

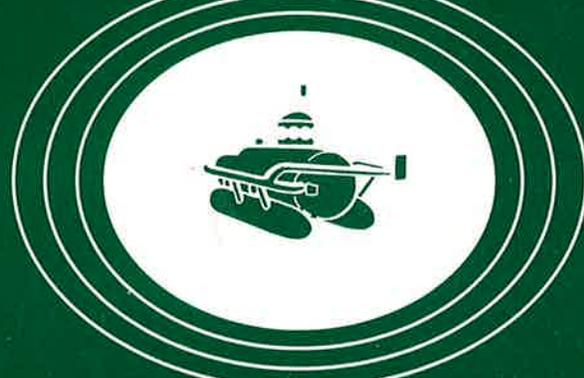
Ref

# 1988 FEDERAL RADIONAVIGATION

Published by  
DEPARTMENT OF DEFENSE  
and  
DEPARTMENT OF TRANSPORTATION



# PLAN



This document is available to the public through the  
National Technical Information Service, Springfield, Virginia 22161

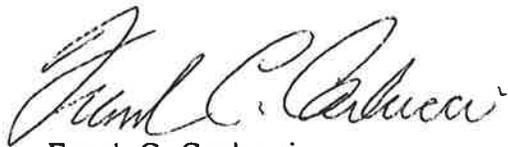
DOD-4650.4  
DOT-TSC-RSPA-88-4

## LETTER OF PROMULGATION

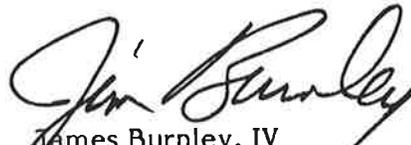
This letter promulgates the fifth edition of the Federal Radionavigation Plan, which was prepared jointly by the Departments of Defense and Transportation. It supersedes the 1986 Federal Radionavigation Plan.

The Federal Radionavigation Plan is published to provide information on the management of those Federally-provided radionavigation systems used by both the military and civil sectors. It supports the planning, programming and implementing of air, marine, land and space navigation systems to meet the requirements shown in the President's budget submission to Congress. This plan is the official source of radionavigation policy and planning for the Federal Government, and has been prepared with the assistance of other Government agencies.

The Federal Radionavigation Plan is revised biennially. Your suggestions for the improvement of future editions are welcomed.



Frank C. Carlucci  
Secretary of Defense



James Burnley, IV  
Secretary of Transportation



1. Report No. DOD-4650 DOT-TSC-RSPA-88-4		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle  FEDERAL RADIONAVIGATION PLAN				5. Report Date 1988	
				6. Performing Organization Code DTS-52	
7. Author(s)				8. Performing Organization Report No.  DOD-4650.4 DOT-TSC-RSPA-88	
				10. Work Unit No. (TRAIS) RS817/P8002	
9. Performing Organization Name and Address U.S. Department of Transportation DRT-1 Washington, D.C. 20590  U.S. Department of Defense (ASD/C <sup>3</sup> I) Washington, D.C. 20301				11. Contract or Grant No.	
12. Sponsoring Agency Name and Address U.S. Department of Transportation DRT-1 Washington, D.C. 20590  U.S. Department of Defense (ASD/C <sup>3</sup> I) Washington, D.C. 20301				13. Type of Report and Period Covered FINAL REPORT January 1987-December 1988	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract  The Federal Radionavigation Plan (FRP) delineates policies and plans for radio-navigation services provided by the U.S. Government to ensure efficient use of resources and full protection of national interests. Developed jointly by the U.S. Departments of Defense and Transportation, the FRP sets forth the Federal interagency approach to the implementation and operation of radionavigation systems.  The FRP is updated biennially. This fifth edition describes respective areas of authority and responsibility, and provides a management structure by which the individual operating agencies will define and meet requirements in a cost-effective manner. Moreover, this edition contains the current policy on the radionavigation systems mix. The constantly changing radionavigation user profile and rapid advancements in systems technology, combined with delays in the U.S. space program, require that the FRP remain as dynamic as the issues it addresses. This edition of the FRP builds on the foundation laid by previous editions and further develops national plans towards providing an optimum mix of radionavigation systems for the foreseeable future.					
17. Key Words Navigation Planning, Radionavigation System, Radio Determination System, Navigation Requirements, Position Location, Global Positioning System			18. Distribution Statement DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE SPRINGFIELD, VIRGINIA 22161		
19. Security Classif. (of this report)  UNCLASSIFIED		20. Security Classif. (of this page)  UNCLASSIFIED		21. No. of Pages	22. Price



## PREFACE

The Department of Defense (DOD) and the Department of Transportation (DOT) have developed the fifth edition of the Federal Radionavigation Plan (FRP) to ensure efficient use of resources and full protection of national interests. The plan sets forth the Federal interagency approach to the implementation and operation of Federally provided, common-use radionavigation systems.

The FRP is a review of existing and planned radionavigation systems used in air, land, and marine navigation and for purposes other than navigation in terms of user requirements and current status. The FRP contents reflect DOT responsibilities for public safety and transportation economy, as well as DOD responsibility for national security.

The plan is updated biennially. The established DOD/DOT interagency management approach allows continuing control and review of U.S. radionavigation systems. Your inputs on this plan are welcome. Interested parties and advisory groups from the private sector are invited to submit their inputs to the Chairman of the DOT Navigation Working Group (Attn: DRT-20), Department of Transportation, Research and Special Programs Administration, Washington, DC 20590.

## METRIC CONVERSION AND OTHER MEASURES

### Length

1 centimeter	= 0.3937 inch	
1 inch	= 2.54 centimeters exactly	
1 foot	= 0.3048 meter	
1 meter	= 3.280 feet	
1 yard	= 0.9144 meter	
1 kilometer	= 1,000 meters	
1 fathom	= 6 feet	= 1.828 meters
1 statute mile	= 1,609.3 meters	= 5,280 feet
1 nautical mile	= 1.852 kilometers	= 1.151 statute miles
1 degree of latitude	= 60 nautical miles	

### Speed

1 knot	= 1 nautical mile per hour	
Mach 1	= 661.5 knots at standard sea level	= 1116.5 ft/sec
1 kilometer per hour	= 0.5399 knot	
1 mile per hour	= 1.47 feet per second	

### Area

1 square inch	= 6.5 square centimeters	
1 acre	= 43,560 square feet	= 4,047 square meters
1 hectare	= 2.47 acres	= 10,000 square meters

### Standard Sea Level

Temperature	= 15° Celsius	= 59° Fahrenheit
Atmospheric Pressure	= 29.92 inches of mercury	(14.696 psi)

### Angular Measure

Degree	= 1/360th of a circle
Mil	= 1/6,400th of a circle

### Radio Frequency Bands

Very low	= (VLF)	Below 30 khz
Low	= (LF)	30 to 300 khz
Medium	= (MF)	300 to 3,000 khz
High	= (HF)	3,000 khz to 30 MHz
Very High	= (VHF)	30 MHz to 300 MHz
Ultra High	= (UHF)	300 MHz to 3 GHz
Super High	= (SHF)	3 to 30 GHz
Extremely High	= (EHF)	30 to 300 GHz
L Band	= L	390 to 1,550 MHz
S Band	= S	1,550 to 5,200 MHz
X Band	= X	5.2 to 10.9 GHz
K Band	= K	10.9 to 36 GHz

### Temperature

Fahrenheit	= 9/5 Celsius + 32
Celsius	= 5/9 (Fahrenheit - 32)

## TABLE OF CONTENTS

	<u>Page</u>
PREFACE	iii
TABLE OF CONTENTS	v
LIST OF FIGURES	x
LIST OF TABLES	xi
EXECUTIVE SUMMARY	xiii
<b>1. INTRODUCTION TO THE FEDERAL RADIONAVIGATION PLAN</b>	<b>1-1</b>
1.1 Background	1-1
1.2 Purpose	1-2
1.3 Scope	1-2
1.4 Objectives	1-3
1.5 Policies and Practices	1-3
1.6 DOD/DOT Current Policy on the Radionavigation System Mix	1-5
1.7 DOD Responsibilities	1-9
1.7.1 Operational Management	1-10
1.7.2 Administrative Management	1-10
1.8 DOT Responsibilities	1-12
1.9 DOD/DOT Interagency Agreement	1-16
1.10 Determination of Future Radionavigation Systems Mix	1-17
1.10.1 Approach to Selection	1-17
1.10.2 Operational Issues	1-18
1.10.3 Special Military Considerations	1-20
1.10.4 Technical Considerations	1-21
1.10.5 Economic Considerations	1-21
1.10.6 Institutional Considerations	1-22
1.10.7 Criteria for Selection	1-24
<b>2. RADIONAVIGATION USER REQUIREMENTS</b>	<b>2-1</b>
2.1 Civil Requirements	2-1
2.2 Requirements Determination	2-1
2.2.1 Process	2-2
2.2.2 User Factors	2-2
2.3 Phases of Navigation	2-3
2.3.1 Air	2-3
2.3.2 Marine	2-4
2.3.3 Land	2-5
2.3.4 Space	2-6
2.3.5 Applications Other than Navigation	2-6

