, direct contact with air traffic controllers over the entire Gulf area -- and that they expected to be a major user of whatever system the FAA develops in the Gulf. The Coast Guard indicated that VHF frequencies would be adequate and no UHF frequencies would be required.

2.4.2 Customs Service

The U.S. Customs Service supports the Drug Enforcement Agency with flight operations in the Gulf and along the Rio Grande. They operate "a few" helicopters and fixed-wing aircraft at ranges of 60 nm off shore and up to 400 nm off shore, respectively. Representatives of the Customs Service said that they had no special requirement for IFR communications in the Gulf (most of their operations are daylight VFR) but that they would probably be a "light" user of the system if one is developed.

CHAPTER THREE

TECHNICAL OPTIONS

Having determined the requirements for a system in the Gulf, the study proceeded to examine the various means of fulfilling the requirements. Each of the various technical means of communicating over the horizon was examined to determine its suitability for application in the Gulf. These means are discussed in these sections in two groups: those involving direct contact between the aircraft and shore, and those involving relays of some kind. In each case, the basic principle is discussed and the method by which the particular means could be used in the Gulf is shown. The advantages and disadvantages of each option are discussed; and the costs of acquisition, installation, operation, and maintenance are estimated.

The cost figures given in this report are estimates of acquisition and installation costs at commercial rates. They are included to allow comparison of the various options. They do not include any engineering or development costs, and should be considered only as relative and not absolute figures.

The discussions of the various options is preceded by a general discussion of radio propagation as it applies to off-shore low-altitude communications.

3.1 RADIO PROPAGATION

The speed of propagation of electromagnetic waves in the atmosphere is slower than that in a vacuum. The difference is rather small and is not usually taken into account in terrestrial voice-link calculations as far as propagation time is concerned. However, the effect does manifest itself in the form of refraction.

The density of the atmosphere varies with altitude, from about 15 psi at the surface to effectively zero at an altitude of about 75 miles. Since the refractive index of a given sample volume is a function of the air density inside, the refractive index of the atmosphere is a strong function of altitude. This refractive gradient causes the top of a wavefront to propagate slightly faster than the bottom, resulting in a downward bending of the waves that causes the propagation path to bend slightly around the curve of the earth, yeilding a "radio Horizon" usually somewhat greater than the geometric line of sight (LOS). This effect is often accounted for by assuming that the radius of the earth is greater than the actual radius. This effective earth radius factor, k, varies with atmospheric pressure and water vapor content between 0.5 and 5, with 1.33, or 4/3, being a typical value. Values of k smaller than 1 and larger than 4/3, called sub- and super-refraction, respectively, can result from anomalous atmospheric conditions. One relatively common example of super-refraction is the phenomenon of "ducting". Super-refractive conditions can cause the waves to bend so sharply that they hit the earth's surface, reflecting back into the super-refractive atmosphere, where they are again bent back to earth. In this case, the super-refractive layer and the surface of the earth behave much like a wave-guide, ducting the trapped waves far beyond the normal radio horizon.

The concept of a "radio horizon" can be used as a rough measure of the range of a VHF transmitter. It is usually approximated by

$$R = \sqrt{2H}^{*} \qquad (1)$$

where

R = range in statute miles

H = antenna height in feet

This assumes an atmospheric refractivity approximated by 4/3 earth radius. To place the "radio horizon" at $\sqrt{2H}$ (that is, assuming a cut-off of communication at that point) assumes typical atmospheric conditions and typical transmitter power, receiver sensitivity, and antenna gains. In fact, ranges in excess of $\sqrt{2H}$ may be obtained in anomalous propagation conditions or through the use of high-powered transmitters, high-sensitivity receivers, or high-gain antennas. In general, range may be calculated from

$$P_R = P_T + G_T + G_R - L_P \qquad (2)$$

where

P_R = received power, dBm

P_T = transmitted power, dBm

G_T = transmitter antenna gain, dBi

G_R = receiver antenna gain, dBi

L_P = path loss, dB

*This is not a "rule of thumb" but is a convenient analytical relationship that can be derived from first principles if one assumes atmospheric refraction that results in k = 4/3.

Path loss is generally a function of frequency and path distance. For instance, so called "free space" path loss, i.e., loss in an unobstructed vacuum, is

$$L = 20 \log f + 20 \log d + c \qquad (3)$$

where

f = frequency

d = distance

c = constant, the value of which depends on units of f and d

But on the surface of the earth, especially over smooth, conductive portions such as long expanses of sea water, there are several other effects to be considered. Loss is generally considered in three regions: a reflection region, an intermediate region, and a troposcatter region. The reflection region is characterized by short transmitter-receiver separations. In this region, multipath reflection causes sharp peaks and nulls, experienced by air mobile stations as a rapid flutter. The tropospheric region is not usually subject to reflections, but large changes in path loss can be expected because of instabilities in the scattering regions of the troposphere. The curve in Figure 2 illustrates median path-loss figures for the intermediate and tropospheric regions, smoothed in the transition region. This curve is adapted from Skolnik* and is drawn for the middle of the VHF aircraft band using a transmitter antenna height of 250 feet and an aircraft height of 100 feet. As can be seen from this curve, some signal may be expected at ranges up to 1,000 miles or more as a result of troposcattering. A sufficiently powerful transmitter could be expected to reach a sufficiently sensitive receiver at this range. Thus the concept of a radio horizon is not necessarily the last word in range determination.

We may now consider the following question: On the basis of the path-loss data, what is the maximum range of our off-shore transmitter-receiver circuit?

We assume:

P_R = 1.5 μV = -104 dBm

P_T = 10 watts = 40 dBm - 4.5 dB cable loss = 35.5 dBm

G_T = 3 dBi

G_R = 0 dBi - 3.7 dB cable loss = -3.7 dBi

*M. Skolnik, *Radar Handbook*, McGraw-Hill Book Company, New York, N.Y., 1970.

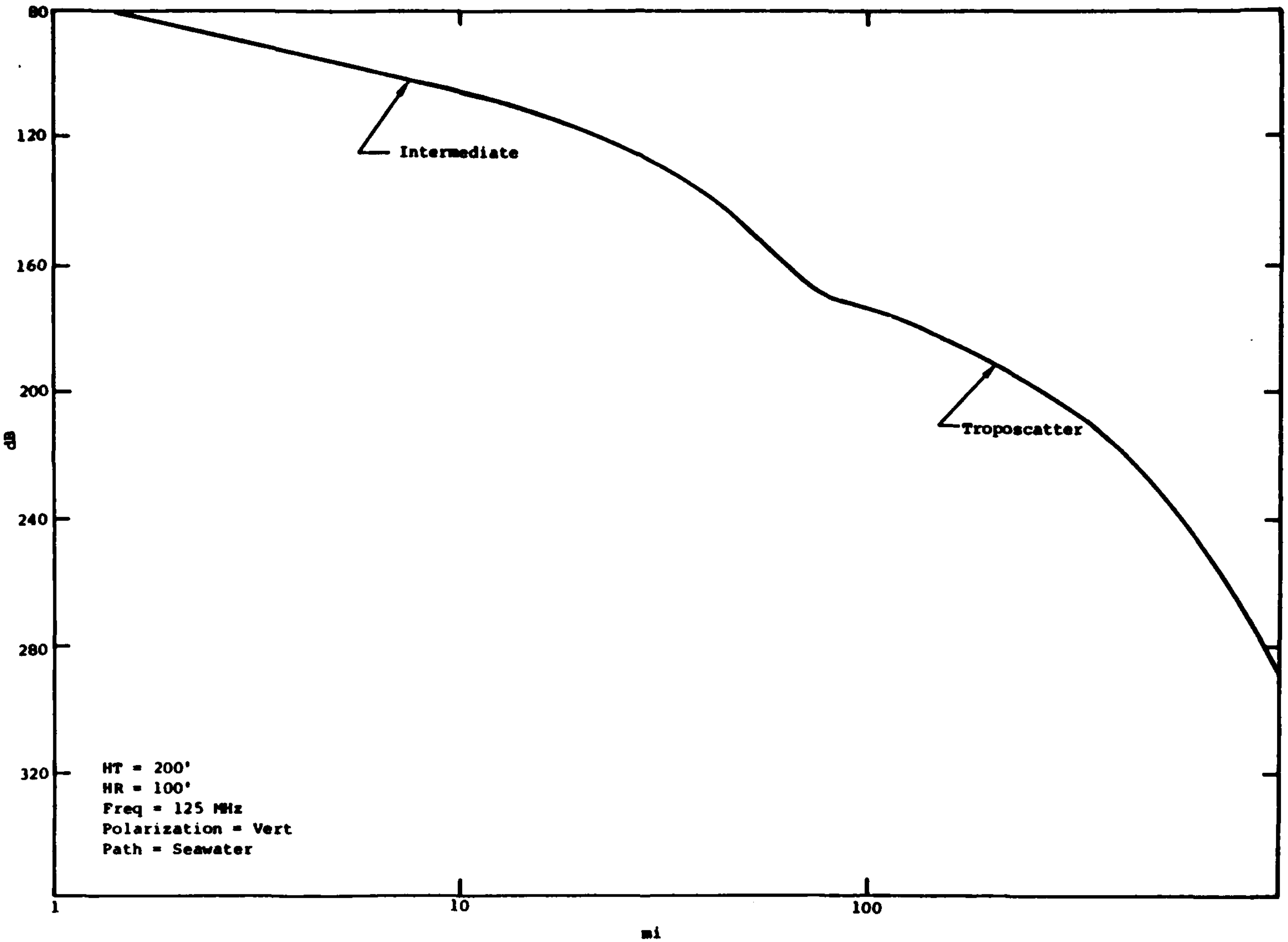


Figure 2. PATH LOSS

We can solve Equation 2 for L_P:

$$L_P = P_T + G_T + G_R - P_R$$
$$= 35.5 + 3 - 3.7 - (-104)$$
$$= 138.8 \text{ dB}$$

That is, we can tolerate about 139 dB of path loss between the transmitter and the receiver. As shown in Figure 2, this corresponds to about 45 statute miles of range, as compared with the calculated 4/3 earth "radio horizon" of

$$D = \sqrt{2 \times 100} + \sqrt{2 \times 250}$$
$$= 36.5 \text{ statute miles}$$

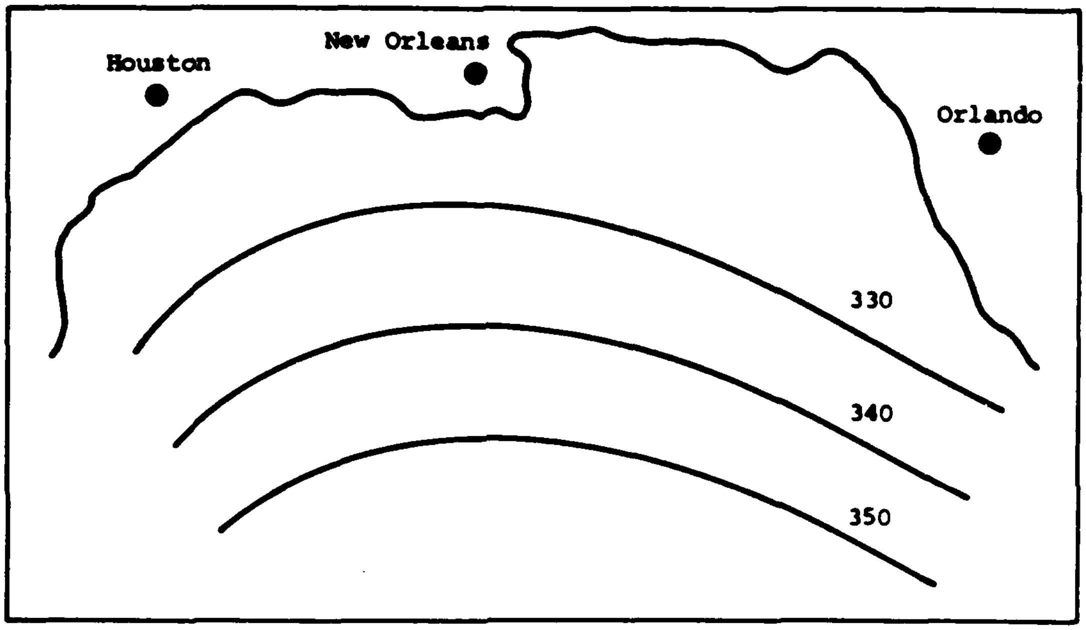
Thus it would seem that it is possible to transmit 8.5 miles farther than the 4/3 earth "radio horizon," an increase of about 23 percent. However, this is a median value, and some fading is to be expected. The system design range should be somewhat less than this to provide a fade margin. Allowing a fade margin of 10 dB will reduce the expected range to about 38 miles -- about equal to the computed 4/3 earth radio horizon. However, note that we have not invoked the 4/3 earth assumption directly. The result is largely coincidental; if, for instance, a 1,000-watt transmitter had been used, the range, adjusted for fade, would have been about 65 miles, or 78 percent more than the "radio horizon".

The use of a 4/3 earth radius in computing radio horizon distance is a "rule of thumb", this being a median value for moderate climates. In fact, as pointed out earlier, this factor (k) can vary over an entire decade from 0.5 to 5, depending on local conditions. The value of k is related in a complex way to the surface refractivity, which in turn is related to atmospheric pressure and moisture content. Figure 3 shows contours of yearly average surface refractivities. The Gulf area has refractivities ranging from 340 to 370. These relate, as shown on the small graph in Figure 3, to k factors of 1.44 to 1.57.

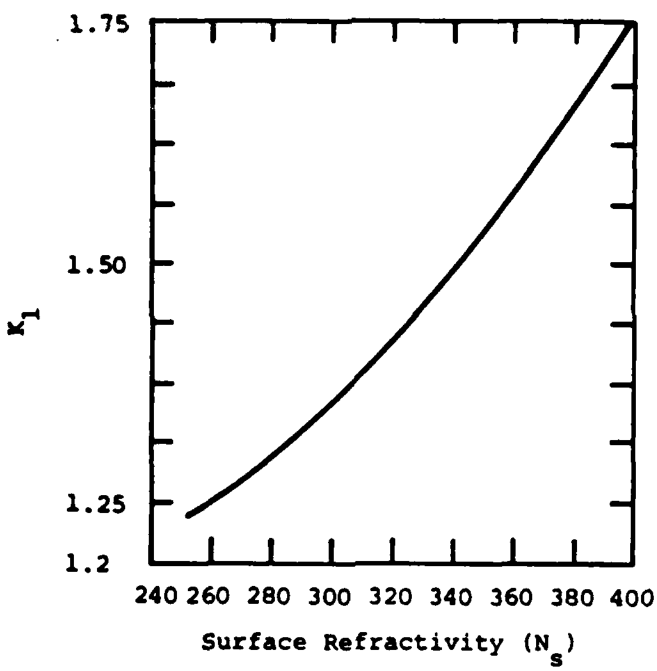
Consider a 100-foot antenna. Assuming 4/3 earth yields a radio horizon distance of $\sqrt{2 \times 100} = 14.1$ miles. Using $k = 1.44$ and 1.57 yields a radio horizon distance of 14.7 and 15.3 miles, respectively, or an increase of 8.5 percent at the most.

The month-to-month variability of the refractivity for the Gulf region is about 60*, indicating that k is at times considerably less than 4/3 (1.33) and at times in excess of 1.75, while averaging in the 1.44-to-1.57 range, depending on locations within the Gulf.

*Bean, Caboon, Samson Thayer; *A World Atlas of Atmospheric Radio Refractivity*, ESSA Monograph 1, 1966.



(a) Refractive Index



(b) k Values

Figure 3. PROPAGATION REFRACTIVITY EFFECTS

In summary, then, the 4/3 earth approximation can be used as a rough measure of the useful range of an off-shore VHF outlet, not due to any fundamental limitation, but merely as the outcome of the calculation of received power taking into account the fade characteristics of the propagation medium. Thus it is not impossible to transmit beyond this "radio-horizon" -- only difficult and expensive.