## TABLE OF CONTENTS (CONTINUED)

	<u>Page</u>	
2.4	Civil Air Radionavigation Requirements	2-7
2.4.1	Aviation Requirements	2-7
2.4.2	Navigation Signal Error Characteristics	2-10
2.5	Current Aviation Navigation Requirements	2-10
2.5.1	En Route/Terminal Phase	2-10
2.5.2	Approach/Landing Phase	2-14
2.6	Future Aviation Radionavigation Requirements	2-17
2.6.1	En Route/Terminal Phase	2-17
2.6.2	Approach/Landing Phase	2-18
2.6.3	Future System Performance Requirements Summary	2-20
2.7	Civil Marine Radionavigation Requirements	2-20
2.8	Ocean Phase	2-22
2.8.1	Requirements	2-22
2.8.2	Minimum Performance Criteria	2-26
2.9	Coastal Phase	2-26
2.9.1	Requirements	2-26
2.9.2	Minimum Performance Criteria	2-27
2.10	Harbor and Harbor Approach Phases	2-27
2.10.1	Requirements	2-27
2.10.2	Minimum Performance Criteria	2-28
2.11	Inland Waterway Phase	2-28
2.11.1	Requirements	2-28
2.11.2	Minimum Performance Criteria	2-28
2.12	Future Marine Radionavigation Requirements	2-29
2.12.1	Safety	2-29
2.12.2	Economics	2-29
2.12.3	Environment	2-30
2.12.4	Energy Conservation	2-30

## TABLE OF CONTENTS (CONTINUED)

		<u>Page</u>
2.13	Civil Land Radionavigation Requirements	2-30
	2.13.1 Requirements	2-30
	2.13.2 Minimum Performance Criteria	2-30
2.14	Military Radionavigation Requirements	2-31
	2.14.1 General Requirements	2-31
	2.14.2 Service Requirments	2-32
2.15	Space Radionavigation Requirements	2-32
2.16	Requirements for Applications Other than Navigation	2-32
	2.16.1 Radiolocation (Site Registration and AVM/AVL)	2-33
	2.16.2 Timing/Frequency Offset Applications	2-33
<b>3.</b>	<b>RADIONAVIGATION SYSTEMS USED IN PHASES OF NAVIGATION</b>	<b>3-1</b>
3.1	Existing Systems Used in the Phases of Navigation	3-1
	3.1.1 Air Navigation	3-1
	3.1.2 Marine Navigation	3-6
	3.1.3 Land Navigation	3-8
	3.1.4 Uses Other Than Navigation	3-8
3.2	Existing Systems - Status and Plans	3-8
	3.2.1 LORAN-C	3-8
	3.2.2 OMEGA	3-12
	3.2.3 VOR, VOR/DME, VORTAC	3-16
	3.2.4 TACAN	3-19
	3.2.5 ILS	3-21
	3.2.6 TRANSIT	3-25
	3.2.7 Aeronautical and Maritime Radiobeacons	3-29
3.3	Developing Systems-Status and Plans	3-33
	3.3.1 MLS	3-33
	3.3.2 GPS	3-35
<b>4.</b>	<b>RADIONAVIGATION RESEARCH, ENGINEERING AND DEVELOPMENT SUMMARY</b>	<b>4-1</b>
4.1	Overview	4-1
4.2	DOT GPS R, E&D	4-3

## TABLE OF CONTENTS (CONTINUED)

	<u>Page</u>
4.2.1 Civil Aviation	4-4
4.2.2 Civil Marine	4-5
4.2.3 Civil Land	4-6
4.3 DOT R,E&D for Existing Civil Navigation Systems	4-7
4.3.1 General	4-7
4.3.2 Specific Civil R,E&D Activities	4-8
4.4 GPS R,E&D Planned by NASA	4-11
4.5 DOD MLS R&D	4-12
4.6 DOD Differential GPS R&D	4-12
<b>APPENDIX A. RADIONAVIGATION SYSTEM DESCRIPTIONS</b>	<b>A-1</b>
A.1. Hybrid Systems	A-1
A.2. Differential Applications	A-1
A.3. Radionavigation System Parameters	A-2
A.3.1 Accuracy	A-2
A.3.2 Availability	A-3
A.3.3 Coverage	A-3
A.3.4 Reliability	A-4
A.3.5 Fix Rate	A-4
A.3.6 Fix Dimensions	A-4
A.3.7 System Capacity	A-4
A.3.8 Ambiguity	A-4
A.3.9 Integrity	A-4
A.4 Radionavigation System Descriptions	A-4
A.4.1 LORAN-C	A-5
A.4.2 VOR, VOR/DME, TACAN	A-9
A.4.3 OMEGA -	A-16
A.4.4 Radiobeacons	A-19
A.4.5 ILS	A-22
A.4.6 MLS	A-28
A.4.7 GPS	A-30
A.4.8 TRANSIT	A-34

**TABLE OF CONTENTS (CONTINUED)**

	<u>Page</u>
<b>APPENDIX B. CHART REFERENCE SYSTEMS</b>	B-1
<b>APPENDIX C. DEFINITIONS</b>	C-1
<b>GLOSSARY</b>	G-1

## LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1-1. DOD NAVIGATION MANAGEMENT STRUCTURE	1-11
1-2. DOT NAVIGATION MANAGEMENT STRUCTURE	1-15
1-3. DOD/DOT RADIONAVIGATION SYSTEMS PLANNING PROCESS	1-19
2-1. NON-PRECISION APPROACH OBSTACLE CLEARANCE AREA FOR CURRENT VOR WITH MAP AT VOR FACILITY	2-19
3-1. OPERATING PLAN FOR LORAN-C	3-9
3-2. OPERATING PLAN FOR OMEGA	3-14
3-3. OPERATING PLAN FOR VOR, VOR/DME	3-17
3-4. OPERATING PLAN FOR TACAN	3-20
3-5. OPERATING PLAN FOR MLS/ILS	3-23
3-6. OPERATING PLAN FOR TRANSIT	3-27
3-7. OPERATING PLAN FOR RADIOBEACONS (AERONAUTICAL AND MARITIME)	3-30
3-8. DOD OPERATING PLAN FOR GPS	3-36
A-1. LORAN-C COVERAGE	A-8
A-2. CONTERMINOUS U.S. MARINE RADIOBEACON COVERAGE	A-23
A-3. ALASKAN MARINE RADIOBEACON COVERAGE	A-24

## LIST OF TABLES

<u>Table</u>		<u>Page</u>
2-1.	CONTROLLED AIRSPACE AVIATION NAVIGATION ACCURACY TO MEET CURRENT REQUIREMENTS	2-15
2-2.	CONTROLLED AIRSPACE AVIATION NAVIGATION ACCURACY TO MEET PROJECTED FUTURE REQUIREMENTS	2-21
2-3.	CURRENT MARITIME USER REQUIREMENTS/BENEFITS FOR PURPOSES OF SYSTEM PLANNING AND DEVELOPMENT - OCEAN PHASE	2-23
2-4.	CURRENT MARITIME USER REQUIREMENTS/BENEFITS FOR PURPOSES OF SYSTEM PLANNING AND DEVELOPMENT - COASTAL PHASE	2-24
2-5.	CURRENT MARITIME USER REQUIREMENTS/BENEFITS FOR PURPOSES OF SYSTEM PLANNING AND DEVELOPMENT - HARBOR AND HARBOR APPROACH PHASES	2-25
2-6.	REQUIREMENTS FOR APPLICATIONS OTHER THAN NAVIGATION	2-34
3-1.	RADIONAVIGATION SYSTEM CIVIL APPLICATIONS	3-2
3-2.	DOD RADIONAVIGATION SYSTEM APPLICATIONS - AVIATION, LAND	3-3
3-2.	DOD RADIONAVIGATION SYSTEM APPLICATIONS - NAVAL	3-4
3-3.	DEFENSE MAPPING AGENCY RADIONAVIGATION SYSTEM APPLICATIONS	3-5
3-4.	LORAN-C PROJECTIONS	3-11
3-5.	OMEGA PROJECTIONS	3-15
3-6.	VOR, VOR/DME, VORTAC PROJECTIONS	3-18
3-7.	TACAN PROJECTIONS	3-22
3-8.	ILS PROJECTIONS	3-24
3-9.	TRANSIT PROJECTIONS	3-28
3-10.	RADIOBEACON PROJECTIONS	3-32
3-11.	MLS PROJECTIONS	3-34
3-12.	GPS PROJECTIONS	3-38

## LIST OF TABLES (CONTINUED)

<u>Table</u>	<u>Page</u>
A-1. LORAN-C SYSTEM CHARACTERISTICS (SIGNAL-IN-SPACE)	A-6
A-2. VOR, VOR/DME SYSTEM CHARACTERISTICS (SIGNAL-IN-SPACE)	A-11
A-3. TACAN SYSTEM CHARACTERISTICS (SIGNAL-IN-SPACE)	A-15
A-4. OMEGA SYSTEM CHARACTERISTICS (SIGNAL-IN-SPACE)	A-17
A-5. RADIOBEACON SYSTEM CHARACTERISTICS (SIGNAL-IN-SPACE)	A-21
A-6. ILS CHARACTERISTICS (SIGNAL-IN-SPACE)	A-26
A-7. AIRCRAFT MARKER BEACONS (SIGNAL-IN-SPACE)	A-27
A-8. MLS CHARACTERISTICS (SIGNAL-IN-SPACE)	A-29
A-9. GPS CHARACTERISTICS (SIGNAL-IN-SPACE)	A-32
A-10. TRANSIT CHARACTERISTICS (SIGNAL-IN-SPACE)	A-35

## EXECUTIVE SUMMARY

The Federal Radionavigation Plan (FRP) delineates policies and plans for Federally-provided radionavigation services. It also discusses privately operated radiodetermination systems recognizing that these systems may impact Government radionavigation planning in the future. This plan describes areas of authority and responsibility and provides a management structure by which the individual operating agencies can define and meet radionavigation requirements in a cost effective manner. It is the official source of radionavigation policy and planning for the Federal Government. This edition of the FRP updates and replaces the 1986 FRP and incorporates common-use radionavigation systems (i.e., systems used by both civil and military sectors) covered in the DOD Joint Chiefs of Staff's (JCS) Master Navigation Plan (MNP). The MNP covers many radionavigation systems used exclusively by the military, and has not been replaced by the FRP.

This document describes the various phases of navigation and other applications of the radionavigation services, and provides current and anticipated requirements for each. As requirements change, radionavigation systems may be added or deleted in subsequent revisions to this plan.

The FRP covers common-use, Federally-operated systems. These systems are sometimes used in combination or with other systems. Privately-operated systems are recognized in the interest of providing a complete picture of U.S. radionavigation.

The systems covered in this plan are:

- Radiobeacons
- LORAN-C
- OMEGA
- VOR, VOR/DME, VORTAC
- TACAN
- ILS
- MLS
- TRANSIT
- GPS

A major goal of DOD and DOT is to select a mix of these common-use civil/military systems which meets diverse user requirements for accuracy, reliability, availability, integrity, coverage, operational utility, and cost; provides adequate capability for future growth; and minimizes unnecessary duplication of services. A significant portion of this plan is devoted to the Global Positioning System (GPS) since it has the potential to replace many existing radionavigation systems.

Selecting a radionavigation systems mix is a complex task, since user requirements vary widely and change with time. While all users require services that are safe, readily available and easy to use, military requirements stress unique defense capabilities such as performance under intentional interference, operations in high-performance vehicles, worldwide coverage and operational capability in severe environmental conditions. Cost remains a major consideration which must be balanced with a needed operational capability.

Navigation requirements range from those for small single-engine aircraft or small vessels, which are cost-sensitive and may require only minimal capability, to those for highly sophisticated users, such as airlines or large vessel operators, to whom accuracy, flexibility, and availability may be more important than initial cost. The selection of an optimum mix to satisfy user needs, while holding the number of systems and costs to a minimum, involves complex operational, technical, institutional, international and economic trade-offs. This plan establishes a vehicle for DOD and DOT to address these questions and arrive at an optimum mix determination. This edition of the FRP attempts to build on the foundation laid by previous editions and further develop national plans toward providing an optimum mix of radionavigation systems for the foreseeable future. The constantly changing radionavigation user profile and rapid advancements in systems technology, as well as delays in the U.S. space programs, require that the FRP remain as dynamic as the issues it addresses. This issue of the FRP contains the current policy on the radionavigation systems mix.

This document is composed of the following sections:

- Section 1     Introduction to the Federal Radionavigation Plan: Delineates the purpose, scope and objectives of the plan, presents the DOD and DOT authority and responsibilities for providing radionavigation services, and the DOD/DOT policy and plan for the radionavigation system mix.
- Section 2     Radionavigation User Requirements: Provides civil and military requirements for air, land and marine navigation.
- Section 3     Radionavigation Systems Plans: Describes how the various radionavigation systems are used in meeting civil requirements, and the status and plans for each system.
- Section 4     Research, Engineering and Development: Presents the research, engineering and development efforts to be conducted by DOT and DOD.
- Appendix A    System Characteristics: Describes present and planned navigation systems in terms of ten major parameters: signal characterization, accuracy, availability, coverage, reliability, fix rate, fix dimension, capacity, ambiguity, and integrity.
- Appendix B    Chart Reference Systems: Discussion of chart reference systems.
- Appendix C    Definitions
- Glossary

## 1. INTRODUCTION TO THE FEDERAL RADIONAVIGATION PLAN

This section describes the background, purpose, and scope of the Federal Radionavigation Plan (FRP). It summarizes the events leading to the preparation of this document and the national objectives for coordinating the planning of radionavigation services. The remaining contents of Section 1 set forth National Policy, Radionavigation Authority and Responsibility, and Radionavigation System Planning.

### 1.1 BACKGROUND

The first edition of the FRP was released in 1980 as part of a Presidential Report to Congress, made in response to the International Maritime Satellite (INMARSAT) Act of 1978. It marked the first time that a joint Department of Transportation/Department of Defense (DOT/DOD) plan for common-use systems (i.e., systems used by both the civil and military sectors) had been developed. Now, this biennially-updated plan serves as the planning and policy document for all present and future Federally-provided radionavigation systems. This edition also reflects input obtained at air, marine, and land radionavigation users' conferences in 1986 and 1988.

The 1979 DOD/DOT Interagency Agreement for joint radionavigation planning, as well as for the development and publication of the FRP, was renewed in August 1984. This agreement recognizes the need to coordinate all Federal radionavigation system planning and to attempt, wherever consistent with operational requirements, to utilize common systems. Since the publication of the first edition of the FRP there have been significant changes in the radionavigation environment. Although the Global Positioning System (GPS) is a principal driving force in the FRP, other external factors such as breakthroughs in low cost Long Range Navigation (LORAN-C) receiver technology, marketplace pressures, delays in the space program, and increasing private sector involvement have affected the evolution of the FRP.

The FRP also has an impact on international radionavigation planning. This has been recognized in the process of selecting the future radionavigation systems mix. The FRP has been distributed to working groups within the International Maritime Organization (IMO), the International Civil Aviation Organization (ICAO), the International Association of Lighthouse Authorities (IALA) and other organizations.

Radionavigation users' conferences held in 1986 and 1988 indicated strong support for the LORAN-C system by air, marine and land users. Marine radiobeacons continue to be important to small boaters, and aeronautical beacons serve many airports without any other navigational aid. Very High Frequency Omnidirectional Range/Distance Measuring Equipment (VOR/DME), an international aviation standard, serves as the basis for the current airway structure and has a very high degree of acceptance among aviators. OMEGA has a small marine user population but continues to be used by business aviation and air carriers throughout the world as well as some specialized users involved in electromagnetic propagation and atmospheric wind studies. The TRANSIT satellite navigation system has a large population of maritime users throughout the world. Users also reported that safe, prudent navigation requires that a backup system be available.

Many users of radionavigation services are anticipating the operational availability of GPS. Civil users, however, are reluctant to state when they might equip with GPS due to operational uncertainties and concerns about receiver costs. Unfortunately, delays in the space program make it difficult to determine a firm operational date for GPS.

The need to consolidate and reduce the number of systems is a major objective of DOD and DOT. The constantly changing radionavigation user profile and rapid advancements in systems technology, as well as delays in the U.S. space programs, require that the FRP and the policies stated therein remain as dynamic as the issues they address. The current DOD/DOT policy on the radionavigation systems mix is presented in Section 1.6.

## 1.2 PURPOSE

The purpose of this FRP is to:

- o Present an integrated Federal policy and plan for all common-use civil and military radionavigation systems.
- o Provide a document for specifying radionavigation requirements and addressing common-use systems and applications.
- o Outline an approach for consolidating radionavigation systems.
- o Provide Government radionavigation system planning information and schedules.
- o Define and clarify new or unresolved common-use radionavigation system issues.
- o Provide a focal point for civil user input.

## 1.3 SCOPE

This plan covers Federally-provided, common-use radionavigation systems, acknowledging that these systems can be used for other purposes. It also briefly addresses privately-owned systems such as racons, radio determination satellite systems and others that interface with or impact on Federally-provided systems. The plan does not include systems which mainly perform surveillance and communication functions.

The major radionavigation systems subject to the planning process described in this FRP are:

- o Radiobeacons
- o LORAN-C
- o OMEGA
- o VOR, VOR/DME, VORTAC
- o TACAN
- o ILS
- o MLS
- o TRANSIT
- o GPS

#### 1.4 OBJECTIVES

The radionavigation policy of the United States has evolved through statute, usage, and in the interest of national defense and public safety. The objectives of United States Government radionavigation policy are to:

- o Support national security
- o Provide safety of travel
- o Promote efficient transportation services

#### 1.5 POLICIES AND PRACTICES

The following policies and practices implement the above objectives:

- A. Implementation and operation of radio aids to navigation. Services which contribute to safe, expeditious, and economic air and maritime commerce and which support United States national security interests are provided.
- B. Installation and operation of radionavigation systems in accordance with international agreements.
- C. Recognition of electromagnetic spectrum planning requirements and avoidance of unnecessary duplication of navigational systems and services. The highest degree of commonality and system utility between military and civil users is sought through early considerations of mutual requirements.