3.2 COMMUNICATIONS OPTIONS

If one wishes to communicate over paths much beyond the radio horizon, several options present themselves. There are several means of directly propagating signals beyond the radio horizon. Other means involve LOS relay. In this study, the interest is in linking VHF-equipped aircraft to shore-based controllers. There are basically two means of doing this: (1) employ a method of making direct contact with the aircraft from shore, or (2) employ remote VHF outlets located off shore and link voice and control back to shore by some method. These are discussed separately in the following subsections.

3.2.1 Direct Modes

To meet the communication requirement by direct shore-to-aircraft means, it is necessary to reliably transmit to and receive from an aircraft at 100-foot altitude and a range of 150 nm. Of course, HF communication, especially ground-wave at frequencies below 5 MHz, is routinely used for this type of communication. However, HF would not be responsive to the industry requirement that no additional equipment be required aboard the aircraft. All helicopters operating in the Gulf are equipped with VHF, while practically none are HF-equipped. In addition, HF is at best a capricious medium, given to fading and static interference. It is especially unsuited for helicopter installation, where safety considerations related to the main and tail rotors prohibit the use of wire antennas (whip-type antennas have been used in some applications, with only limited success). It is true that HF is currently used for ATC communications with aircraft on high-altitude oceanic routes. But such routes are characterized by low traffic density, large aircraft separations, and long transit time, making HF communication drop-outs less serious.

Gulf helicopter routes, on the other hand, are characterized by much higher traffic densities, short routes, and smaller separations, making such operations much more susceptible to communication failure. Reliable, real-time communication is required, making HF an undesirable solution. HF is discussed further in Subsection 3.2.2.4.

The other alternative is the use of over-the-horizon VHF propagation. As discussed earlier, the so-called radio horizon does not represent an impassable barrier to communication, only a region of relatively high attenuation. A sufficiently tall antenna, fed by a sufficiently powerful transmitter, may be expected to contact a receiver at great distances.

VHF propagation beyond the horizon is subject to another effect that has a bearing on its suitability: diffraction. Just as light is diffracted by a knife edge into light and dark bands, VHF radio signals are diffracted by obstacles, or in this case by the earth's curved surface. The diffraction region is characterized by peaks of phase addition, which can in principle be up to 6 dB above the undiffracted level; and nulls of phase cancellation, which can in principle offer infinite attenuation. An air mobile station experiences these peaks and nulls as a flutter effect that tends to degrade the quality of communication. The depth of the peaks and nulls over a sea-water path is not easily predictable in real time and depends on factors such as sea state, wave height, wave spacing, and water salinity and temperature. Thus it is not a highly reliable propagation mode -- with those links which are successful depending for that success largely on circumstance in the alignment of antennas with propagation peaks.

The troposcatter mode is somewhat more reliable. Inconsistencies in upper atmospheric regions produce a scattering effect as the wavefronts refract and re-refract through the region. The path losses associated with this mode are shown in the right-hand portion of Figure 2.

In the present application, a series of stations spaced along the Gulf coast would be needed, employing tall towers, high-gain antennas, and high transmitter power. The number of stations required would be determined by the antenna beamwidth that could be used; the larger the beamwidth, the fewer the stations. However, beamwidth varies inversely with gain; thus a trade-off between coverage and transmitter power is called for. Referring to Equation 2, we can solve for effective radiated power (ERP) $P_T + G_T$:

$$P_T + G_T = P_R - G_R + L_P$$

Substituting, we have

$G_R = 0$ dBm

$P_R = -104$ dBm ($= 1.5\ \mu V$)

L_P at 150 miles = 180 dB (from Figure 2)

Thus

$$P_T + G_T = (-104) - 0 + (+180)$$
$$= 76 \text{ dBm}$$

Now, 76 dBm is almost 40,000 watts of ERP. This power can be achieved by using a transmitter/transmission-line combination that delivers 1,000 watts to a 16-dBi antenna. Because a 16-dBi VHF antenna would have to be a yagi type with a beamwidth of less than 20°, each station would cover only about a 50 nm sector at the extreme of its range, and much less at closer ranges. Even six such stations, while providing more or less complete coverage at long range, would need supplemental stations to provide coverage closer to shore. Note that these calculations assume a 250-foot transmitting antenna, much higher than that normally used at an RCAG facility;

it is assumed that space on a commercial tower could be obtained. Thus such a scheme could provide spotty coverage at the expense of numerous stations, towers, and links. However, consider the return link: taking the average aircraft transmitter to be 10 watts, this is fully 20 dB less power than in the above calculation, requiring either a more sensitive shore receiver or a higher-gain antenna. The option of using 1 kW transmitters on the helicopters is made impractical by space, weight, and power limitations, and is not responsive to the industry requirement that no additional or different equipment be required on the aircraft. Allowing a 10 dB increase in receiver sensitivity and a 10 dBi increase in shore antenna gain would make reception just possible at the limits of the receiver sensitivity; 26 dBi gain VHF antennas are, of course, theoretically possible, but in practice they require stacked phased arrays that multiply expense and complexity. On the basis of having six shore stations to provide some overlap in coverage at maximum range, and single-channel capability, the costs of the system are estimated as follows:

- Acquisition Costs

•• Transmitter and receivers	$ 19,506	($1,340 + 1911 × 6)
•• Antennas (4 bay)	2,880	($120 × 4 × 6)
•• Linear amplifiers	6,000	($1000 × 6)
•• Buildings (based on estimate of $200,000 for a typical RCAG, less towers)	900,000	($150,000 × 6)
•• Leased circuit installation ($50 per circuit)	300	
Total Acquisition	$928,686	

- Monthly Costs

•• Tower rental: (50¢ per foot per month)	$ 750
•• Maintenance	3,000
•• Leased lines (8660 × 2 × 6)	1,640
Total Monthly	$5,390

If six additional transmitters, receivers, and antennas are provided for coverage close to shore, this will add about $15,000 to the initial expense, bringing the total to an estimated $943,686, or roughly $950,000.

Thus this hypothetical system, which would be operating at the limit of its capabilities and only just capable of providing the needed coverage, would cost on the order of $1 million to install and about $65,000 a year to maintain. Even at this low level of performance, which would not provide any appreciable fade margin, the system would be at the limit of what is practical with available equipment. Of course, taller towers, if available, would add to the quality of the system; but even that is a diminishing-returns situation since doubling the tower height does not double the range, but only increases range by a factor of 1.414.

3.2.2 Relay Modes

The other major means of communicating beyond the range of a single link is to provide for one or more relay stations that receive, amplify, and retransmit the signal. A common example of this type of system is a microwave relay system. At microwave frequencies, propagation is essentially limited to the radio horizon since almost no diffraction takes place. Relay stations are placed, usually within LOS of each other, and the signal relayed from one to the next. Of course, LOS relay is possible at any frequency but works best in, and is limited in practical application to, VHF and higher.

Such relay stations could be used to link a remote VHF outlet operating on an appropriate frequency in the aircraft band back to shore-based ATC facilities. A number of factors influence the choice of frequencies to use in the relay network: distance to be covered, terrain, antenna size, power, etc. In general, clearance of obstacles and the earth's surface is determined by whether the path of the beam clears the obstacle by a distance greater than the radius of the first Fresnel zone. Since the size of the Fresnel zones is inversely related to frequency, the higher frequencies allow less stringent clearance requirements. Higher frequencies also provide more gain from a given-diameter antenna, and smaller beamwidths, making the links more efficient. However, the use of such relay systems does have the disadvantage of dependence on each link. Failure of one link can make the entire system inoperative.

3.2.2.1 Costs

The systems described in this section would all entail the use of remote VHF outlets. The outlets would consist of at least two transmitters (main and standby), two receivers (main and standby), antenna, transmission line, power supply, battery backup, and audio/control interface. The cost of these components (the basic working elements of the standard FAA RCAG) is estimated as follows:*

- Initial Costs
  - Transmitters — $3,822 (2 @ $1,911)
  - Receivers — $2,680 (2 @ $1,340)
  - Antenna — $300 (including transmission line and mounting)
  - Power supply — (included in transmitter and receiver)
  - Battery backup — $1,000
  - Audio/control interface — $6,000

*Installation costs will be considered in each discussion of link options, since much of the transportation cost would be shared by the outlet and link equipment.

- Recurring Costs
  - Power: negotiable with platform operator, estimated at $100 per month
  - Maintenance: $1,890 per month

Maintenance cost is based on an estimated 2-hour maintenance trip, one trip every two months, assuming helicopter rental of 4 hours at $250 per hour plus $850 per day and $20 per hour technician salary. This will vary somewhat with the choice of link schemes; if a number of outlets are called for, several could be visited on one day, reducing the cost per location. This factor will be discussed in the various sections on link options.

Such VHF outlets would be required in any system in which direct VHF air-shore contact is not provided. Hence, the cost associated with the outlet itself is largely a constant when this type of system is being considered. Thus when the various means of linking such outlets to shore are being addressed, only those costs peculiar to that link scheme will be discussed.

3.2.2.2 Antenna and Platform Options

An off-shore communication system based on LOS relay would have to be configured for directional antennas or omni antennas. This choice is related to the choice of the platform that will be used to support the antenna and other equipment. Nonstable platforms such as buoys, ships, or other floating platforms require omni-directional antennas since the accurate pointing angles required by directional antennas cannot be maintained. Using omni antennas places severe limitations on the efficiency of the system, requiring higher transmitter powers and greater receiver sensitivities than would otherwise be required. Buoy-mounted systems are discussed later in this chapter.

Rigid platforms of the type employed in oil drilling can support a relay station. Since directional antennas are feasible in this case, the advantage of higher frequencies can be realized, as discussed earlier. Again, separation is limited to about radio LOS; but much-lower-power transmitters, with attendant savings in power and complexity, can be used by virtue of the higher antenna gains, typically 40 dBi or more. Such links would be far more stable, and not subject to such degrading influences as heavy seas rocking the antenna or blocking the transmission path.

The various means of linking remote VHF outlets placed on either rigid or floating platforms are discussed in the following subsections.

3.2.2.3 Troposcatter

Propagation

Radio waves propagating through the upper atmosphere encounter regions of nonuniform ion density and refractivity. As a result of repeated reflection and refraction of the wave in this non-homogeneous region, a certain amount of the signal is "scattered" and can be received on the earth's surface at distances considerably in excess of those otherwise obtainable. These signals are quite weak, requiring careful selection and orientation of the antennas, and are subject to at least two distinct forms of basically unpredictable fading.

In a troposcatter communication system, it is essential that the transmitting and receiving antennas be carefully aligned to illuminate the same volume of the troposphere.

From Harvey*, the median path loss over such a circuit is estimated by $L(0.5) = 30 \log f - 20 \log d + F(\Theta d) - G_p - V(de)$ dB

where

f = frequency, MHz

d = distance between antennas

$F(\Theta d)$ = function of Θ, angle between radio horizon rays, and distance d, (see Figure 4a)

$V(de)$ = climate adjustment (see Figure 4b)

$$G_p \simeq G_t + G_r - 0.07 \exp (0.055\ G_t + G_r)$$

where

G_t = transmitter antenna gain

G_r = receiver antenna gain

Because it is necessary to align the antennas accurately, parabolic types are often used, dictating that frequencies above approximately 700 MHz be used to attain sufficient gain with practical-sized reflectors.

An off-shore air-ground system based on troposcatter links could be configured as shown in Figure 4c. Since exact alignment of the antennas is necessary, a separate on-shore antenna would be required for each link. Use of a central facility with multiple antennas would help reduce the system cost.

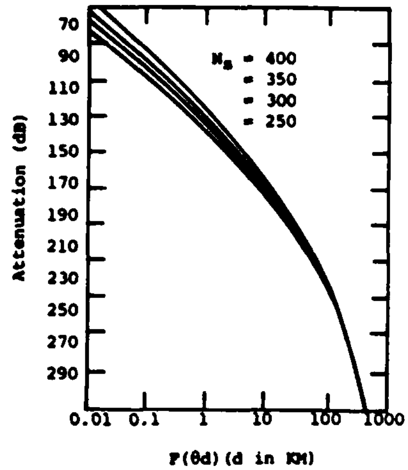
Solving the loss equation for

f = 2 GHz

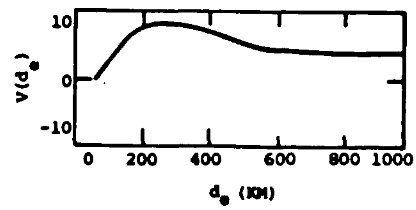
d = 150 miles

$G_t = G_r$ = 43 dB ($\simeq$ 30-foot dish)

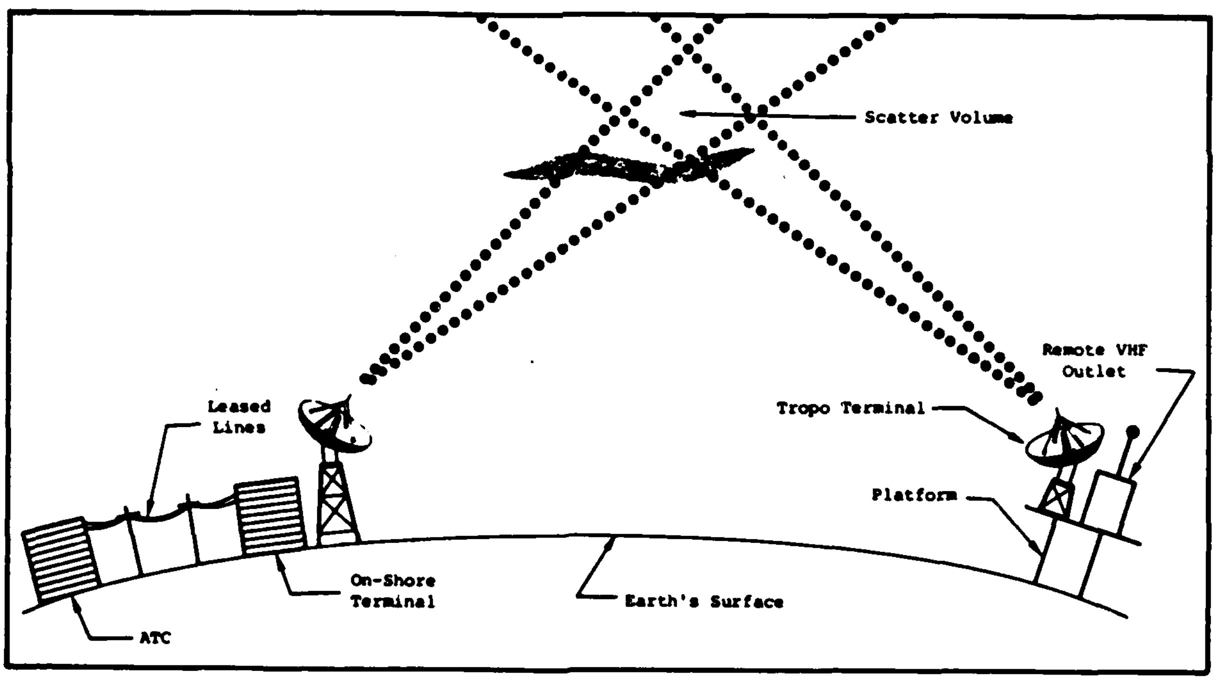
*A.F. Harvey, *Microwave Engineering*, Academic Press New York, New York, 1963; also *Estimations of Tropospheric-Wave Transmission Loss*, CCIR Eighth Plenary Assembly, MV Report 425-1, Geneva, 1974.



(a) Antenna Effects



(b) Climatic Effects for V(d_e)



(c) System Layout

Figure 4. TROPOSCATTER

yields a loss of about 204 dB.

The received power is then

$$P_r = P_t + G_t + G_r - L_p$$
$$\approx -84 \text{ dBm (a value well within practical limits)}$$

for operation at the 90 percent reliability level assuming a 1 kW transmitter and the 30-foot dish antennas. This represents an achievable system if the costs, both acquisition and operational, are acceptable. Of course, lower frequencies present somewhat lower path losses (because of the free-space component, the scatter component is largely frequency-independent), but lower frequencies also offer lower gain from a given-diameter antenna.

The troposcatter mode is subject to fading from at least two distinct sources. Short-term fading, with periods of minutes or seconds, generally follows a Rayleigh distribution and is the result of multipath transmission.