- D. Promotion of transportation safety and environmental protection by requiring certain vessels and aircraft to be fitted with navigational equipment as a condition for operating in the controlled airspace or navigable waters of the United States.
- E. Direction to ensure that radionavigation services available to civil users meet projected demand, performance, safety, and environmental protection requirements considering economic constraints on radionavigation systems providers and users.
- F. Evaluation of domestic and foreign radio aids to navigation, with support for the development of those systems having the potential to meet unfulfilled operational requirements; offering major economic advantages over existing systems; and providing significant benefits in the national interest.
- G. Promotion of international exchange of scientific and technical information concerning radionavigation aids.
- H. Guidance and assistance in siting, testing, evaluating and operating radio aids to meet unique aviation requirements not supported by the Federal Government.
- I. Promotion of national and international standardization of civil and military radionavigation aids.
- J. Establishment, maintenance, and dissemination of system and signal standards and specifications.
- K. Development, implementation, and operation of the minimum special radionavigation aids and services for military operations.
- L. Operation of common-use radionavigation systems as long as the United States and its allies accrue greater military benefit than potential adversaries. Operating agencies would cease operations or change characteristics and signal formats of radionavigation systems only during a dire national emergency.
- M. Control of LORAN-C stations by DOT to optimize utilization by non-marine users, within the constraints imposed by the need to provide quality service to maritime navigation.
- N. Provision of the GPS Standard Positioning Service (SPS) for continuous, worldwide civil use at the highest level of accuracy consistent with U.S. national security interests. It is presently projected that a predictable and repeatable accuracy of 100 meters (2 drms) horizontally and 156 meters (2 sigma) vertically will be made available during the first year of full GPS operation. During the development phase of the GPS program, the satellites will be transmitting both Precise Positioning Service (PPS) and SPS signals in the clear in support of government sponsored tests. Civil users are cautioned that the system is under development, and signal availability and accuracy are subject to change without advance warning, at the discretion of the DOD. Therefore, until the system is declared operational, any use of the system is at the user's own risk.

- O. Equipment of military vehicles, as appropriate, to satisfy civil aviation and maritime navigation safety requirements. U.S. military vehicles and users will be equipped with navigation systems which best satisfy mission requirements. In general, a combination of radionavigation and self-contained navigation aids is required. Standardization, although important, may be disregarded when unique military systems provide the capability to operate safely without reference to civil radionavigation systems.
- P. Establishment of mechanisms, where practical, for users of Federally-provided radionavigation aids to bear their fair share of the costs for development, procurement, operation, and maintenance of these systems.
- Q. Provision, through DOD/DOT interagency agreements, of comprehensive management for all Federally-provided common use radionavigation systems.
- R. Ensure in accordance with established national policy, reliance on the private sector to support the design, development, installation, operation, and maintenance of all equipment and systems required to provide common-use radionavigation aids in support of this FRP (within the constraints of national security).

#### 1.6 DOD/DOT CURRENT POLICY ON THE RADIONAVIGATION SYSTEM MIX

The Department of Transportation (DOT) is responsible for ensuring safe and efficient transportation. Radionavigation systems play an important role in carrying out this responsibility. The two main elements within DOT that operate radionavigation systems are the United States Coast Guard (USCG) and the Federal Aviation Administration (FAA). The agency responsible for coordinating navigation planning within DOT is the Research and Special Programs Administration (RSPA).

The USCG has the statutory responsibility to define the need for, and to provide aids to navigation and facilities required for safe and efficient marine navigation. The FAA has the responsibility for the development and implementation of radionavigation systems to meet the needs for safe and efficient air navigation, as well as control of all civil and military aviation, except for military aviation needs peculiar to warfare and primarily of military concern. The FAA also has the responsibility to operate aids to air navigation required by international treaties.

The Department of Defense (DOD) is responsible for developing, testing, evaluating, implementing, operating, and maintaining aids to navigation and user equipment required for national defense and ensuring that military vehicles operating in consonance with civil vehicles have the necessary navigational capabilities.

All common-user systems currently operating or planned were considered in developing the current policy on the mix of Federally-provided radionavigation systems. The statement that follows is the current DOD/DOT radionavigation policy for the period 1988-1990.

**DOD/DOT POLICY AND PLANS  
FOR THE  
FUTURE RADIONAVIGATION SYSTEMS MIX  
1988 - 1990**

PURPOSE:

This statement sets forth the policy for Federally provided radionavigation systems to be supported for the remainder of this century and into the early part of the next.

OBJECTIVES:

The Federal Government operates radionavigation systems as one of the necessary elements to enable safe transportation and encourage commerce within the U.S. It is a goal of the Government to provide this service in a cost effective manner. In order to meet both civil and military radionavigation needs, the Government has successively established a series of radionavigation systems over a period of years, each utilizing the latest technology available at the time, and each designed to meet an existing unfulfilled need, usually in terms of improved accuracy and/or expanded coverage. This policy statement addresses how and for what period each system should be part of the Federal radionavigation system mix. To date few systems have been discontinued.

DOD is currently introducing a new high-technology radionavigation system, the Global Positioning System (GPS), which will have wide civil application on a global basis. This system has the potential to meet or better the accuracy and coverage capabilities of most other radionavigation systems. Consequently, if the full civil potential of GPS is realized, the Department of Transportation will consider phasing out some of the existing radionavigation systems.

Any decision to discontinue Federal operation of existing systems will depend upon many factors including: (a) resolution of GPS accuracy, coverage, integrity and financial issues; (b) determination that the systems mix meets civil and military needs currently met by existing systems; (c) availability of civil user equipment at prices that would be economically acceptable to the civil community; (d) establishment of a transition period of 10-15 years; and (e) resolution of international commitments.

## INDIVIDUAL SYSTEM PLANS:

RADIOBEACONS: Maritime and aeronautical radiobeacons serve the civilian user community with low-cost navigation. They will remain part of the radionavigation mix into the next century.

LORAN-C: LORAN-C provides positioning and timing services for both civil and military air and surface users. It is the Federally provided navigation system for the U.S. Coastal Confluence Zone (CCZ). LORAN-C is approved as a supplemental air navigation system and is being implemented as a non-precision approach aid. Signal monitors necessary for LORAN-C nonprecision approaches will be operational in 1989. By 1990, additional transmitting stations will be installed to complete signal coverage over the 48 conterminous states. The LORAN-C system serving the continental United States (including Alaska) and the coastal areas will remain a part of the navigation system mix into the next century. DOD will not have a requirement for LORAN-C after December 1994.

OMEGA: OMEGA is a global navigation system serving maritime and aeronautical users. OMEGA is expected to remain part of the radionavigation system mix through the remainder of the century. It is a sole means of air navigation in some oceanic areas. Recapitalization of equipment and antennas, required at several stations in the mid-1990's, will be based on cost benefit analyses that may lead to elimination or reduction of service in some areas. The normal transition period of 10 to 15 years may be shortened due to escalating maintenance costs and availability of alternative navigation systems such as GPS. DOD will phase out military air use of OMEGA by December 1994; however, some naval receivers may continue in operation after that date.

VOR/DME: VOR/DME provides users with a sole means of air navigation in the National Airspace System (NAS). VOR/DME, as the international standard for civil air navigation in controlled airspace, will remain a short-range aviation navigation system into the next century. DOD will phase out military support and use of VOR/DME by 1997.

TACAN: TACAN is a short-range navigation system used primarily by military aircraft. When DOD determines that GPS, properly integrated with other onboard aircraft systems, is an acceptable radionavigation system for military use in controlled airspace, the DOD requirement for land-based TACAN will terminate. Based upon the planned GPS operational date of 1992, the DOD requirement for land-based TACAN should terminate by December 1997. The requirement for shipboard TACAN will continue until a suitable replacement is operational.

ILS; MLS; DME/P: These are precision approach systems for aircraft. MLS will replace ILS, and will be completely installed at civil airports by 2003.

TRANSIT: TRANSIT is a satellite-based radionavigation system operated by DOD. The DOD requirement for TRANSIT will terminate and system operation will be discontinued by December 1996.

GPS: GPS is a DOD developed, worldwide, satellite-based radionavigation system that will be the DOD's primary radionavigation system well into the next century. The constellation will ultimately consist of 24 operational satellites (21 plus 3 operating spares). The GPS constellation will be declared fully operational by DOD when 21 satellites are functioning in their assigned orbits, planned to occur in 1992. If current R&D satellites remain functional beyond their design life, this could occur before 1992.

GPS Precise Positioning Service (PPS), the service that requires the use of cryptographic keys, will be primarily limited to military and official Government users. GPS Standard Positioning Service (SPS) will be made continuously available, without charge to all users worldwide, and will provide 100 meter (2 drms) or better positioning accuracy.

AIR USE: GPS has the potential to become a sole means air navigation system. Approval of civil air navigation receivers to operate with the GPS is expected initially to be on a supplementary basis. Resolution of coverage and integrity issues is needed to certify GPS as a sole means system.

SURFACE USE: GPS will satisfy the requirements for the ocean phase of maritime navigation, some coastal phase requirements and some land user requirements. At the 100-meter accuracy level planned, however, GPS will not meet the requirements for some coastal phase maritime applications or the requirements for harbor/harbor approach navigation. Additionally, some land navigation requirements, as stated by the users, demand accuracy in the 10-meter range. It is possible that an enhanced form of GPS, such as differential GPS, could satisfy these more stringent requirements.

DIFFERENTIAL: The Coast Guard and the DOD are investigating the capabilities of differential GPS. Although there are currently no Federal Government plans to provide a differential GPS service for common use, the DOD in coordination with the DOT will control differential GPS transmissions to prevent interference with GPS satellite transmissions and to protect U.S. national security interests.

## 1.7 DOD RESPONSIBILITIES

DOD is responsible for developing, testing, evaluating, operating, and maintaining aids to navigation and user equipment required for national defense, and for ensuring that military vehicles operating in consonance with civil vehicles have the necessary navigational capabilities. Specific DOD responsibilities are to:

- o Define performance requirements applicable to military mission needs.
- o Design, develop, and evaluate systems and equipment to ensure cost-effective performance.
- o Maintain liaison with other government research and development activities affecting military radionavigation systems.
- o Develop forecasts and analyses as needed to support the requirements for future military missions.
- o Develop plans, activities, and goals related to military mission needs.
- o Define and acquire the necessary resources to accomplish mission requirements.
- o Identify special military route and airspace requirements.
- o Foster standardization and interoperability of systems with NATO and other allied countries.
- o Operate and maintain ground radionavigation aids as part of the civil National Airspace System (NAS) when such activity is economically beneficial and specifically agreed to by the appropriate DOD and DOT agencies.
- o Derive and maintain astronomical and atomic standards of time and time interval and to disseminate these data.

The Defense Mapping Agency (DMA) is responsible for military mapping, charting, and geodesy aspects of navigation, including geodetic surveys, accuracy determination, and positioning. Within DOD, DMA acts as the primary point of contact with the civil community on matters relating to geodetic uses of navigation systems. Unclassified data prepared by the DMA are available to the civil sector.

The U.S. Naval Observatory (USNO) is responsible for determining the positions and motions of celestial bodies, the motions of the Earth and precise time; for providing the astronomical and timing data required by the Navy and other components of DOD and the general public for navigation, precise positioning, and command, control and communications; and for making these data available to other government agencies and to the general public.

DOD carries out its responsibilities for navigational coordination through the internal management structure shown in Figure 1-1. The two major parts of the structure represent the administrative and the operational chains of command reporting to the Secretary of Defense.

#### 1.7.1 Operational Management

The Joint Chiefs of Staff (JCS) are the top level in the operational chain of command (beneath the Secretary of Defense), and serve as military advisors to the President and the Secretary of Defense, as authorized. Additionally, the JCS provide guidance to the military departments and the armed forces in the preparation of their respective detailed navigational plans. The JCS are aware of operational navigation requirements and capabilities of the Unified and Specified Commands and the Services, and are responsible for the development, approval, and dissemination of the JCS Master Navigation Plan (MNP).

The MNP is the official navigational policy and planning document of the JCS. It is a coordinated navigational system plan which meets identified operational defense requirements. The MNP also facilitates the integration of required military navigational systems and the implementation of JCS policy for radionavigation.

The following organizations also perform navigation management functions:

The Deputy Director for Defense-Wide Command, Control and Communications Support, Joint Staff, is responsible for:

- o Analysis, evaluation, and monitoring of navigational system planning and operations.
- o General navigational matters and the JCS MNP.

The Commanders of the Unified and Specified Commands perform navigational functions similar to those of the JCS. They develop navigational requirements as necessary for contingency plans and JCS exercises that require navigational resources external to that command. They are also responsible for review and compliance with the JCS MNP.

#### 1.7.2 Administrative Management

Three permanent organizations provide radionavigation planning and management support to the Assistant Secretary of Defense for Command, Control, Communications and Intelligence (ASD/C<sup>3</sup>I). These organizations are the Positioning/Navigation (POS/NAV) Executive Committee; the POS/NAV Working Group; and the Military Departments/Service Staffs. Brief descriptions are provided below.

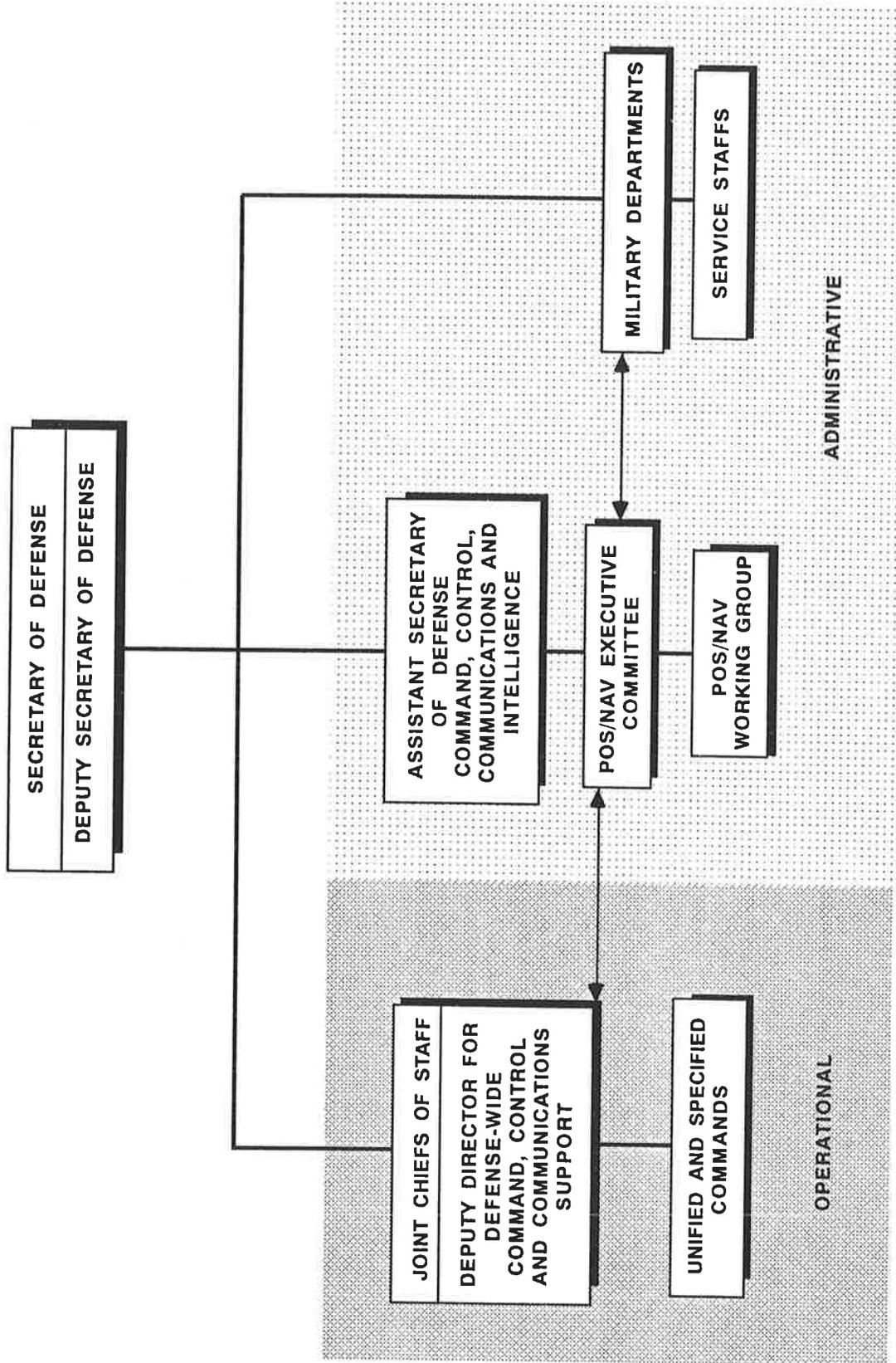


FIGURE 1.1. DOD NAVIGATION MANAGEMENT STRUCTURE

The DOD POS/NAV Executive Committee is the DOD focal point and forum for all DOD POS/NAV matters. It provides overall management supervision and decision processes, including intelligence requirements (in coordination with the Defense Intelligence Agency and the National Security Agency). The Executive Committee contributes to the development of the FRP and coordinates with the DOT Navigation Council.

The DOD POS/NAV Working Group supports the Executive Committee in carrying out its responsibilities. It is composed of representatives from the same DOD components as the Executive Committee. The Working Group identifies and analyzes problem areas and issues, participates in the revision of the FRP, and submits recommendations to the Executive Committee.

The Military Departments/Service Staffs are responsible for participating in the development, dissemination and implementation of the JCS MNP and for managing the development, deployment and operation and support of designated navigation systems.

A special committee, the GPS Phase-In Steering Committee, has been established to guide the development and implementation of the policies, procedures, support requirements, and other actions necessary to enable DOD GPS users to operate safely and effectively anywhere in the world without reference to any other external radionavigation system except those systems necessary for aircraft precision landing approach or ship approach to harbors.

## 1.8 DOT RESPONSIBILITIES

DOT is the primary government provider of aids to navigation used by the civil community and of certain systems used by the military. It is responsible for the preparation and promulgation of radionavigation plans in the civilian sector of the United States.

The Secretary of Transportation, under 49 USC 301, has overall responsibility for navigational matters within DOT and promulgates radionavigation plans. Three DOT elements have statutory responsibilities for providing aids to navigation: the USCG, the FAA and the Saint Lawrence Seaway Development Corporation (SLSDC). In addition, several other elements of DOT have responsibilities and interests which may be satisfied by radionavigation or radiolocation systems.

The USCG has the responsibility to define the need for, and to provide, aids to navigation and facilities required for safe and efficient navigation. Section 81 of Title 14, United States Code provides:

"In order to aid navigation and to prevent disasters, collisions, and wrecks of vessels and aircraft, the Coast Guard may establish, maintain, and operate:

(1) aids to maritime navigation required to serve the needs of the armed forces and the commerce of the United States;

(2) aids to air navigation required to serve the needs of the armed forces of the United States peculiar to warfare and primarily of military concern as determined by the Secretary of Defense or the Secretary of any department within the Department of Defense and as requested by any of those officials;

(3) electronic aids to navigation systems (a) required to serve the needs of the armed forces of the United States peculiar to warfare and primarily of military concern as determined by the Secretary of Defense or any department within the Department of Defense; or (b) required to serve the needs of the maritime commerce of the United States; (c) required to serve the needs of the air commerce of the United States as requested by the Administrator of the Federal Aviation Agency.