The use of spatial diversity, i.e., two antennas separated by about 60 wavelengths (about 30 feet at 2 GHz) should prove effective in reducing the effects of the short-term fading. Of course, this doubles antenna costs and would present difficulties in mounting on some smaller oil rigs. A second source of fading is long-term fading, with periods of hours or days, which results from changes in the rate at which the refractive index of the atmosphere falls off with altitude $\left(\frac{dN}{dH}\right)$. Such fading is inherent to the mode and is not significantly affected by the use of diversity. In the preceding example, the calculated loss value is expected not to be exceeded 90 percent of the time.

Costs

The cost of establishing an eight-station tropo-based system are estimated as follows:

- Off-Shore Terminal
  - Radio Sets: 8 @ $90,000 = $720,000
  - Antennas (2 per site): 16 @ $30,000 = $480,000
- On-Shore Terminal
  - 8 Radios @ $90,000 = $720,000
  - 16 Antennas @ $30,000 = $480,000
  - 1 Shelter and Miscellaneous = $10,000
- Installation: estimated as helicopter time: 2 trips (one for equipment, one for antennas in sling load) of 4-hour round-trip @ $250/hour + $850/day = $2,850 per installation; 8 installations @ $2,850 = $22,800.

Thus the estimated total cost of establishing the off-shore portion of the system is about $1,250,000. It should be noted, however, that system costs varied by as much as a factor of 5 from manufacturer to manufacturer.

Installation of the on-shore station is, of course, much simpler. An estimated 125 man-hours per antenna is required, or 16 antennas × 125 hours × $20 per hour = $40,000.

Installation of the equipment and shelter is estimated at 80 man-hours, bringing the total to about $42,000.

Maintenance costs for the off-shore terminals include the transportation costs discussed earlier, plus an estimated eight man-hours per month for antenna maintenance.

Maintenance of the on-shore terminal will not present the transportation problems of the off-shore installation, but some maintenance on the 16 antennas is expected. An estimate is 10 hours per month, or about $200.

Summary

The troposcatter option will provide reliable links, but at a high cost. It would cost well over $1 million to acquire and install the system, and extensive and complex off-shore installation work would be involved. The total system would involve some 32 dish antennas 30 feet in diameter, which would represent a continuous maintenance requirement.

3.2.2.4 High Frequency (HF)

High frequency (HF) radio frequencies are defined as those lying between 3 and 30 MHz, the so-called "short-wave bands". Propagation at these frequencies is principally dominated by two effects: groundwave and skywave.

Groundwave

Signals at frequencies of less than about 8 MHz propagate in a mode referred to as groundwave. The vertically polarized component* of the signals follows the dielectric curved surface of the earth, allowing communications at distances considerably greater than would be predicted from LOS considerations. Figure 5a illustrates this effect and shows a graph of estimated losses for this mode.

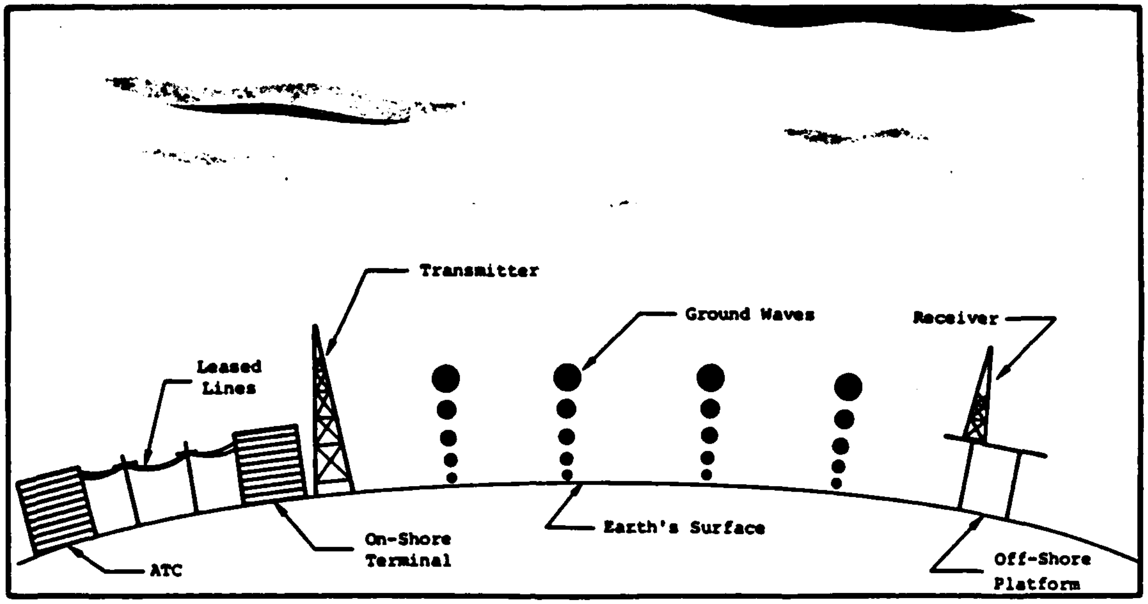
The groundwave mode is relatively reliable but is subject to some fading as the result of changes in atmospheric refractivity and skywave reflections. Multipath reflections from the ionosphere can cause fading in this mode if the two path end-points are separated by medium distances.

Skywave

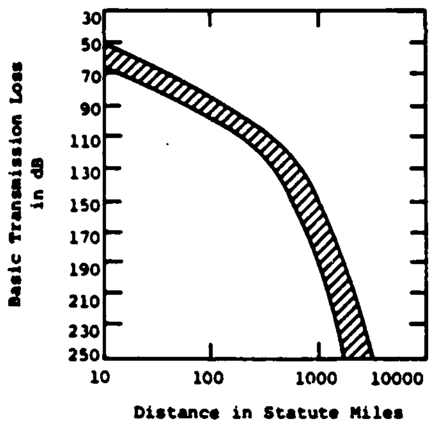
The ionosphere** is a layer of the atmosphere in which solar radiation has caused ionization to occur. The layer can be used to reflect radio

*The horizontally polarized component is effectively short-circuited by the dielectric surface of the earth.

**Also called the Heavyside Layer.



(a) Link Scheme



(b) Path Loss

Figure 5. HIGH FREQUENCY (HF)

signals back to earth, allowing long-range over-the-horizon communications. The degree to which the signal is reflected is a strong function of the state of ionization in the ionosphere, which is in turn a strong function of the amount of solar radiation incident upon it. This varies greatly with time of day and time of year and is strongly a function of the sunspot number.

The reflectivity of the ionosphere thus varies greatly with time. Another factor is the frequency of the signal. Generally, less energetic signals (i.e., longer wavelengths) are reflected more strongly than more energetic signals (shorter wavelengths). Thus at any given moment there is a maximum frequency that will be reflected by a given amount. This so-called Maximum Usable Frequency (MUF) varies with time of day often by a factor of 3 or more within a 24-hour period.

A great deal of effort is expended by various agencies in an attempt to predict the state of the ionosphere and hence the performance of skywave paths, but it remains at best an inexact science. Forecasting notwithstanding, periods during which contact is not possible are characteristic of HF links in general, and especially skywave links.

Other Factors

Most HF voice equipment available today uses amplitude modulation of one sort or another. HF does not generally lend itself to frequency modulation for voice operation because of the large bandwidth required and phase distortions introduced by skywave reflections. This makes the receiver susceptible to atmospheric and man-made electrical noise and static. According to the available data on atmospheric noise*, the Gulf experiences atmospheric noise as intense as that anywhere in the world. Although the intensity of the noise peaks at frequencies somewhat below normal HF channels, sufficient levels are still present on these channels to present significant problems, especially during thunderstorms.

The environment in which these links are being considered for operation, off-shore oil rigs, is expected to be man-made-noise-intensive. A variety of electric motors operate pumps, valves, blowers, compressors, etc., with the power coming from on-site generators. These combine to produce electrical noise that could degrade HF performance.

An additional factor to be considered in the choice of an HF link scheme is skywave interference. Other stations operating on or near the system frequency may occasionally interfere with the local links even though they may be located very far away, even on the other side of the world. Anomalous skywave propagation can occasionally permit very long paths, causing intermittent interference between stations that are normally far out of range of each other.

System Configuration

If HF were used to support a Gulf air-ground communication system, it would be configured as illustrated in Figure 5b. Remote VHF outlets would be linked by HF to shore-based facilities (as discussed earlier, HF is for the most part inappropriate for communication direct to the aircraft). A separate set of HF frequencies would be required for each VHF channel to allow adaptation to changing propagation conditions. For the distances involved in the Gulf, the groundwave mode would probably be preferred because of its higher reliability relative to the skywave mode over such distances. Assuming frequencies in the aeronautical mobile band of 3.4

*From CCIR Report 322, Tenth Plenary Assembly, Geneva, 1963.

to 3.5 MHz, this would entail vertical antennas about 70 feet tall installed with adequate ground systems. Such large antennas might pose a problem on crowded oil rigs, which often use swinging cranes, and in any case must be able to accommodate helicopter landings without hazard. The ground system should pose no problem, since sea water forms an excellent ground and antenna counterpoise (ground plane). In addition to the VHF outlet equipment discussed earlier, such a system would require the antenna discussed above, the HF transmitter and receiver, power supplies, and control circuits. Transmitters in the 100-watt class would be required.

Costs

The initial cost of an HF system for each off-shore site is estimated as follows:

- HF Transmitter: $11,993
- HF Receiver: $11,326
- Antenna: $900
- Control Circuit: included in transmitter and receiver
- Racks, cables, miscellaneous: $2,000

For a system of eight off-shore outlets, this would come to about $210,000 for the off-shore equipment.

Installation costs can be estimated as follows: one helicopter run per installation carrying both VHF and HF equipment -- 4-hour round trip @ $250/hour + $850/day = $1,850 per installation for transportation. Allowing 60 man-hours for installation (VHF and HF) @ $20/hour = $1200 brings the total estimated installation cost to $3,050 per installation, or about $25,000 for an eight-station system.

Assuming a shore-terminal facility similar to an RCAG equipped for eight off-shore channels, the cost of establishing such a facility is estimated at about $300,000. The shore facility might be combined with an existing facility, avoiding the real estate and shelter construction costs associated with the establishment of an entirely new facility. In this case, initial costs for the shore facility are estimated to be:

• Transmitters: 8 @ $11,993 =	$95,944
• Receivers: 8 @ $11,326 =	$90,608
• Antennas: 8 @ $900 =	$ 7,200
• Miscellaneous (racks, cables, connectors, etc.)	$20,000
Total	$213,752

The major portion of the cost of maintaining any of the off-shore components of a system is expected to be transportation. Thus,in essence, the costs will be shared in this case by the VHF outlet equipment. The cost of any actual maintenance of the equipment short of complete replacement is expected to be negligible compared with the cost of transporting the maintenance technician. These costs were estimated in previous sections, and apply in this case as well. Recurring cost for the on-shore terminals is estimated to be similar to that encountered with RCAGs, that is, about $3,000 per month. (The validity of assuming similar costs for RCAGs and the on-shore HF terminal stems from the similarity in the number and complexity of transmitters, receivers, and antennas.)

Summary

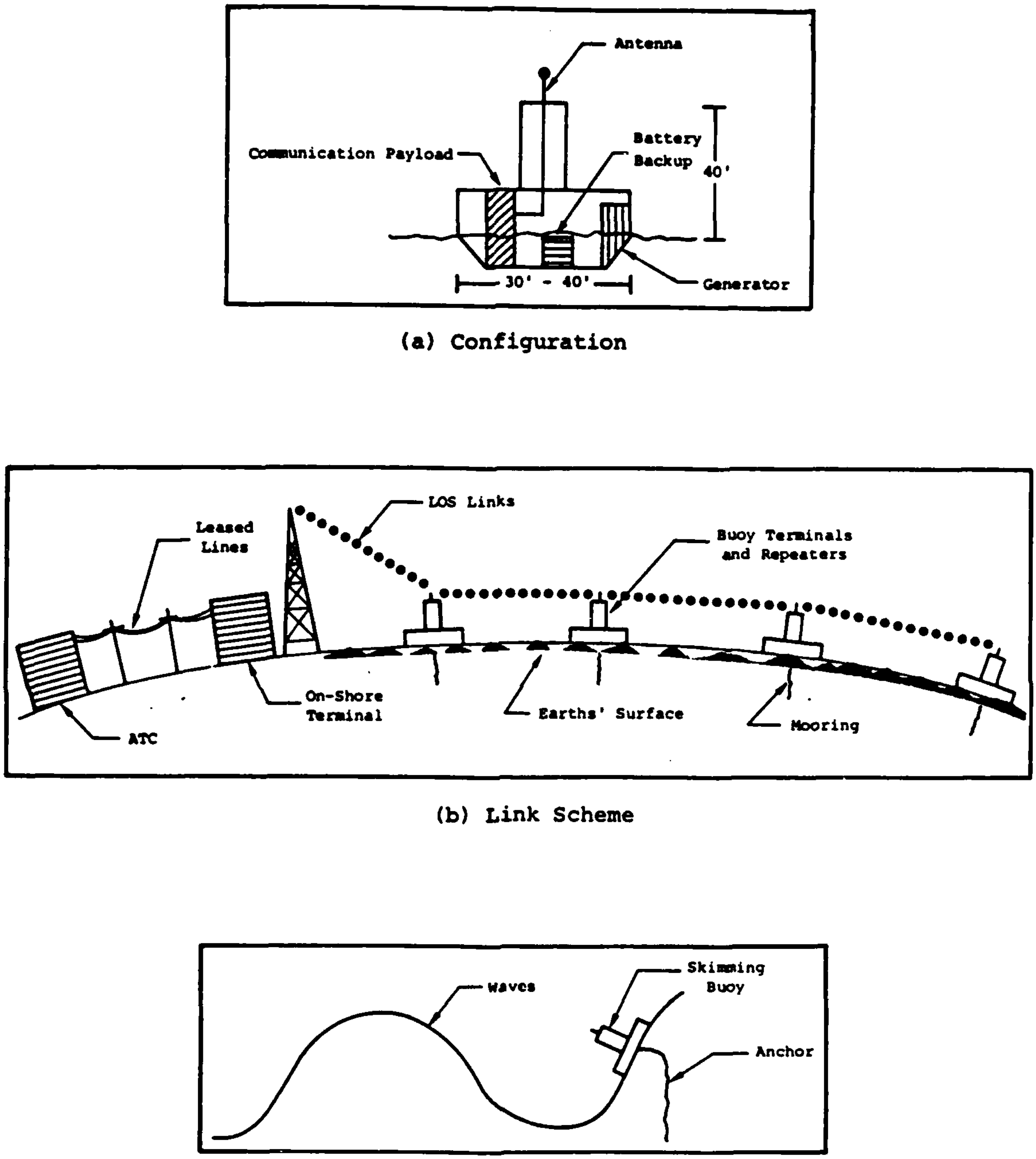
The use of HF to link off-shore VHF outlets to shore is a straightforward task from a technical-hardware standpoint. The required equipment is available off the shelf and is relatively inexpensive. However, there are several important disadvantages to this approach. The most important of these is the variable nature of HF propagation. It is characteristic of HF for there to be frequent fading and periods during which contact is difficult, degraded, or impossible. Such systems are also subject to atmospheric and man-made electrical noise (static) and to skywave interference from distant stations. In short, skywave is a somewhat capricious medium, the vagaries of which are essentially unpredictable in the short term. This lack of 24-hour-per-day reliability makes HF a poor choice for ATC applications, which, perhaps more than any other terrestrial communications applications, require constant, real-time communication. HF is used on high-altitude oceanic routes simply for lack of any other means, and the problems inherent in the mode are tolerated out of necessity. When other, more reliable means of communications are possible, HF is generally not the preferred mode.

3.2.2.5 Buoys

The option of buoy-mounted LOS relay stations was briefly addressed earlier in this report. This section examines the option in more detail.

The limited time scale of the interim plan does not permit the design and construction of custom buoys. However, the National Oceanographic and Atmospheric Administration (NOAA) operates a system of oceanographic data buoys that contain equipment similar to that required in a remote VHF outlet. Figure 6a shows the configurations of these buoys. The size of the buoy is determined by hydrodynamic considerations; the buoys are in fact much larger than would otherwise be necessary to accommodate the equipment package. These buoys contain data transducers for temperature, current, etc., and either an HF or UHF satellite link transmitter-receiver. The system transmits the data in either a polled or timed mode. The equipment is powered by either a diesel generator or a bank of nonrechargeable batteries. The generator installations run unattended for a year, operating on a 5000-gallon supply of fuel, and the battery installations run for two to three years on a set of batteries.

These buoys and power systems are available more or less off the shelf and could be used to support a remote VHF outlet. There is ample room aboard the buoy to accommodate the necessary equipment, and environmental conditions inside the buoy should not exceed equipment limitations with proper cooling system design.



(a) Configuration

(b) Link Scheme

(c) Wave Actions

Figure 6. BUOY REPEATERS

A buoy-mounted outlet would be configured as shown in Figure 6b. The superstructure of the buoy acts as an antenna mount, positioning the antenna about 40 feet above the water.

Power

The system would be powered by either a diesel generator or nonrechargeable batteries. Solar-rechargeable batteries are being experimented with but are not currently available. A diesel-powered system could be backed up by batteries to provide for generator failure.

Links

There are several ways in which a buoy-mounted outlet could be linked to shore. One method used with some success by NOAA is HF, but it is not wholly reliable. However, the non-real-time nature of the data makes their system somewhat less susceptible to degradation introduced by delays incurred in HF dropouts. Another method used successfully is satellite linkage. The GOES satellite receives the data via a UHF uplink from an onmidirectional antenna on the buoy and relays the data to shore-based facilities. The satellite option is, of course, a very attractive one from an operational point of view, but it may not be a practical solution for the near term. This option is discussed in Subsection 3.2.2.9.

The remaining link option is that of a series of buoys acting as repeater stations. Figure 6b illustrates this configuration. The range of a signal from the buoy is about $R = \sqrt{2H} = \sqrt{2 \times 40} = 8.9$ miles, or, in round figures, 10 miles. The maximum separation for the buoys is therefore about 20 miles. Thus, to cover just one route of 150 miles, about seven buoys would be required. Note that each buoy would need both VHF outlet and relay equipment to provide coverage over the entire route, and not just at the end-points. The eight terminal areas defined by the FAA could be covered by a buoy in the center of each, linked back along one of the route chains.

In view of the fact that segments of several routes within a sector could be covered by one buoy, it is estimated that a total of about 20 buoys would be required to provide the needed coverage.

Costs

Acquisition. Acquisition costs for each buoy are estimated at about $100,000, including equipment and buoy placement.

Maintenance. Maintenance personnel must reach the buoy by boat since helicopter landings on the buoy are not possible. NOAA has incurred maintenance expenses of about $100,000 per buoy per year, including an allowance for a haul-out and refurbishing during a three-month lay-by once every three years.

Operational Considerations

Although it is certainly possible to construct a system such as the one described, several important disadvantages are inherent in the concept. First, these, and most such buoys, are designed to skim over the surface of waves and swells, remaining essentially flat against the wave's surface (see Figure 6c). Thus in heavy seas the antenna will move to a position as much as 45° away from the vertical, reducing the range of the station on two counts: (1) the antenna is only about 70 percent of its normal height, reducing the radio horizon range; and (2) the angled antenna presents a lower-gain portion of its antenna pattern to most quadrants of the horizon.

Another consideration is duty cycle. As mentioned earlier, the buoys must be removed from service and overhauled every three years. The process takes three months, during which time a back-up buoy must be used. This creates the requirement to maintain extra standby buoys.

Although it is a rare occurrence, the buoys have broken their moorings and capsized in heavy seas. This factor raises a related issue. Any chain of relay stations is susceptible to failure as the result of a "break in the chain". The failure of a single buoy could shut down an entire area until the buoy was replaced or repaired. Some repairs can be made at sea, but most major work must be completed in port, necessitating a haul-out. The repeater-chain concept carries this weakness with it: if the probability of failure of a single unit is N, then the probability that the entire chain of M units will fail is approximately $N \times M$, since failure of any link results in failure of the entire chain. Of course, a certain amount of redundancy is possible by making key-route buoys part of two or more chains. Thus failure of a single buoy would not isolate all those off-shore of it. This scheme would offer increased reliability but at the cost of additional buoys to cross-link the various chains.

Summary

A system of buoy-mounted repeaters linked to shore in a repeater chain offers a means of providing remote VHF coverage over wide areas. However, these same areas are also densely populated by oil and gas rigs, which could serve as well as or better than a buoy. Considering the very high cost of establishing and maintaining a buoy-based system, there seems little advantage in the near term.

However, as exploration continues outward in the Gulf, it may become necessary to provide communications coverage in areas where there are no platforms. Buoy-mounted outlets might prove to be an efficient solution, especially if a satellite link is available.

3.2.2.6 Tethered Balloons

Large helium-filled tethered balloons can be used to carry a VHF outlet to altitudes that would be impractical or impossible to reach with tower installations. They represent a special case of the tall-tower option discussed earlier. These balloons are marketed commercially in the United States and are often exported to developing nations for use as microwave relays or television facilities, as an improvement to and substitute for HF, which is of somewhat limited reliability, and satellite service, which can be quite expensive. Equipment for transmitting and receiving is carried in the body of the blimp-shaped balloon; and voice, data, power and control circuits are carried by the tether line. Some of the larger of these balloons can fly at altitudes of up to 15,000 feet, giving them a maximum radio horizon distance of about 175 miles.

There are two ways in which balloons could be used to support VHF communication in the Gulf. One is to install a balloon with about a 10,000-foot altitude in a central location along the Gulf coast, providing coverage over the entire operational area. A second approach is to install balloons at lower altitudes off shore, near the center of the off-shore portions of each sector.

These configurations are discussed below in turn.

Single On-Shore Installation

To achieve the required 150 nm range, the height of an on-shore antenna must be

$$150 - 14 = \sqrt{2H}$$

(accounting for aircraft altitude of 100 feet: $\sqrt{2 \times 100} = 14$ miles)

$$H = \frac{(136)^2}{2}$$

$$= 9,248$$

or roughly 10,000 feet. Such a balloon could provide coverage over the entire operational area. Separate channels would have to be provided for each sector since coverage would overlap all sections. Figure 7 illustrates this configuration.

Off-Shore Installations

Balloon-borne repeaters could be stationed on off-shore oil rigs near the center of the off-shore portions of each of the sectors, and the audio and control circuits could be linked back to shore via the microwave circuits already in existence. This is a special case of a microwave relay-based system involving only one off-shore facility per sector.

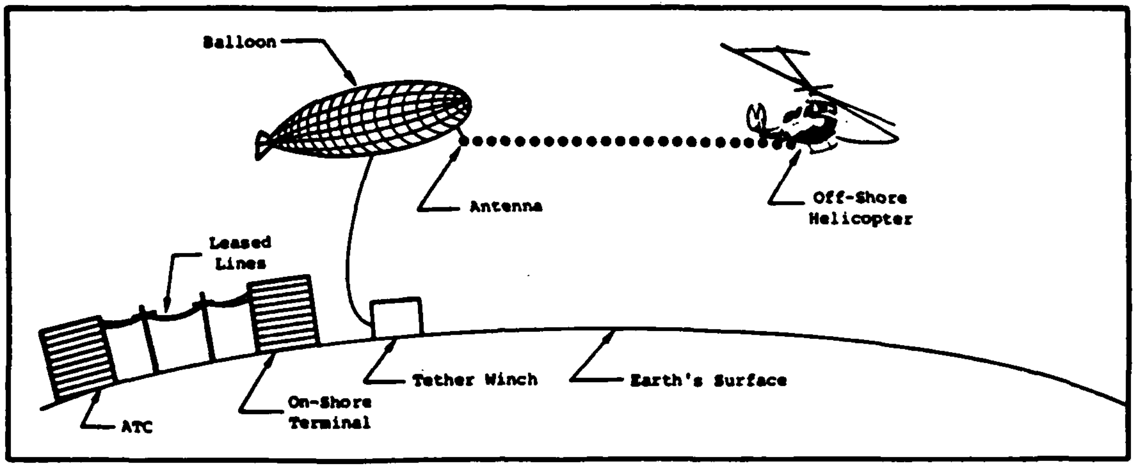


Figure 7. BALLOON SYSTEM

The required communication ranges are as follows:

- Beaumont sector - 75 miles
- Lafayette sector - 60 miles
- Baton Rouge sector - 40 miles
- Harvey sector - 75 miles

This corresponds to the following balloon heights:

- Beaumont - 2,800 feet
- Lafayette - 1,800 feet
- Baton Rouge - 800 feet
- Harvey - 2,800 feet

Of course, higher-altitude balloons could be used to cover more than one sector, but this may be undesirable, as discussed later in this subsection.

Operational Considerations

Although the use of balloon-borne repeaters offers a relatively easy means of achieving great ranges, it has several disadvantages. As these balloons come under FAA regulations concerning aerostats, a restricted zone around each balloon's position is required. This type of balloon derives aerodynamic lift from the wind, limiting drift to about 10 percent of balloon altitude, which would help limit the size of the restricted area. However, considering the poor to nonexistent navigational aids in the Gulf, it may not be reasonable to expect VFR helicopters unequipped with LORAN-C or Omega to be able to avoid a particular area smaller than 1/2 mile in diameter.

With respect to the related issue of safety, the balloon (especially its tether) represents a hazard to aircraft that may be difficult to avoid, particularly in conditions of limited visibility. The required balloon altitudes coincide with common operating altitudes for off-shore helicopters, making their avoidance a major concern. Helicopters are even more susceptible to wire strikes than fixed-wing aircraft since a fixed-wing aircraft might remain under some control after a wire strike on the wing, while wire strikes on a helicopter rotor are much more likely to cause a crash or forced landing.

Reliability is another concern. The balloons are large and are very subject to wind and storm damage. Most must be reeled in and secured in winds higher than 45 knots and in thunderstorms, removing them from service at just the time when they may be needed the most. Since the Gulf is a region prone to numerous thunderstorms and hurricanes, this imposes a serious limitation on the serviceability of the balloons.

Costs

The initial cost for a balloon is in the range of $5 million to $10 million per balloon depending on size, altitude, load-carrying capability, and installation requirements.

Recurring costs for maintenance and support are estimated at $100,000 to $150,000 per year per balloon. Off-shore balloons would involve the additional transportation costs discussed earlier in connection with the VHF outlets. Recurring costs will also include the salary of an operator stationed at the site -- actually several operators per balloon -- probably on a 7-day-on/7-day-off shift. A manned site is almost essential for large balloons. If the balloon is located off shore, one of the rig crew might be trained in operating the equipment to eliminate the need to station an additional person on the rig, but this would interfere with the performance of rig crew duties.

As mentioned earlier, there is a disadvantage to combining coverage of all sectors in one high-altitude balloon. Removal of this one facility from service would effectively shut down all sectors. As the thunderstorms in the Gulf are often quite localized, having separate facilities in each region would permit reeling in only the affected balloon, leaving the others on the air. Similarly, failure of the system aboard one balloon would not affect other sectors.

3.2.2.7 Meteor Scatter

Each day many thousands of meteors and micro-meteors enter the earth's atmosphere. Even though the vast majority of these objects are no larger than a grain of sand, each leaves an ion trail as it burns. These ion trails are of sufficient frequency and duration to support over-the-horizon radio communications up to distances of about 1,200 miles. The ion trails reflect best at the VHF range of 50 to 80 MHz. With the exception of 74.60 to 75.40 MHz, this band is reserved for land fixed and mobile communications, including military tactical applications. The 74.60 to 75.40 MHz frequency is assigned to air navigation for marker beacons used in connection with the instrument landing systems and other landing and navigation systems.

While these meteor and micro-meteor trails are sufficiently reliable to permit their use in data communications, they are highly intermittent, with lapses of up to ten minutes between useful trails. They will not support real-time communications requirements such as Air Traffic Control. In addition, the system is best suited to fixed point-to-point applications.

3.2.2.8 Relay Aircraft

It is possible to extend VHF coverage by providing relay stations carried aboard aircraft that usually hold over a known position, flying a ractrack pattern. This type of repeater provides the same coverage as the balloon-borne repeaters discussed earlier. The principal difference is an operational one.

The Coast Guard often uses this method during search and rescue operations, where it is advantageous to have a highly mobile repeater capability. However, these operations are of limited duration, usually a few days at most, and are limited to daylight hours.

The cost of operating a fleet of relay aircraft to provide continuous coverage in the Gulf would be very high. As with balloons, the disadvantage of a single high-altitude aircraft is that communications in all sectors are affected by trouble with a single facility. This problem can be avoided by using separate facilities for each sector.

Even the most modest aircraft capable of carrying the required equipment represents operating expenses of at least $200 per hour for piston equipment, exclusive of crew salaries. The annual cost of continuous operation ($200 × 24 × 365) is more than $1.75 million per aircraft station, not including transit time or salaries.

The continuous-service nature of the communication requirement in the Gulf makes relay aircraft a difficult mode. The limitations that apply to balloons in violent weather apply equally to aircraft; the aircraft could not remain on station in a thunderstorm. Of course, aircraft can maneuver around storm cells, giving some flexibility in this area.

Providing one relay aircraft station for each of the four sectors would require at least two aircraft per station to permit refueling and crew change, plus at least one (and preferably two) back-up aircraft to allow for maintenance and downtime of the operational aircraft. This arrangement represents a total of nine or ten aircraft, with acquisition costs of $200,000 each and upward depending on the aircraft, plus the estimated $200 per hour operating expenses. Pilots earning $20,000 per year each would add at least $160,000 per year to the total system operating costs. Thus it would cost $1 million to $2 million to establish the system, with annual operating expenses of about $8 million. These figures are for a very modest twin-engine piston aircraft. Use of turbine or pure jet equipment would make the system far more expensive to acquire and operate.

3.2.2.9 Satellites

During the course of the ARINC Research investigation of communication options for the Gulf, it appeared that there was a potential for using satellite-based links in the short term. Eventually, this approach proved to be impractical, but since it was considered, this discussion of the satellite option is included for completeness. This brief treatment of the very complex field of satellite communications will be supplemented by a more thorough discussion in the final report to be published at the end of Phase II of this study.

There are basically two types of satellites: synchronous and non-synchronous. The orbital period of a satellite varies with its distance from the earth, from a minimum of about 80 minutes at low orbital altitude (about 100 miles) to infinity at infinite distance.

Low-altitude satellites, with their attendant short periods, appear from the earth's surface to pass overhead quite quickly about every one and one-half hours. The rest of the time, such satellites are of little use in communication because they are below the horizon. This intermittency limits the usefulness of low-altitude satellites. Of course, a number of these satellite could be placed in the same orbit, spaced so that one or more was always in view from a given point on the earth. This approach, however, multiplies the cost of the system, as well as the probability of failure of one of the satellites in the system. A much more straightforward approach is the use of a geo-synchronous satellite.

It is clear that as the orbital period increases with altitude, a point is reached at which the period is the same as the rotational period of the earth. A satellite placed at this altitude in an orbit in or near the equatorial plane will appear to remain nearly motionless in the sky over a particular point on the earth's surface, allowing the full-time use of the satellite facilities by all subscriber stations at all times. A synchronous-orbit altitude of about 22,300 miles above the earth's surface is not too inconvenient an altitude, although antennas must be carefully selected and oriented.

Direct communication between helicopter and satellite is a difficult goal. The size and weight limits imposed by the nature and construction of the helicopter make it generally unsuited to carrying satellite terminals, especially if high antenna gains are required. Further problems can arise from effects involving blade modulation of the signals. In addition, the use of helicopter satellite terminals would not be responsive to the industry requirement that no additional equipment be placed aboard the aircraft.