These aids to navigation, other than electronic aids to navigation systems, shall be established and operated only within the United States, the waters above the Continental Shelf, the territories and possessions of the United States, the Trust territory of the Pacific Islands, and beyond the territorial jurisdiction of the United States at places where naval or military bases of the United States are or may be located."

The FAA has responsibility for development and implementation of radionavigation systems to meet the needs of all civil and military aviation, except for those needs of military agencies which are peculiar to air warfare and primarily of military concern. The FAA also has the responsibility to operate aids to air navigation required by international treaties.

The RSPA coordinates navigation issues and planning which is intermodal in nature.

The Maritime Administration (MARAD) investigates position determination using existing and planned navigation systems, conducts precision radar navigational experiments and investigates the application of radar transponders to navigation and collision avoidance. These efforts are designed to enhance U.S. Merchant Marine efficiency and effectiveness.

The Office of Commercial Space Transportation (OCST) in DOT is charged with : (1) promoting, encouraging, and facilitating commercial space transportation by the U.S. private sector and (2) ensuring public safety with respect to commercial space transportation, operation of launch sites and spaceports by the U.S. private sector, and commercial satellites not otherwise licensed by another Federal agency. Accordingly, OCST is interested in the demand for space launches by providers of satellite-based services including radiodetermination.

The SLSDC has responsibility for assuring safe navigation along the seaway. The SLSDC provides navigational aids in U.S. waters in the St. Lawrence River and operates a Vessel Traffic Control System with the St. Lawrence Seaway Authority of Canada.

The Federal Highway Administration (FHWA), the National Highway Traffic Safety Administration (NHTSA), Federal Railroad Administration (FRA) and the Urban Mass Transportation Administration (UMTA) have the responsibility to conduct research, development, and demonstration projects, including projects on land uses of radiolocation systems. They also assist state and local governments in planning and implementing such systems and issue guidelines concerning their potential use and applications.

The National Aeronautics and Space Administration (NASA) supports navigation through the development of technologies for navigating aircraft and spacecraft. NASA is responsible for development of user and ground-based equipment, and is also authorized to demonstrate the capability of military navigational satellite systems for civil aircraft, ship, and spacecraft navigation and position determination.

DOT carries out its responsibilities for civil navigational systems planning through the internal management structure shown in Figure 1-2. The structure was established by DOT Order 1120.32, dated April 27, 1979, for the following purposes:

- o To coordinate policy recommendations and integrate navigation planning among the operating elements of DOT, and to ensure the most efficient implementation of those policies and plans without decreasing the responsibility, or usurping the authority of the individual operating elements.
- o To facilitate coordinated navigational planning on a continuing multimodal basis within DOT; and to serve as a focal point for recommendations on DOT navigation policies and plans.
- o To provide the Secretary of Transportation with consolidated information and to provide the means to obtain coordinated high level review of proposed navigational policies and plans.
- o To establish a plan allowing the DOT operating elements the maximum latitude to conduct navigational system research, development, and implementation while avoiding duplication of effort.
- o To provide supplemental technical resources for the navigation planning, implementation, coordination, and decision-making of the operating elements.
- o To coordinate input from those elements of DOT not having a continuous interest in navigational problems.
- o To provide a DOT focal point for multimodal or interdepartmental navigational issues.

The DOT Navigation Council is the top level of the structure. It consists of the DOT Chief Scientist as Chairman, the Assistant Secretary for Budget and Programs, Assistant Secretary for Policy and International Affairs, the Director of the Office of Commercial Space Transportation, and one policy-level representative each from the USCG, FAA, MARAD, RSPA and the SLSDC. The Council meets as required, with representatives of other operating elements occasionally attending to consider specific items. The DOT Navigation Council:

- o Formulates coordinated policy recommendations to the Secretary
- o Coordinates policies with similar committees in other government agencies according to any agreements between DOT and those agencies
- o Provides guidance to the subordinate Navigation Working Group.

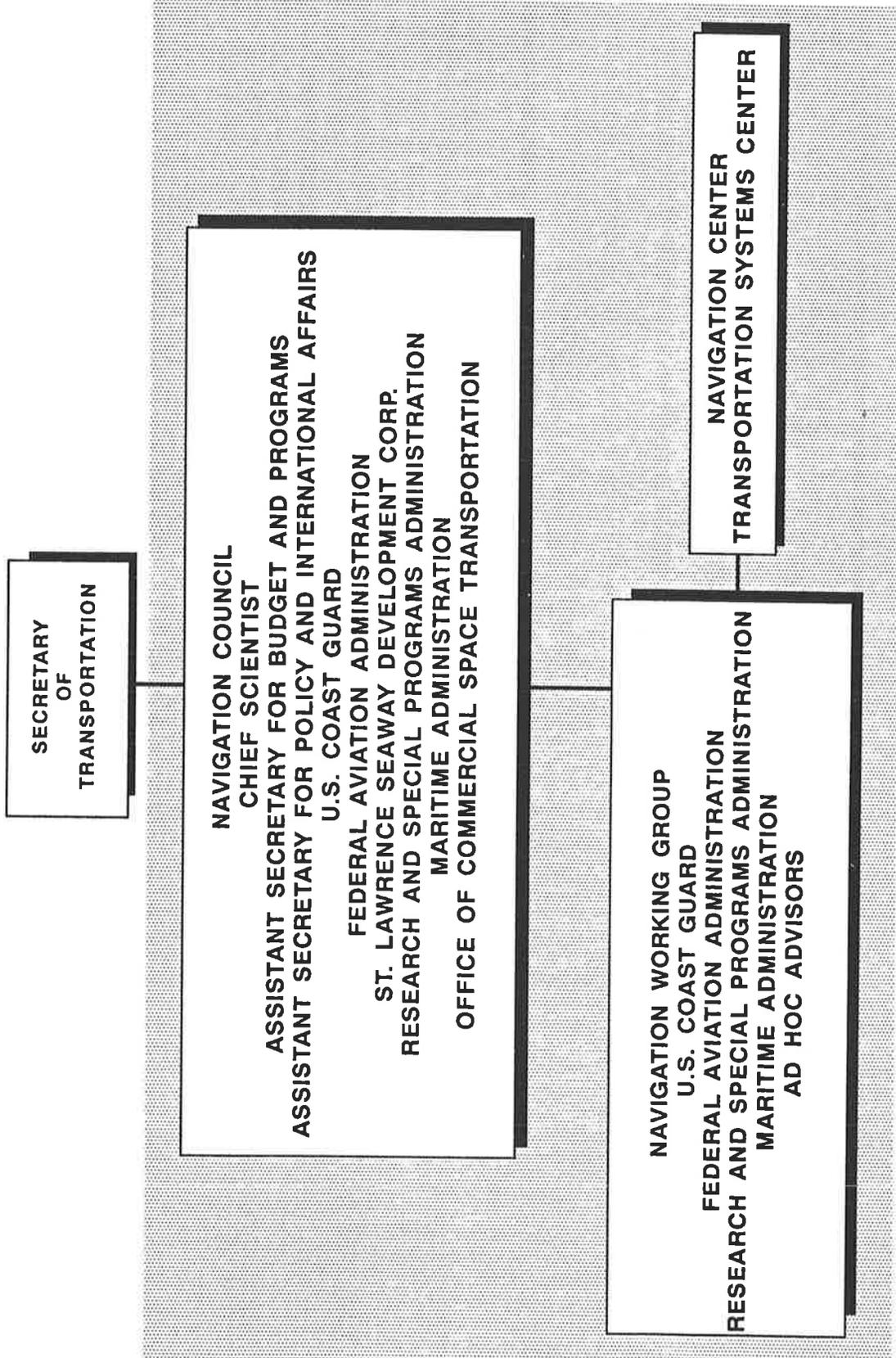


FIGURE 1-2. DOT NAVIGATION MANAGEMENT STRUCTURE

The Navigation Working Group is the core of the structure, consisting of one representative each from the USCG, FAA, MARAD and RSPA. Each representative may be assisted by advisors. Ad hoc advisors from other DOT operating elements having an interest in navigation are invited to attend meetings as appropriate. These elements are the FHWA, FRA, NHTSA, and UMTA. The Navigation Center at the DOT Transportation Systems Center (TSC) provides technical assistance to the Navigation Working Group, as requested. The Navigation Working Group facilitates the coordination of:

- o Navigation requirements developed by the DOT operating elements
- o Navigation plans
- o Navigation R,E&D and implementation programs
- o DOT navigation planning with DOD, NASA, and other Federal agencies, as required
- o Multimodal navigation issues with other governmental agencies, industry, and user groups, as directed by the Navigation Council
- o Suggestions for the improvement of future editions of the FRP.

#### 1.9 DOD/DOT INTERAGENCY AGREEMENT

An Interagency Agreement between DOD and DOT for radionavigation planning became effective in 1979 and was updated in 1984. This agreement requires coordination between the DOD and DOT internal management structures for navigation planning. The Interagency Agreement recognizes that DOD and DOT have joint responsibility to avoid unnecessary overlap or gaps between military and civil navigation systems/services. Furthermore, it requires that both military and civil needs be met in a manner cost-effective for the Government and civil user community. Implicit in this joint responsibility is assurance of civil sector radionavigation readiness for mobilization in national emergencies. The agreement provides that DOD and DOT will jointly:

- o Inform each other of the development, evaluation, installation, and operation of aids to navigation with existing or potential joint applications.
- o Coordinate all major navigation planning activities to ensure consistency while meeting diverse navigational requirements.
- o Attempt, where consistent with diverse requirements, to utilize common systems, equipment, and procedures.
- o Undertake joint programs in the research, development, design, testing, and operation of radionavigation systems.
- o Prepare a standard definition of requirements and a joint requirements document.