An alternative approach is to use satellite circuits to link remote VHF outlets to shore. Such a system would be configured as shown in Figure 8. A satellite link could be used in conjunction with either rig- or buoy-mounted VHF outlets. However, there is a trade-off in satellite design concerning antennas. Because of their distance from the earth, synchronous satellites generally require a considerable amount of antenna gain either at the terrestrial station or at the satellite, or at both. A satellite with a large high-gain antenna, such as the ATS-6 statellite had,* can permit access by terrestrial stations with very modest antennas (only a foot or so in extent). Other satellites, such as the present MARISAT, have very small antennas in orbit, requiring the earth terminal to have a rather large dish-type antenna that must be pointed at the satellite with considerable accuracy. Thus if buoys were chosen to support the outlet and link, a satellite with a large high-gain antenna would be required, since it would be difficult and expensive to install a large high-gain antenna on a buoy, especially in light of the stabilization problem caused by the buoy's motion. On the other hand, an oil rig could easily accommodate a satellite dish of considerable dimensions; indeed, several rigs are already so equipped.

The RCA system is an example of the kind of service available from commercial communication satellites. By December 1979, the RCA system will consist of three satellites, at west longitudes 119°, 132°, and 136°. These satellites provide a variety of services, including network broadcast links, high-volume/high-rate data trunking, and point-to-point low-rate voice and data service. This latter service would be suited to the present application. The RCA satellites require at least a 15-foot dish for access, and alignment is critical; moving platforms such as ships and floating oil rigs require extensive stabilization. RCA leases both earth terminals and transponder services (space segment) at the following rates:

- First two stations: $9,000 per month
- Each additional station: $4,000 per month

These figures include installation, maintenance, and space segment links. The terminals may be purchased outright for an estimated $150,000 each and installed on the rig, and space segment service can be leased at an estimated $1,000 per channel per month. Thus a system of eight offshore terminals needed to cover the areas specified by the Southwest Region

---

*ATS-6 is no longer in service.

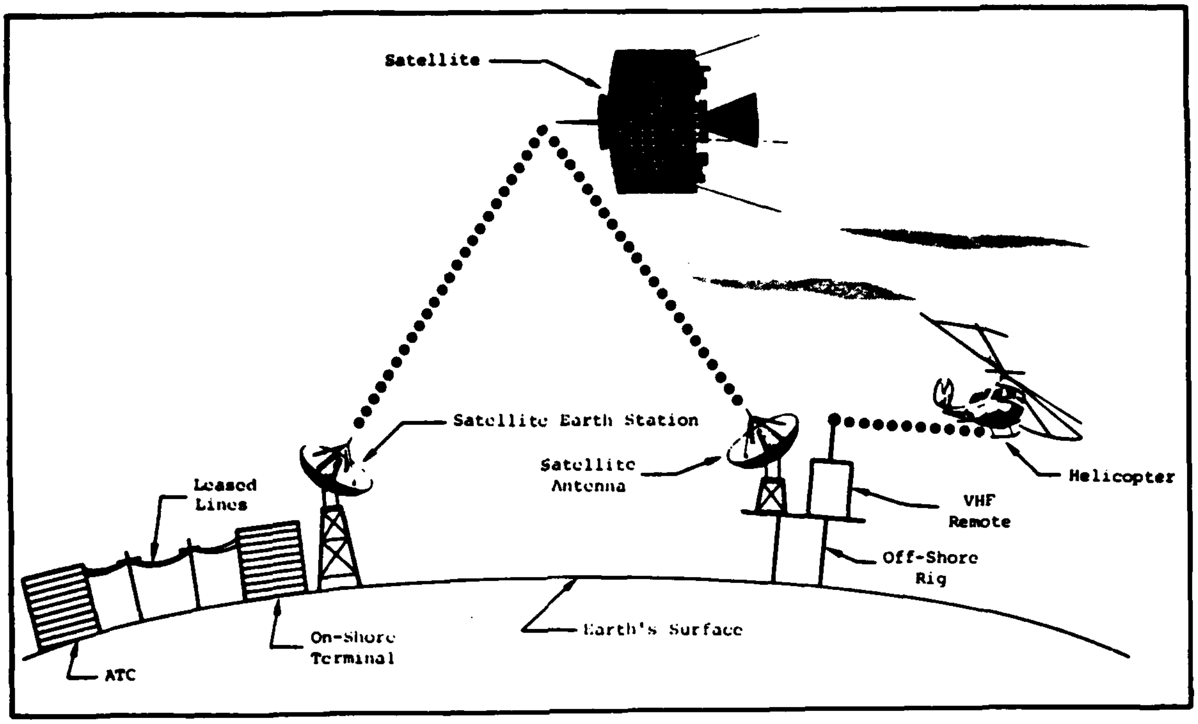


Figure 8. SATELLITE SYSTEM

would cost an estimated $37,000 per month to lease (eight off-shore stations + one shore-based terminal). Purchase of the system would cost an estimated $1,350,000 plus about $9,000 per month for space segment links. The latter figure assumes one channel for each station. The number of channels could be reduced by using TDMA techniques and consolidating more than one station onto one channel. In this way the number of channels needed is reduced, but at the expense of additional multiplexing equipment. In addition, propagation delays, which can amount to 0.25 second or more, may make such an approach impractical. Similarly, a polled system would introduce delays that would render real-time voice transmission impossible.

Another potential approach to a satellite-based system is to consolidate the FAA's system with an existing or planned military system. The Navy has for some time leased special UHF channels aboard the MARISAT satellite. The Navy's lease on these channels expires in 1980, at which time Comsat General plans to turn off the Navy transponders in an attempt to prolong the life of the satellite for L-, and C-band commercial service through and beyond the end of its design life in 1981. However, the FAA may be able to obtain the use of those channels for some period of time, at the end of which some channels on the Navy's new satellite may be available. The subject has been discussed informally with the Navy and Comsat General, and both have termed the idea "not out the question". This approach offers several advantages. First, the UHF terminals involved are standard military units, the AN/WSK-3, which may be available to the FAA through

Government channels at reduced cost. Second, the FAA would probably not be paying commercial rates for the satellite channels.

It became evident during the course of the ARINC Research investigation that the lead time involved in acquiring, installing, and commissioning a satellite-based system made it an impractical option for the near term. However, the potential of this approach should not be overlooked as exploration in the Gulf extends outward. If coverage were required in areas not supported by other means of communication, the satellite option would merit close attention. In addition, the more general problem of communication with and surveillance of low-altitude aircraft, not only off-shore but anywhere in the NAS, lends itself to satellite-based solutions. This area will be covered in more detail in the final report published at the end of Phase II of this project.

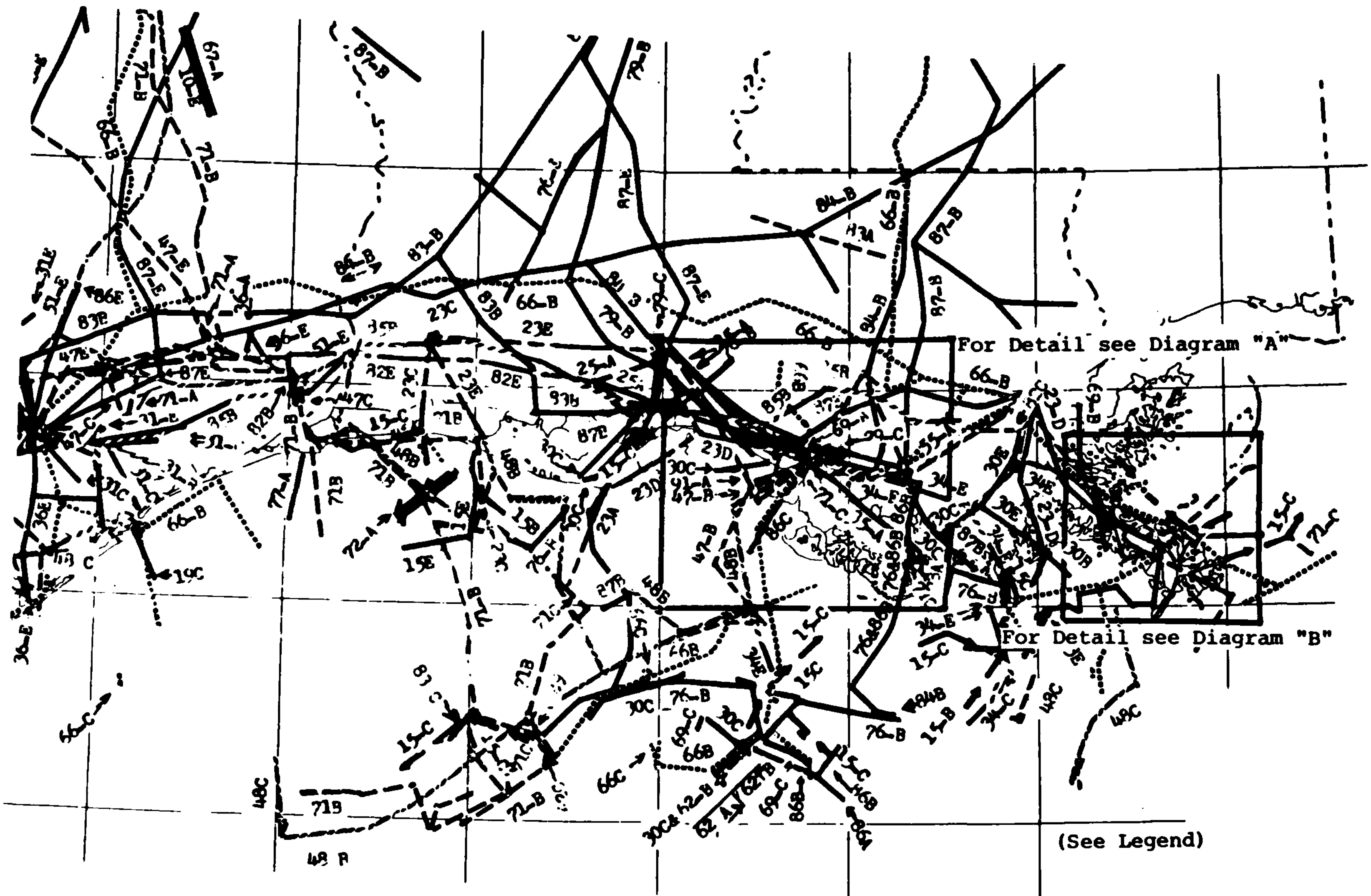
3.2.2.10 Microwave Links

Many of the more than 5,000 off-shore oil-gas platforms in the Gulf are linked to shore by privately owned and operated microwave networks. These networks provide telephone service for the rig crews and remote control and telemetry for the operation of unmanned platforms. Figure 9 shows the extent and location of the present networks. However, the configuration of the links and terminals is dynamic, changing with requirements and the relocation of mobile drilling rigs.

The high-quality voice-grade links provided by these systems could be used to link voice and control circuits of VHF outlets located on the platforms to shore. Of course, it would be technically possible for the FAA to establish its own system of off-shore platforms and microwave links, but the cost of such a system would be prohibitive. It is obviously much more cost-effective to make use of the existing platform and microwave resources, especially in light of the petroleum industry's stated willingness to provide platform space, power, and microwave channels to the FAA at nominal cost. (It is clearly in the industry's own best interest to cooperate with the FAA in this project, since it has the most pressing need for IFR services and will profit from the enhanced capabilities provided.)

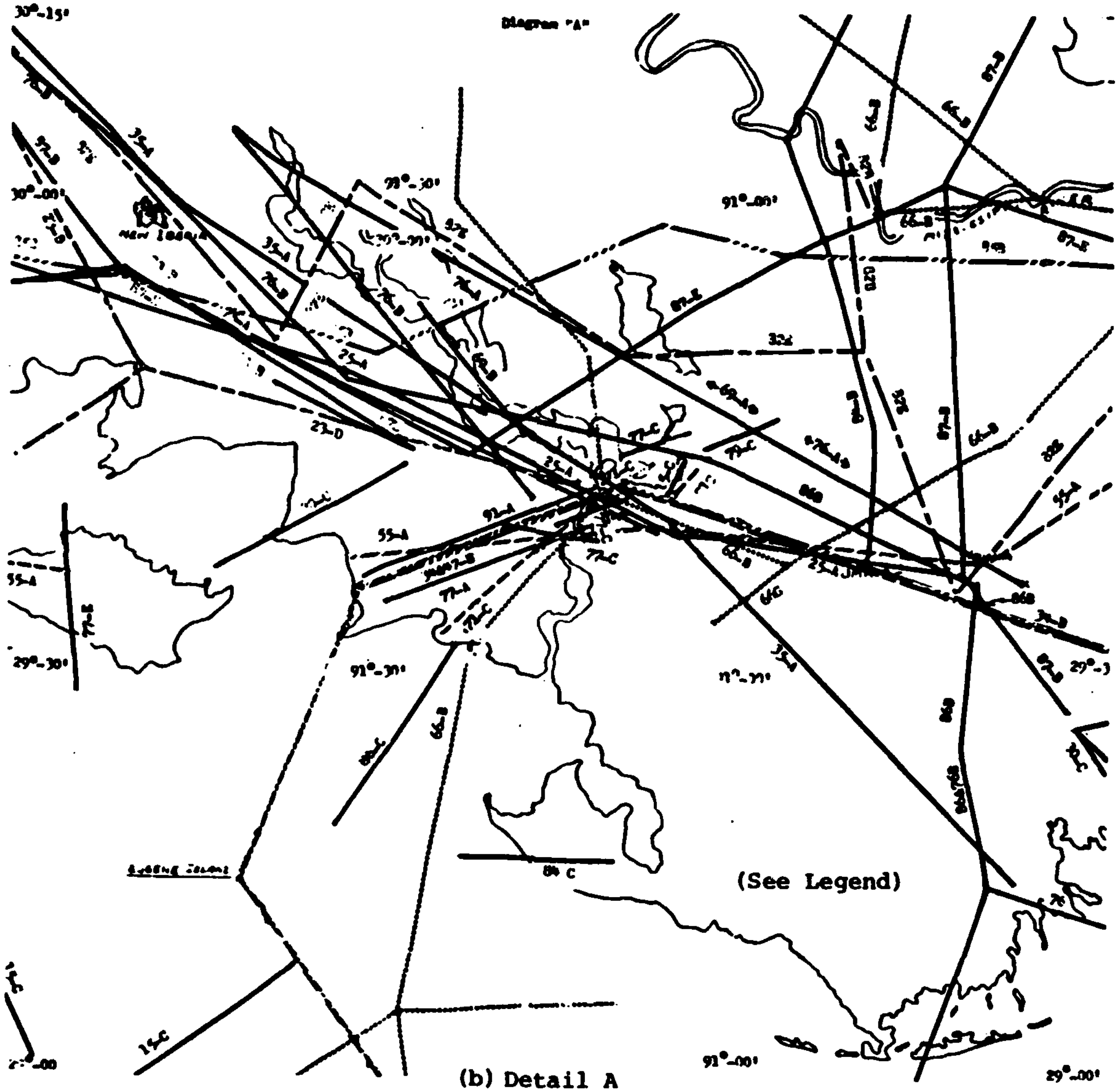
A system using this approach would be configured as illustrated in Figure 10. The microwave systems terminate at the platforms in telephone-type service, making them compatible with existing FAA RCAG-type equipment which, sited on the platform, would interface with the telephone-like terminal of the microwave network. At the shore terminal, conventional leased lines would carry the voice and control circuits to the ATC center.

The advantages of such an approach are numerous. First, microwave links provide high-quality, highly reliable links and are generally not subject to large-scale fading, static, or any of the other disadvantages associated with lower frequencies. In addition, the facilities to support such a system are already in place, requiring no large capital outlay on the part of the FAA. As mentioned earlier, several large petroleum companies that operate microwave-serviced platforms have expressed a willingness



(a) Microwave Systems Layout

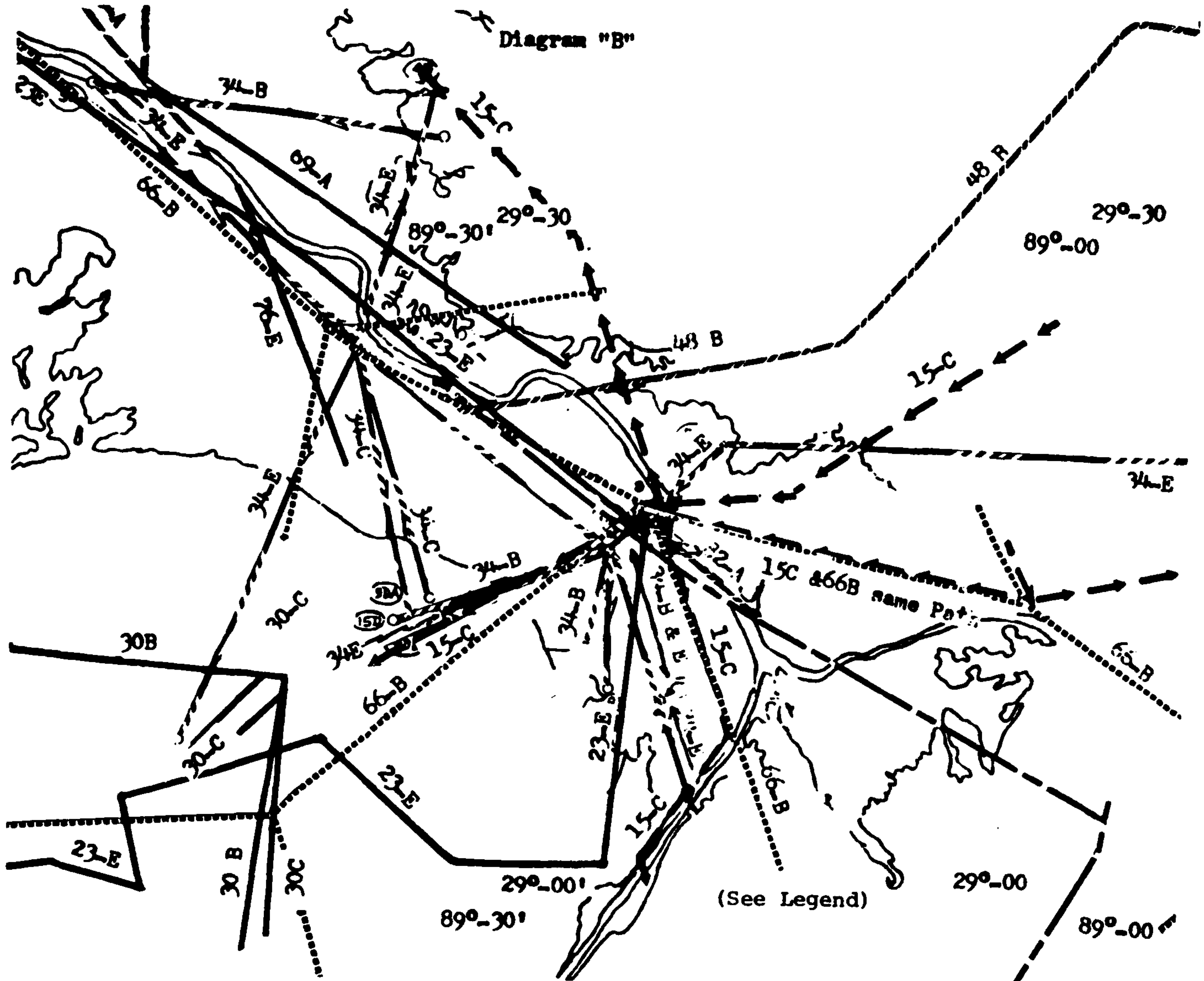
Figure 9. MICROWAVE SYSTEMS (continued)



(b) Detail A

Figure 9. (continued)

(continued)



(c) Detail B

Figure 9. (continued)

(continued)

Legend

The numbers indicate the company and the letters following these numbers show the frequency band.

A - 950-960 MHz
B - 1850-1990 MHz
C - 2100-2200 MHz
D - 2500 MHz
E - 6 GHz
F - 12 GHz

1 - 565 Corp.
2 - Amdel Pipeline Co.
3 - American Oil Co.
4 - American Petro Fina
5 - ARCO Communications
6 - ARCO Pipeline Co.
8 - Atlantic Seaboard Corp.
9 - Bi-Stone Fuel Co.
11 - BP Communications
12 - Algonquin Gas Corp.
13 - C.E.R. Geonuclear Corp.
14 - Chevron Communications
15 - Chevron Oil Co.
16 - Circle Drilling Co.
17 - Cities Service Gas Co.
18 - Clarke Oil Well Service
19 - Coastal States Gas Producers
20 - Colorado Interstate Gas
21 - Columbia Gas Systems
22 - Commonwealth Oil Refining
23 - Conoco Pipe Line Co.
24 - Consolidated Natural Gas Corp.
25 - Delta Drilling
26 - Dow Chemical Corp.
28 - East Ohio Gas Co.
29 - El Paso Natural Gas Co.
30 - Exxon Communications
31 - Exxon Pipeline Co.
33 - Florida Gas Transmission Co.
34 - Gulf Oil Communications
35 - High Seas, Inc.
36 - Houston Pipeline Co.
39 - BP Eastern Pipeline Co.
41 - Kentucky-West Virginia Gas Co.
43 - Marathon Pipeline Co.
44 - Michigan-Wisconsin Pipeline Co.
45 - Mid Valley Pipeline Co.
46 - Mississippi River Transmission
47 - Mobil Pipeline Co.
48 - Mobil Oil Telecommunications
49 - Mountain Fuel Supply Co.
51 - Natural Gas Pipe Line Co. of Am.
52 - Northern Natural Gas Co.
55 - Ocean Drilling Co.
56 - Oklahoma Natural Gas Co.
58 - Pacific Gas Communications Co.
59 - Pacific Gas & Electric Co.
60 - Pan American Petroleum Co.
61 - Panhandle Eastern Pipe Line Co.
62 - Penzoil Offshore Gas Operations
63 - Penrod Drilling Co.
64 - Phillips Communications
66 - Shell Communications
67 - Sohio Pipeline Co.
68 - South Georgia Natural Gas Co.
69 - Southern Natural Gas Co.
70 - Southwest Gas Producers
71 - Sun Services
72 - Superior Oil Co.
74 - Taps Communications System
75 - Teledyne Movable Offshore
76 - Tenneco
77 - Texas Mineral Corp.
78 - Texas Eastern Transmission Co.
79 - Texas Gas Transmission Co.
80 - Trans-Western Pipe Line Co.
81 - Texas New Mexico Pipeline Co.
82 - Texas Pipe Line Co.
83 - Trunkline Gas Co.
84 - Transcontinental Gas Pipe Line Corp.
85 - Union Carbide Company
86 - Union Oil Co. of California
87 - United Gas Pipe Line Co.
88 - Western Slope Gas Co.
89 - Wiser Oil Co.
90 - Commonwealth Natural Gas Co.
91 - Cities Service Oil Co.
92 - Service Pipeline Co.
93 - Black Mesa Pipe Line Co.
94 - Getty Oil Co.
95 - Northwest Natural Gas Co.
96 - Cities Service Pipeline Co.

Numbers 7, 10, 27, 32, 37, 38, 40, 42, 50, 53, 54, 57, 65, and 73 were not assigned.

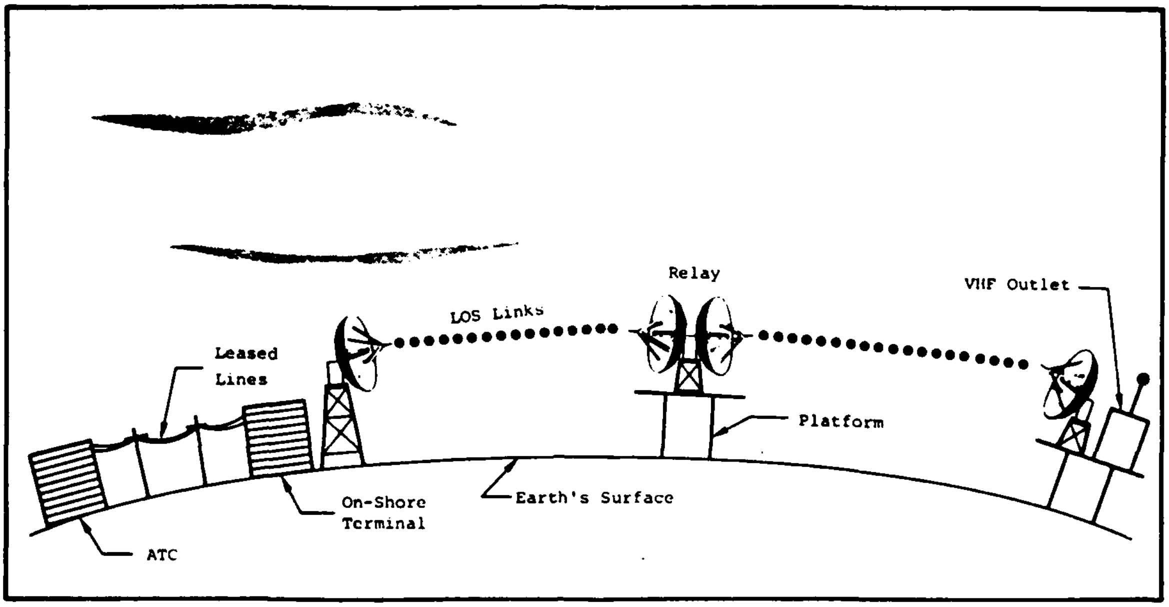


Figure 10. MICROWAVE LOS RELAY

to work with the FAA in a cooperative effort by making facilities available. Using these resources would reduce the lead time involved in establishing an operational system in the Gulf.

Figure 10 illustrates how these facilities could be used in establishing an off-shore ATC communication system in the Gulf. The remote outlets consist of one transmitter, one receiver, and one antenna per channel, together with control and audio interfaces, back-up equipment, standby power, and test equipment. They would be positioned on platforms in appropriate locations and would be powered primarily by the platforms' own generators. The on-shore terminal of the microwave systems would be linked to the ATC center by conventional leased lines. By judicious positioning of the outlets, each ATC sector and off-shore en route and terminal area could be covered independently, as required.

It is instructive to examine the systems established by private industry to meet their own communication requirements in the Gulf. One of the largest is that operated by Mobil Oil.

The Mobil system is configured as shown in Figure 11. Data on the system are presented in Table 2. Mobil operates a number of air-ground VHF outlets in support of its helicopter operations.

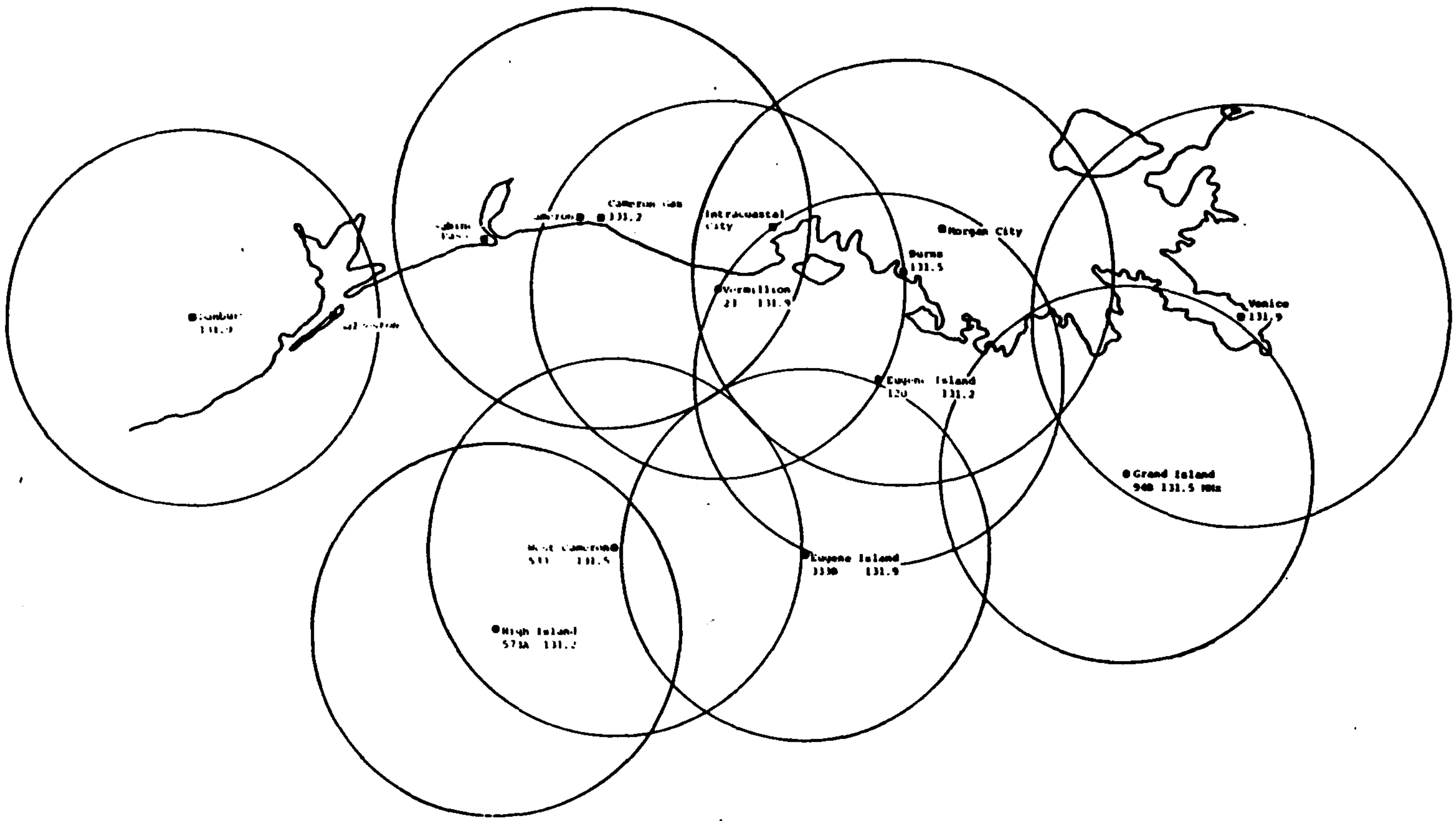


Figure 11. MOBILE NETWORK FREQUENCIES IN MHz (CIRCLES SHOW ESTIMATED RANGE TO AIRCRAFT AT 1500 FEET)

Table 2. MOBIL AIR GROUND SYSTEM		
Location	Frequency (MHz)	Call Sign
Grand Island 94B	131.5	WSE9
Venice (On-Shore)	131.9	KRA3
B'urns, Louisiana (On-Shore)	131.5	WMNP
Eugene Island 120	131.2	KQR2
Eugene Island 333B	131.9	KQS4
Vermilion 23	131.9	KRA4
Cameron Gas (On-Shore)	131.2	KQM9
West Cameron 533	131.5	KRA6

Each of the VHF outlets is equipped with the following:

- Transmitter: AIRCOM 7072, 10 to 25 watts, AM
- Receiver: AIRCOM 8080
- Antenna: DB Products Model 222 or 224, depending on location, finished with DB Products Iridite finish
- Antenna Height: On-shore locations, 250 feet; off-shore locations, typically 105 to 200 feet, 100 feet at least
- Power: All equipment operates on 110 Vac, 60 Hz.
- Back-up: None

Each of the outlets listed is remoted to the Morgan City dispatcher by means of a dedicated microwave channel; that is, a separate channel is used for each outlet. The microwave system has three major nodes: Morgan City, Cameron Gas Plant, and Beaumont, Texas. The network is completely owned by Mobil with the exceptions of the leg from Morgan City to Venice, which is a Bell line, and the link from Venice to Grand Island 76, which is on a Shell circuit.

The system is operated by a dispatcher at the Morgan City location. This operator has control over the entire system and monitors each channel for traffic. In communicating with the pilot, the operator will key the outlet nearest the aircraft; no frequency offset or multi-outlet keying is used. In addition to the outlets listed in Table 2, there are two others that are not part of the system proper. One is located at East High Island 573A and uses a frequency of 131.9 MHz. The other is on shore at Danbury, Texas, using a frequency of 131.9 MHz. These outlets are operated by a separate dispatcher located at Pearland, Texas.