- o Assist in informing or consulting with other government agencies involved in navigation system research, development, operation, or use, as necessary.
- o Publish a single FRP to be implemented by internal departmental actions. This plan will be reviewed and updated biennially.

## 1.10 DETERMINATION OF FUTURE RADIONAVIGATION SYSTEMS MIX

Many factors determine the choice of the systems mix to satisfy diverse user requirements. They may be categorized according to operational, technical, economic, institutional and/or international parameters. System accuracy and coverage are the foremost technical parameters, followed by system availability and reliability. Certain unique parameters, such as anti-jamming performance, apply to military needs.

The current investment in ground and user equipment must also be considered. In some cases, there may be international commitments which must be honored or modified in a fashion mutually agreeable to all parties.

In most cases, current systems were developed to meet distinct and different requirements, and they must be retained until such needs no longer exist or can be met by an acceptable system mix. This development of systems to meet unique requirements led to the development of multiple radionavigation systems and was the impetus for early radionavigation planning. The first edition of the FRP was published to plan the mix of radionavigation systems and promote an orderly life cycle for them. It described an approach for selecting radionavigation systems to be used in the future. Early editions of the FRP, including the 1984 edition, reflected that approach with minor modifications to the timing of events. By 1986 it became apparent that a final recommendation on the future mix of radionavigation systems was not appropriate and major changes to the timing of system life cycle events were required. Consequently, it was decided that starting with the 1986 FRP, a current recommendation on the future mix of radionavigation systems would be issued with each edition of the FRP. This current recommendation reflects, among other things, delays in the GPS implementation schedule, dynamic radionavigation technology, changing user profiles, and input received at civil radionavigation users' conferences held by the FAA, USCG, and the RSPA during 1986 and 1988.

### 1.10.1 Approach to Selection

There are long-term and short-term aspects that need to be addressed in the overall selection process. The long-term goal is to establish, through an integrated DOD/DOT planning and budgeting process, a cost-effective, user-sensitive, mix of systems for the post-2000 timeframe. As part of this long-term goal, until GPS is fully implemented and it can be clearly established which civil requirements being met by existing systems can be met by GPS, there may be a need to improve or expand existing systems. The selection process for the systems to be used in the future allows the flexibility to adopt incremental improvements where justified over the short term. Similarly, the process permits system upgrading and research

and development to allow the satisfaction of operational requirements which are not met by existing or planned systems. One example is the effort of the USCG and the FAA to provide midcontinent LORAN-C coverage.

Figure 1-3 shows the revised sequential process for selecting the Federally-provided radionavigation systems to be used in the future. It is recognized that GPS may not meet the needs of all civil users of radionavigation systems. Therefore, some system life cycles are independent of the GPS implementation date. After GPS is fully operational and its ability to meet user needs has been verified, systems it would potentially replace will be reviewed for future requirements or phase out.

DOT will maintain liaison with the civil users of radionavigation systems through user conferences or other appropriate means prior to updating the FRP or prior to any significant changes in policy. Input received will become a vital part of the biennial decision-making process on radionavigation system life cycles. This consultation, review and recommendation cycle will be continued until the ability of GPS to meet civil user needs has been determined. At that time, long term phase-out or phase-over continuation plans will be considered for those systems replaceable by GPS. During 1988 and 1989, international, intragovernmental, and user consultations will take place on the future of Federally-provided radionavigation systems. Developments in GPS and the changing needs of civil users will be reviewed. The status and impact of commercial radionavigation systems will also be considered as a part of this process. In addition, as an alternative to the phasing out of civil radionavigation systems, consideration will be given to the possibility of phasing over operation of them to the private sector.

For each common-use system, the following process is used to select systems to be part of the future radionavigation systems mix. DOT will evaluate civil requirements for a system including requirements for redundancy and, if needed, the system will be retained as part of the system mix. Evaluating civil user requirements and determining a cost effective mix of systems to meet that requirement entails a continual dialog with civil users and consultations with international organizations such as the IMO and the ICAO. It also requires a review of U.S. international commitments and resolution of any conflicts. DOD decides whether a given system is necessary to meet military requirements and if so, the system will be retained as part of the system mix. An intensive effort is necessary and desirable to establish a stable framework for long-range planning by users and others affected by the transition to a new combination of systems. Consideration of operational, technical, economic and institutional issues will dominate this selection process. However, the goal is to meet all military and civil requirements with the minimum number of common-use systems. Finally, a national policy will reflect: 1) national security requirements, 2) U.S. allies and civil user consultations and 3) DOD/DOT deliberations.

### 1.10.2 Operational Issues

Mobile users/operators want the safest, most direct, and economical path to their destinations or, in some cases, the user wants to locate a fixed point or boundary. Users must be able to respond correctly and quickly to traffic control services. They must navigate with accuracy consistent with their environment, the

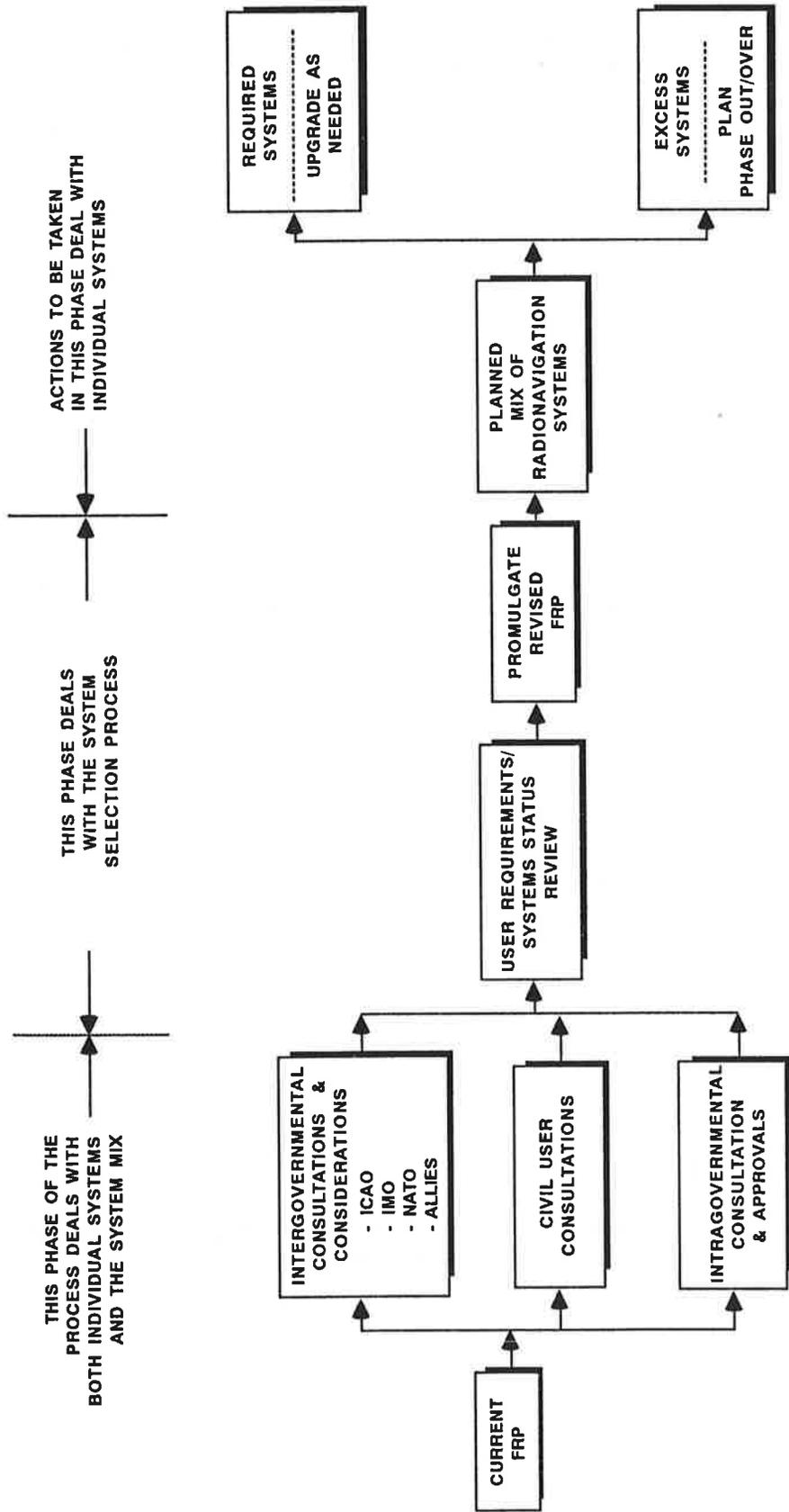


FIGURE 1-3. DOD/DOT RADIONAVIGATION SYSTEMS PLANNING PROCESS

capability of others sharing their space, the performance of their craft, and the rules, regulations, and procedures which govern operations. Areas of operation, mission, economics, personal preference and Federal regulations largely determine the radionavigation aids chosen by operators. They choose different kinds of equipment to use the particular aid selected, and generally wish to limit or minimize the cost.