Several problem areas have become evident in the short time the system has been in operation. The Eugene Island 120 outlet has proven to be susceptible to overload from close-in aircraft, making communication difficult. This is thought to be a problem with that particular receiver, since all the other installations of the receiver operate satisfactorily. A second problem is that when the dispatcher keys a remote transmitter, the signal sometimes is received by a nearby outlet receiver operating on the same frequency, causing the dispatcher to hear himself on that outlet and causing a channel-busy indication on his status panel. This problem is, of course, related to the reuse of frequencies at sites within range of each other. The intermittent nature of this problem is the result of a related problem: range variations with time of day and season. This type of problem is inherent in VHF propagation and is not considered to be a fault in the system.

Continuity of power has been a problem at some installations. The 110 Vac power used by the outlet is for the most part provided off shore by gasoline or desel generators. These generators are not usually backed up, and a power failure simply shuts down the outlet until repairs can be made. The microwave system has battery back-up that will operate the system for about 60 hours, during which time a repair crew can usually effect repairs. No such back-up is provided for the VHF outlets. This situation is characterized by Mobil as being a problem but not a serious one. No problems or failures related to the operating environment of the system, i.e., salt water, spray, and high wind, have been reported. The equipment is housed in heated and air conditioned enclosures.

The success of Mobil's system can be measured by the wide area of coverage and operational reliability it enjoys. Figure 11 shows the estimated coverage of the various VHF outlets and their location and frequency. Coverage is maintained over the entire IFR operational area with considerable redundancy, which makes the system less susceptible to degradation by the failure of a single outlet.

For the requirements under study, the FAA could emulate the system approach used by Mobil, and others, with the expectation of achieving similar results.

The cost of establishing a system of remote VHF outlets linked to shore by the existing microwave networks would be limited to that of acquiring and installing the outlet equipment itself. Other required facilities would be obtained by the FAA from the operators of the platform and microwave systems at whatever price the FAA could negotiate.

The installation costs for a remote VHF outlet can be estimated as follows:

- Helicopter time - one trip carrying all required equipment; 4-hour round trip at $250 per hour + $850 per day = $1,850

- Installation - estimated at 40 man-hours at
  $20 per hour = $800

- Total - $2,650 per installation, $21,200 for an eight-station system.

Recurring costs include power, floor space, and microwave channel rental. These costs are largely dependent on negotiations between the FAA and the platform operators; however, one figure mentioned unofficially by Mobil for channel rental was about $4.00 per circuit mile per month, which represents commercial rates. Maintenance transportation costs are as discussed previously.

This option is discussed further in Chapter Four.

3.3 OPTION SUMMARY

There are many factors to be taken into account in determining which of the available options is the overall "best" solution. It is beyond the scope of this study to address the myriad combinations and permutations of all of the available options and the trade-offs associated with them. The purpose of this phase of the study is to identify that scheme which can be implemented quickly and still meet the system requirements.

Table 3 shows the relative merits of the various options, rated on an arbitary scale of 1 to 10. A rating of 10 indicates the most acceptable, and 1 represents the least acceptable. Options with equal merit in a given area are given equal scores.

These scores are essentially subjective engineering judgments based on collected data and conversations with specialists in the various fields.

The scores for initial and recurring costs are based mostly on quantitative assessment; the rest are mostly qualitative. Implementation time is based on the estimated number and complexity of the installations, as well as the time required to obtain the equipment from the supplier. Maintainability is considered a function of the amount and complexity of the equipment, the requirement for regular maintenance, and the ease of access. The reliability score considers both the link reliability and the likelihood that the facility will be in place and in service at any given moment. Quality takes into account the relative levels of distortion expected from each of the various modes. Required platform space was estimated on the basis of the amount of equipment expected to be located there. Several options do not use platform-mounted equipment and are marked NA. In the totaling of scores, these are counted as 10 since they represent the advantage of not requiring platform resources. Power requirements were judged by the estimated power required versus power available. Aircraft-mounted VHF terminals and repeaters were not scored in this area, since they would be powered by the aircraft's own power systems. Operator requirements reflect the need for manual operation of the equipment. Most

Table 3. OPTION RATINGS

Helicopter Communications Options	Rating									
	Initial Cost	Time to Implement	Recurring Costs	Maintainability	Reliability	Communication Quality	Platform Space Requirements	Power Requirements	Operator Requirements	Total
Microwave with VHF Remotes	10	9	9	9	10	10	10	10	10	87
HF with VHF Remotes	8	8	8	8	3	5	9	7	10	66
Satellite with VHF Remotes	4	7	7	8	9	10	8	9	10	72
Buoy Relay with VHF Remotes	2	1	2	1	6	5	NA	1	10	38
VHF/UHF Repeaters with VHF Remotes	3	5	8	8	9	8	6	7	10	64
Troposcatter with VHF Remotes	6	7	8	8	8	7	8	5	10	67
Meteor-Scatter with VHF Remotes	9	8	8	8	1	1	8	8	10	61
Tall Tower - VHF Direct	7	7	10	10	6	6	NA	8	10	74
Balloons - VHF Direct	1	3	5	2	6	9	NA	6	2	44
Relay Aircraft - VHF Direct	1	3	1	4	7	9	NA	NA	1	46

options are exclusively automatic or remote-controlled by the communications user (ATC) in the course of normal operation and are thus all highly acceptable in this area. The two exceptions are aircraft and balloons, both relatively manpower-intensive.

The "Total" column is a simple sum of the various factors. This might be considered an overall "figure of merit" for each option. As mentioned above, these are not quantitative results but are judgments as to the suitability of the various options for the immediate application.

Most of the scores in Table 3 fall in the middle ranges, indicating a mixture of advantages and disadvantages. Some of the high (and low) points are discussed below.

The microwave option scores highly in a number of areas. The options involving remote VHF outlets share the requirement that the outlet be acquired and installed on the platform. Except for the microwave option, all relay options require some additional equipment. For this reason, the microwave option is the least expensive of the remote options to install, operate, and maintain. The key to this is, of course, the fact that the microwave system already exists and is available to the FAA by dint of the cooperation and participation of the petroleum industry. Similarly, implementation time is the lowest of the rig-mounted relay options since every other such option requires installation of some equipment in addition to the VHF equipment. Also, the VHF equipment is readily available to the FAA through normal supply channels. The maintainability of this option is the best of all the remote VHF options, again because of the lack of additional equipment (the microwave system being maintained by its owners). In terms of reliability and quality, the microwave option provides service on a par with telephone line service. Space and power requirements are low, once again because no additional equipment is required. No operator is needed for this or most of the other options.

HF scores quite low in the area of reliability because of the inherent instability of HF propagation and its susceptibility to man-made and environmental noise. It scores somewhat higher in the area of maintainability and space requirements because of the small size and relative simplicity of the equipment.

Satellite links would provide superior quality and reliability, but at considerable expense and with a somewhat protracted acquisition and installation period.

Buoy-mounted outlets and repeaters score very poorly in the area of maintainability, because of the difficulties involved in reaching and working on the buoys; implementation time, because of the need to custom-equip and position a large number of the buoys; and in power requirements, which would be a major recurring problem.

The reliability and quality of such a system are somewhat questionable in several aspects related chiefly to antenna motion, shielding in high seas, and the possibility of buoy loss in heavy weather. No platform space is needed in this option, which could be considered an advantage.

The use of VHF/UHF repeaters is similar to the microwave option, except that all the relay equipment would have to be acquired and installed on the rigs by the FAA. This amounts to duplicating an existing capability. Such repeater service would also offer somewhat lower quality and reliability than microwave because of the greater susceptibility of the lower frequencies to fading and propagation anomalies.

Tropscatter links with VHF remotes involve equipment similar to that needed for satellite links, e.g., large dish antennas. This option scores somewhat lower in the area of reliability because of the variable nature of the scatter propagation medium.

The meteor-scatter option scores very low in reliability and quality. The highly intermittent nature of this type of communication makes it ill-suited to a real-time voice application.

The use of tall towers on shore to extend VHF coverage permits very easy maintenance and ease of access, but the number and complexity of the stations needed to provide coverage over the required off-shore areas give this option a fairly high initial cost. In addition, the quality and reliability of the communications provided would at best be marginal. The system would be operating at the limit of its capabilities and would be susceptible to fading and anomalous propagation effects.

Tethered balloons offer a means of placing antennas at very high altitude, allowing good-quality communication over long ranges. However, the initial cost of such a system is very high, and the operation and maintenance of the balloon and associated system are manpower-intensive. In addition, these balloons are susceptible to damage from wind and turbulence and must be reeled in during severe weather such as thunderstorms, removing them from service when they are needed most.

The use of relay aircraft would provide high-quality communication that would be quite reliable as long as the aircraft could remain on station. However, severe weather could ground the aircraft, removing them from service. The use of aircraft in this application is extremely manpower-intensive: multiple flight crews, maintenance crews, support personnel, etc. Acquisition and recurring costs are therefore very high.

CHAPTER FOUR

RECOMMENDED SYSTEM CONFIGURATION

A review of the options that would permit implementation in the Gulf in the specified period and examination of the trade-offs between cost and performance associated with each lead to the recommendation that the FAA employ remote VHF outlets located on off-shore oil platforms, with audio and control linked back to shore via the petroleum microwave service links already in place, supplemented by a VHF repeater and shore-based installations. This would be, in large part, a cooperative effort between the FAA and industry, which has generally indicated a willingness and desire to aid in establishing an ATC communication system in the Gulf.

The system would be configured as shown in Figure 12.

Minimum difficulty in interfacing between the outlet equipment and the microwave system is anticipated. Both the remote VHF equipment (similar to that used in RCAG facilities) and the microwave links terminate in telephone-type interfaces. The control signals used in RCAGs are audio tones that require no separate channels. The on-shore terminals of the microwave links would be connected to Houston center by conventional leased lines.

The coverage provided by these off-shore facilities would be supplemented by on-shore facilities, either existing or added, to provide coverage close to shore.

Figure 13 shows the recommended locations for the various installations.

4.1 OFF-SHORE INSTALLATIONS

The off-shore installations should be located on platforms in or near the following off-shore areas:

- High Island 582
- East High Island 323
- West Cameron 585
- West Cameron 509
- Vermilion 245

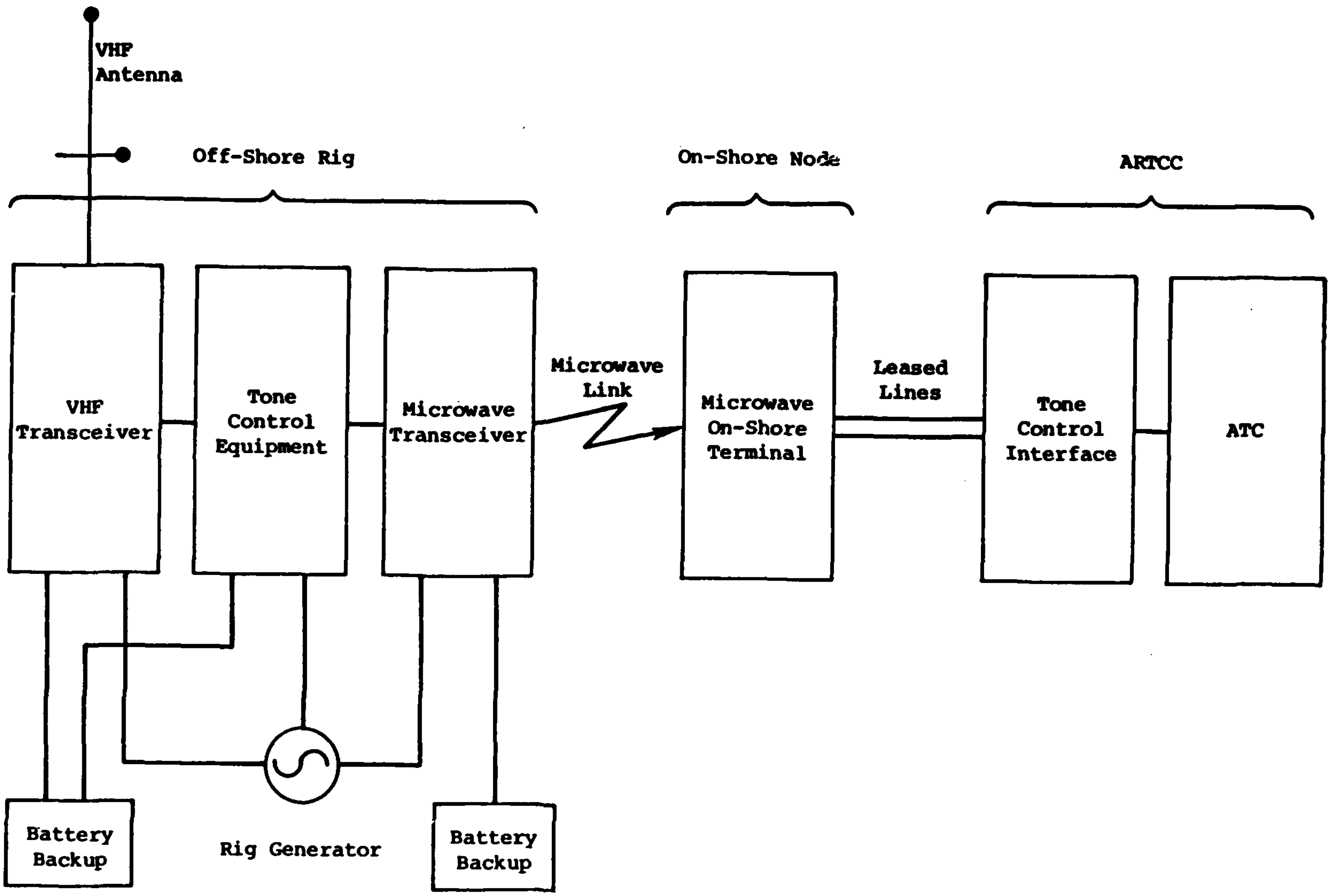


Figure 12. SYSTEM CONFIGURATION

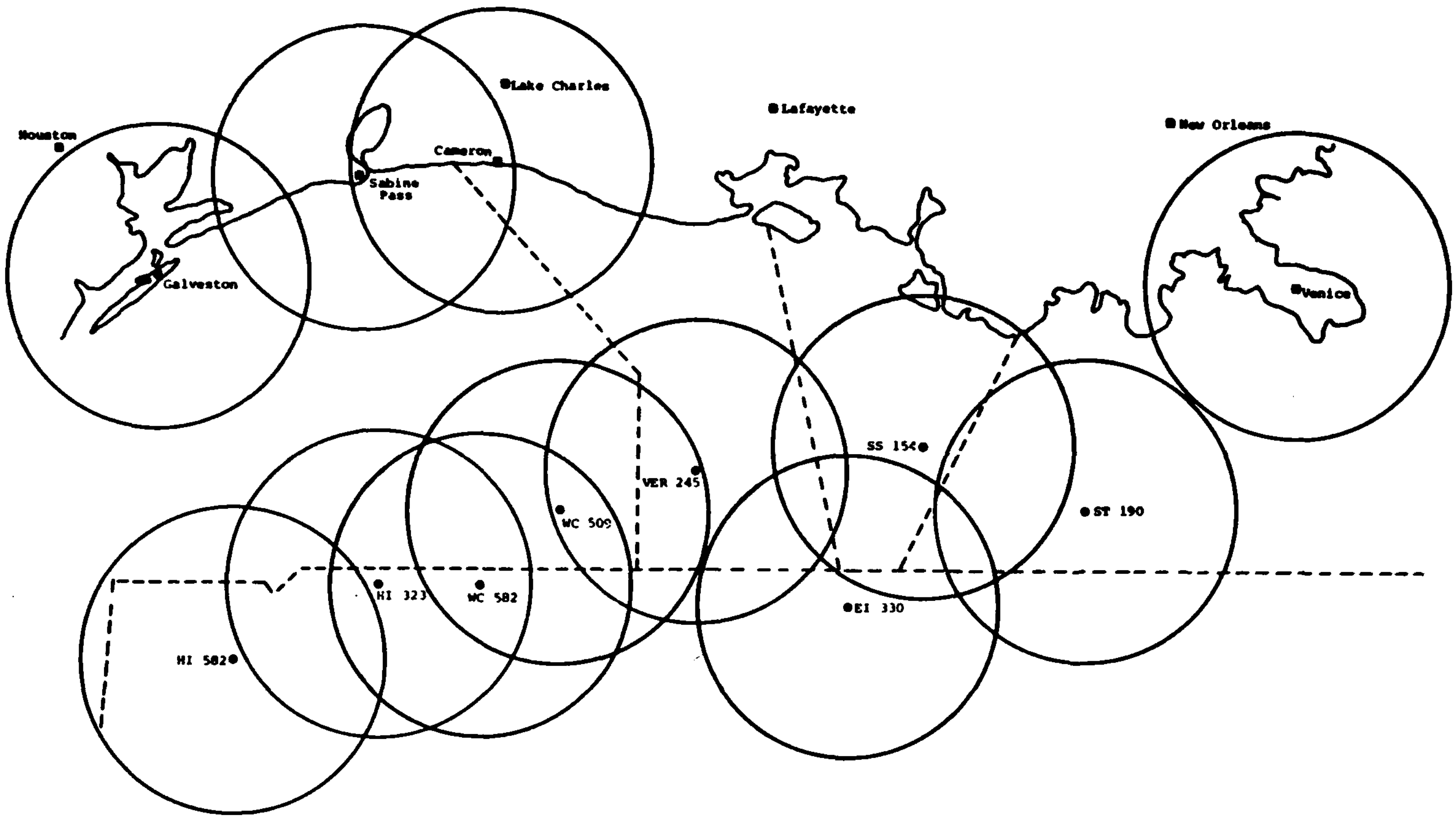


Figure 13. SYSTEM LAYOUT

- Eugene Island 330
- Ship Shoal 154
- South Timbalier 190

There are numerous platforms near each of these areas served by microwave links, with the exception of High Island 582. The requirement to cover this area could be met by using a VHF or UHF repeater to link a platform in this area to the Mobil microwave-supported platform some 20 miles east.

The circles around each installation on Figure 13 indicate the expected coverage for aircraft at an altitude of 100 feet.

Coverage to aircraft at en route altitudes of at least 700 feet extends over all sectors. These coverages assume the following VHF configuration:

- Transmitter - 10 watts to antenna
- Antenna - 3 dBi
- Antenna Height - 250 feet above water
- Receiver - Standard RCAG type

The coverage also assumes a 10 dB fade margin, providing 90 percent reliability.

As the FAA negotiates with the petroleum industry for use of off-shore facilities, a primary consideration will be microwave service. The following companies provide service in the indicated areas:

- High Island 582 -- FAA-installed link to Mobil facilities 20 miles to the east
- East High Island 323
  - Mobil Oil Telecommunications
  - Sun Oil
- West Cameron 585
  - Mobil Oil Telecommunications
  - Sun Oil
  - Chevron Oil Company
- West Cameron 509
  - Mobil Oil Telecommunications
  - Sun Oil
  - Chevron
  - Trunkline Gas Co.
  - Tenneco

- Vermilion 245
  - Mobil Oil Telecommunications
  - Sun Oil
  - Chevron Oil
  - Trunkline Gas Co.
  - Tenneco
- Engine Island 330
  - Exxon Communications
  - Penzoil Off-Shore Gas Operations
  - Shell Communications
  - Tenneco
- Ship Shoal 154
  - Chevron Oil
  - Gulf Oil Communications
  - Tenneco
  - Shell Communications
- South Timbalier 190
  - Chevron Oil
  - Gulf Oil Communications
  - Mobil Oil Telecommunications

Although this is not an exhaustive list (complete microwave facilities are shown in Figure 9), the companies listed are those with microwave facilities nearest the desired areas of coverage, and they should give the FAA sufficient latitude and flexibility in negotiations and siting.

Other factors that must be considered by the FAA in siting these stations are power, floor space and housing, and tower resources.

Power is normally supplied on the rigs by on-board generators. These are sometimes, but not always, backed up. The output of these generators is generally 110 Vac, 60 Hz, and is of more than sufficient capacity to power the remote outlet equipment and charge the battery back-up.

The amount of floor space available for FAA equipment will vary widely from rig to rig, which emphasizes the need for flexibility in FAA planning. The presence of air conditioning is another factor if this is considered necessary to protect the equipment.

The antenna should be located 250 feet or more above the water. Most platforms have superstructures extending this far, but care should be taken in locating the antenna so that is as clear of nearby metal structures as possible.

In the attempt to determine the extent to which these requirements can be met on platforms near the desired location, it became evident that this was a highly variable factor. Most operators indicated a willingness to provide some limited space and facilities at little or no charge, but beyond that it was largely a function of financial compensation. One oil company official summed up the situation by saying, "For the right price you have the whole platform."

The foregoing factors are the "bargaining chips" that the FAA will use in negotiating with the various platform and microwave operators. It is beyond the scope of the present effort for ARINC Research to make these arrangements on behalf of the FAA. Budget, regulatory waiver, and other such considerations are properly the function of the FAA.

4.2 SYSTEM EXAMPLE

It is instructive, however, to consider how the system might be implemented. Mobil Oil Telecommunications operates one of the most extensive microwave networks in the Gulf and has indicated a willingness to cooperate with the FAA in establishing a system. As an example of how the resources of this company might be incorporated into the required system, consider the following system layout: A total of 4 VHF channels would be available, one for each sector. These are denoted herein as channel A for the off-shore portions of Beaumont sector, channel B for the Lafayette sector, channel C for the Baton Rouge sector, and channel D for the Harvey sector.

4.2.1 Off-Shore Facilities

Off shore facilities would consist of VHF outlets located on the following platforms:

Platform	Channel
High Island 536 (see text)	A
East High Island 343	A
West Cameron 609	A
West Cameron 533	A
Vermilion 215	B
Eugene Island 333A	C
Ship Shoal 108B	C
Grand Isle 95A	D

Each of these platforms, with the exception of High Island 536, is supported by Mobil microwave service and is within 10 nautical miles of the centers of the designated coverage areas (exception: the Grand Isle site is 17 nm from the designated South Timbalier area center). The coverage area centered on High Island 582 could be covered by an outlet located on one of the platforms in High Island 536 or 537 and linked via microwave or VHF repeater to the Mobil supported platforms at High Island 572.

These Mobil microwave circuits come ashore at Morgan City and Cameron, and links extend into Houston. The FAA circuits could terminate at Morgan City or Cameron and be linked to Houston by conventional leased lines or, if it could be arranged with Mobil, could extend into Houston on the Mobil system. It is again largely a question of compensation and what share of the expense the company would be willing to bear as the result of negotiations with the FAA.

4.2.2 On-Shore Facilities

On-shore facilities would be required to supplement en route coverage over the off-shore portions of the routes.

One such area is the north-west quadrant of the off-shore part of the Beaumont sector. The existing facility at Galveston could be incorporated into the system or a new facility added there. An additional facility could be added at Sabine Pass, especially since the Southwest Region expressed a requirement for on-the-ground coverage there. These two on-shore stations would be on channel A and would serve to fill in the near-shore coverage area in this sector.

A facility on channel B could be positioned at Cameron, especially since the Southwest Region expressed a requirement for on-the-ground coverage there. This facility would provide coverage in the northwest leg of the off-shore segment of the Lafayette sector.

Finally, an on-shore facility on channel D would be required in or near Pilotown, Louisiana, southeast of Venice, to provide en route coverage of the southeastern segment of the Harvey sector.

Each of these on-shore facilities would consist of a remote transceiver and an antenna at the 250-foot level (above sea level). They would be linked back to Houston ARTCC via conventional leased lines.

4.3 COSTS

4.3.1 Off-Shore Equipment

The cost of acquiring and installing the off-shore equipment for the example system is estimated as follows:

- Acquisition
  - Transmitters — 16 @ $1,991 = $30,576 (8 primary + 8 backup)
  - Receivers — 16 @ $1,340 = $21,440

- •• Antennas 8 @ \$ 300 = \$ 2,400
- •• Audio/Control 8 @ \$6,000 = \$ 48,000

Total = \$102,416

- Installation
  - •• 1 four-hour round trip for cargo helicopter at \$250 per hour + \$850/day = \$1,850 per site

    8 sites = \$14,800
  - •• 40 man-hours per site installation at \$20 per hour = \$800 per site

    8 sites = \$ 6,400

    Total = \$21,200

4.3.2 On-Shore Facilities

The cost of on-shore facilities depends largely on whether existing towers and equipment shelters are available. If they are available, equipment costs are estimated as follows:

- Transmitters (2 each at 4 locations) 8 @ \$1,911 = \$15,288
- Receivers (2 each at 4 locations) 8 @ \$1,340 = 10,720
- Control Circuit (4 at site, 12 at ARTTC) 16 @ \$6,000 = 96,000
- Battery Back-Up 4 @ \$1,000 = 4,000

If towers are not available, an additional \$5,000 per site will be required for tower construction. If shelter for the equipment is not available, an additional \$5,000 will be required for a portable shelter.

Installation costs for the on-shore sites will be minimal in cases where the tower and shelters are available for lease. About 40 man-hours is estimated per site: 40 hours @ \$20 per hour × 4 sites = \$3,200. If tower and shelter must be erected, about one man-month is estimated to be required, exclusive of tower construction (the cost of the tower includes installation). Installation costs are estimated as follows:

- One man-month @ \$20 per hour = \$3,360 × 4 sites = \$13,440
- Leased lines: 12 lines at \$50 per line = \$600

4.3.3 Recurring Costs

Off-shore recurring costs include channel leasing and space and power:

- Channel Lease - 1350 circuit miles @ \$4.01 = \$5,413.50

- Space and Power - most operators indicated that enough space and power for the equipment envisioned could be made available to the FAA at no charge.

On-shore recurring costs include:

- Tower rental (for existing towers): 250 feet @ 50¢ = $125 per month

  Equipment space: 2 spaces @ $45 = $90 per month

- Real Estate lease for FAA-constructed facilities:

  Estimated @ $40 per month for each 1 acre site
  4 sites = $160 per month

- Leased Lines: 1600 miles @ 60¢ = $960

  24 circuit end-points (8 off-shore, 4 on-shore circuits, 2 end-points each) @ $86.60 = $2,078.40

Maintenance of off-shore equipment is estimated at one two-hour visit every two months per site. It is expected that half of the off-shore sites could be visited in one day. The cost of such maintenance will be mostly transportation; a small helicopter could be used since no heavy equipment would normally be required. Such helicopters rent for $600 per day + $100 per hour. A total of about five flight hours would be needed on each trip covering four off-shore platforms, or $1,100 for each day. Two such trips to cover all installations brings the total to $2,200 every two months, or $1,100 per month. These two trips would use about 20 man-hours @ $20, or $400 for technician time.

Maintenance of the on-shore equipment is expected to occupy no more than about one man-hour per site per month, or 4 man-hours per month @ $20, or $80 per month plus an allowance for ground transportation, for a total of $150 per month.

Total acquisition and installation costs are $262,224 with existing on-shore facilities or $295,664 if towers and shelters are constructed. Recurring costs for operation and maintenance are estimated to total $10,500 per month.

4.3.4 Discussion

The system layout and costs discussed in the preceding sections are given as an example of how a system might be configured by using resources available from Mobil Oil. Numerous other platform and microwave operators have facilities that could serve just as well, although costs and service vary from company to company and rig to rig. In each of the lists of operators of facilities near the desired locations, at least one operator has already indicated a willingness to work with the FAA in establishing a system. Thus it is possible that the costs of such elements as transportation related to installation and maintenance of off-shore equipment might be shared or borne entirely by the industry or individual companies as their part in a cooperative effort. The costs discussed above are therefore subject to alterations as the result of negotiations between the oil companies and the FAA.

4.4 IMPLEMENTATION

The system described responds to the entire Southwest Region requirement for coverage. It is unlikely that the whole system could or should be implemented at a single stroke. A more likely approach would be to establish one or a few off-shore facilities and use them operationally to test pilot and controller reaction and to determine operational reliability figures.

It is recommended that the first such facility be located on or near Vermilion 245. This area, central to the IFR operational area, would provide coverage over a large number of routes. It is served by a number of microwave services, and the operators of several of these services have indicated that channels and platform facilities would be available for FAA use.

It is recommended that the second facility be located in or near the East High Island 333 area and the third in or near the Ship Shoal 154 area; both of these areas are also well serviced by microwave facilities operated by companies that have indicated the availability of services to the FAA.

Providing coverage at these three areas will provide communications over most of the IFR operational area at en route altitudes. Helicopter operators interviewed agreed that these areas were the most advantageous, and they believed that such coverage would fill a large part of the need for communications in the Gulf. Then, as time and resources permit, the FAA could install additional facilities, extending coverage to the other designated areas in the Gulf.

CHAPTER FIVE

SURVEILLANCE

The two cornerstones of ATC are communications and surveillance. This chapter addresses the latter as it applies to the situation in the Gulf.

Historically, ATC surveillance has been performed by three means: primary radar, secondary radar, and position reporting. The frequencies involved in both primary radar and secondary radar are such that the LOS limitation discussed in relation to VHF applies even more strongly to them: propagation at radar frequencies is almost entirely optical. This limitation makes providing low-level radar coverage of the Gulf a difficult goal for shore-based radars. Of course, it is technically feasible to place a radar off-shore and remote the video and control circuits back to shore. However, this is itself an ambitious goal and not within the scope of the near-term effort.

In the early days of pre-war ATC, position reporting by voice radio was the only means of surveillance available. This is, of course, a crude means, leading to large aircraft spacings along routes because of the uncertainties involved in the reporting process. It could be used in the Gulf, however, with far more precision because of the modern navigational equipment carried aboard IFR helicopters. All IFR helicopters engaged in Gulf IFR operations are equipped with Omega, LORAN-C, or both. These provide very accurate location information that could be used as the basis of a position reporting system.

Such a system is currently used with success in the Atlantic area. Three routes based on the Atlantic City VORTAC are available there. They are named, for convenience, "GAS", "OIL", and "TAR". In making a position report, a pilot simply reports that he is, for example, at "GAS 50", meaning he is at the 50 nm DME point on the GAS route (LORAN-C and Omega can provide VOR-DME type data). Since the route structure in the Gulf is laid out in a similar fashion, this approach is appropriate for use there.

A refinement of this technique would be to automate the process. The LORAN and Omega sets in use have facilities for outputting position data (or sometimes unprocessed LORAN time differences) via data ports. These data could be transmitted every few seconds via the voice circuit to the ARTCC, where, with appropriate processing, they could be displayed on the controller's screen exactly as if the aircraft were under direct surveillance.

This automation technique is the more elegant scheme, but there are several obstacles to incorporating it in the near term. First, it is not responsive to the industry requirement that no additional equipment be carried aboard the aircraft. Second, it would have to be certified by the FAA, which might be a lengthy process involving engineering and flight testing. Another factor is cost: the price to a helicopter operator of adding this automated position reporting capability to his LORAN or Omega receiver is estimated at $2,500. Over the 50-plus IFR aircraft fleet, this represents a $125,000 investment -- in addition to the estimated $100,000 for installation of equipment at each ARTCC.

For the near term, then, it is recommended that surveillance be performed by means of voice position reports based on route DME fixes, as in the Atlantic area.

CHAPTER SIX

CONCLUSIONS

This report has examined the requirement for IFR communications in the Gulf, the various technical means of meeting the requirement, and the performance trade-offs involved. It has presented a system plan based on the Mobil microwave network as an example of how such resources could be organized into a system that would meet near-term requirements.

The establishment of a helicopter IFR communication system is expected to be a cooperative effort between the FAA and industry. The degree of industry participation in the program is not specifically known, since this will depend on what arrangements can be negotiated between industry and the FAA. ARINC Research is not empowered to perform such negotiations committing the FAA to financial obligations. Therefore, rather than specifying a particular platform and microwave linking scheme, the report identifies several alternatives in each area, allowing the FAA maximum flexibility in negotiations; if satisfactory arrangements cannot be made with a particular operator, an alternative is available.

The microwave link option was selected because of the small capital investment involved and the short lead time required for system establishment, as well as the high quality and reliability of the circuits it provides. Other means that provide the same level of performance require extensive equipment installations in addition to the remote VHF outlet required by the microwave-link scheme.

Options such as satellite and troposcatter would be more suitable for use in areas where microwave service was not practical, as in remote drilling areas far off-shore. In such areas, these options would become viable.

END
8-87
DTIC