### 1.10.3 Special Military Considerations

#### A. Military Selection Factors

Operational need is the principal influence in the DOD selection process. Precise navigation is required for vehicles, anywhere on the surface of the earth, on and under the sea, and in and above the atmosphere. Other factors that affect the selection process are:

- o Flexibility to accommodate new weapon systems and technology
- o Immunity of systems to enemy interference or exploitation
- o Interoperability with the systems used by allies and the civil sector
- o Reliability and survivability in combat
- o Interruption, loss or degradation of system operation by enemy attack, political action, or natural causes
- o Development of alternate means of navigation
- o Geodetic accuracy relative to a common reference system, to support strategic and tactical operations
- o Worldwide mobility requirements

The selection of DOD navigational systems is influenced by the fact that military operations may be conducted in areas where navigational facilities are inadequate or non-existent. Therefore, where feasible, military radionavigation systems designed to operate in forward areas will be mobile and hardened against the effects of conventional and nuclear weapons.

#### B. Civil/Military Compatibility

DOD aircraft and ships operate in, and must be compatible with, civil environments. Thus, there are potential cost advantages in the development of common civil/military systems.

#### C. Review and Validation

The DOD radionavigation system requirements review and validation process:

- o Identifies the unique components of mission requirements

- o Identifies technological deficiencies
- o Determines, through interaction with DOT, the impact of new military requirements on the civil sector

The requirements review and validation process will investigate system costs, user populations, and the relationship of candidate systems to other systems and functions.

#### 1.10.4 Technical Considerations

In evaluating future navigation systems, there are a number of technical factors which must be considered:

- o Received Signal Strength
- o Multipath Effects
- o Signal Accuracy
- o Signal Acquisition and Tracking Continuity
- o Signal Integrity
- o Availability
- o Vehicle Dynamic Effects
- o Signal Coverage
- o Noise Effects
- o Propagation
- o Interference Effects (Natural, Man-made)
- o Installation Requirements
- o Environmental Effects
- o Human Factors Engineering
- o Reliability

#### 1.10.5 Economic Considerations

A number of systems may play major roles in navigation in the future. Some of these systems, such as VOR/DME, are limited to use by a single class of users; e.g., aircraft, in specific areas. Others, such as LORAN-C, have wider coverage areas and application. Still others, such as GPS, have broad application and global coverage. The optimal policy must consider Government investment in future

radionavigation systems to meet user requirements, as well as the significant user investment in existing systems, and other economic aspects.

There are many benefits derived from radionavigation systems, including improved safety of navigation, greater efficiency in transportation and other commercial activity, and more effective national security. Efficiency in commercial enterprise produces economic benefits which are generally obvious, but not so easily quantifiable. Improvements in general safety and security provide additional, significant economic benefits through the prevention of loss of life and limb and protection of capital investment.

Direct cost to the government, as the operator of radionavigational services, and to the user, who must buy the equipment needed to use the services, must be carefully analyzed. The analysis of these costs must consider the initial investment, operation, maintenance and replacement costs, as well as the unamortized capital investment remaining at the time that replacement of the system is contemplated. In the civil sector, the cost of user equipment, more than any other single factor, influences the acceptability of a new system by the majority of civil users. Substantial unamortized investment in user equipment for a current system will cause strong resistance to replacement and the demand for an extended phase-out period.

DOD is a major investor in navigational systems, subsystems and components. The acquisition of a system which is not cost-effective diverts DOD resources from more productive uses; therefore, affordability from a life cycle/cost view is a prime concern.

#### 1.10.6 Institutional Considerations

The principal institutional considerations in the formulation of a strategy for radionavigation systems selection include the following:

##### A. Cost Recovery for Radionavigation Services

Because of the nature of the electromagnetic medium, radionavigation services presently provided to meet U.S. requirements are available to any suitably equipped user. There is no direct charge or fee levied by the U.S. Government for the use of any of the Federally-provided radionavigation systems. The only cost recovery for radionavigation services from civil users, either domestic or foreign, is obtained from the aviation community for DOT-provided air transportation services. This cost recovery is achieved through indirect measures such as fuel taxes, registration fees, and/or ticket taxes, and at this time covers only part of DOT's costs. There is presently no corresponding cost recovery from the marine users of DOT-provided radionavigation services.

DOT has proposed the implementation of fees sufficient in total, to approach full cost recovery from the civil transportation users who directly benefit from Federally-provided transportation related services. The various fees would be set at an amount so as to generate total revenue from each of the user groups consistent with the cost of the services provided to that group. This proposal is

part of the Administration's effort to impose user fees where a service provides benefit to identifiable recipients above and beyond those which accrue to the general public. Under the DOT proposal, the costs of DOT provided services would be recovered through an appropriate and convenient fee system:

- o The USCG will attempt to establish a cost recovery program for those services in which there is a direct transaction such as licensing, inspections, permits and similar programs. A Notice of Proposed Rule Making is being prepared to cover licensing of Class I Private Aids. It is not anticipated however, that it would be cost effective to develop a mechanism to enforce collection of user fees for radionavigation services provided by the USCG.
- o The cost of services provided by the FAA would be recovered through the following fee system: passenger ticket tax, aviation gasoline fuel tax, jet fuel tax, freight waybill tax, international departure tax, and a tire and tube tax.

#### B. Signal Availability in Times of National Emergency

The availability of accurate navigation signals at all times is essential for safe navigation. Conversely, guaranteed availability of optimum performance may diminish national security objectives, so that contingency planning is necessary. The U.S. national policy is that all radionavigation signals (LORAN-C, OMEGA, VOR/DME, GPS, TRANSIT, etc.) will be available at all times except during a dire national emergency, when only those radionavigation signals serving the national interest will be available.

#### C. International Acceptance of Navigational Systems

The goals of standardization and cost minimization of user equipment influence the search for an international consensus on a selection of radionavigation systems. For civil aviation, the ICAO establishes standards for internationally-used radionavigation systems. For the international maritime community, a similar role is played by the IMO. Traditionally, IMO has been less stringent in establishing radionavigation requirements for the maritime community than ICAO has been for the aviation community. The IALA also has a working group and technical committee attempting to develop international radionavigation guidelines. IMO is currently reviewing existing and proposed radionavigation systems to identify a system or systems that could meet the requirements of, and be acceptable to members of the international maritime community. In addition to technical and economic factors, national interests must also be considered in the determination of a system or systems to best meet the civil user's needs. Further international consultations will be required to resolve the issues.

#### D. Role of the Private Sector

Radionavigation services have historically been operated by the government for reasons of safety, security and to enhance commerce. These systems are used for air, marine and land applications, including navigation and positioning, and also for time and frequency dissemination.

For certain applications such as positioning and surveying over a limited area, a number of privately operated systems are available to the user as an alternative or adjunct service. In addition, the advent of FCC authorized commercial Radiodetermination Satellite Service (RDSS) will make radiolocation information available over a wide coverage area.

Since the role of privately operated systems is increasing, and there is current interest in an increased private sector role in Federally-provided radionavigation systems, the whole issue of the private sector role in radionavigation services needs to be examined. Some of the factors to be considered include:

- o Impact of privately-operated services on usage and demand for Federally operated services.
- o Impact of permitting privately-operated systems to provide basic safety of navigation services in conjunction with communications services.
- o Need for a free Federally-provided safety of navigation service if commercial services are available.
- o Liability considerations.
- o Consideration of phase over to private operation as a viable alternative to phase out of a Federally operated radionavigation service.

#### 1.10.7 Criteria for Selection

Criteria have been defined to compare alternative navigation systems configurations. At the minimum, future systems should meet the following selection criteria:

- A. Service: Necessary service should be provided to meet the needs of the military and civil communities.
  - o Military Operations: At a minimum, navigation services to support accomplishment of DOD tactical and strategic missions should be provided in an effective and efficient manner.
  - o Transportation Safety: At a minimum, navigation services sufficient to allow safe transportation should be provided.
  - o Economic Efficiency: To the extent possible and consistent with cost effectiveness, navigation services which benefit the economy should be provided.
- B. Viability: Radionavigation systems should be responsive and flexible to the changing operational and technological environments.
  - o Orderly Transition: Orderly transitional operations should be provided for, to accommodate technical improvements and the modification of operational requirements.

- o **Flexibility:** Navigation services should be provided to a variety of user classes with the minimum number of systems.
  - o **Coverage:** Navigation services should be provided in all relevant operating areas.
  - o **Evolving Technology:** Research and introduction of new systems and concepts should be considered, particularly where unmet requirements or cost savings exist.
- C. **Standardization:** A necessary degree of standardization and interoperability should be recognized and accommodated for both domestic and foreign operations.
- o **International Acceptance:** Navigation services and systems should be technically and politically acceptable to diverse groups, including NATO and other allies, ICAO, and IMO.
  - o **Civil/Military Interoperability:** The basic capabilities to permit common use and common operational procedures by civil and military users should be provided.
  - o **Equipment Standardization and Compatibility:** To the extent feasible, compatibility between civil and military navigation equipment should be provided.
- D. **Costs:** The required level of service should be achieved in an economic manner.
- o **Combined User/Government Costs:** Life-cycle costs of a mix of radionavigation systems for Government and users should be consistent with adequate service and reasonable benefits.
  - o **Transition Period Cost:** Parallel (new and old) system operations will be carried out over a sufficient period to minimize user investment cost penalties and to permit equipment replacement to occur at normal intervals.



## 2. RADIONAVIGATION USER REQUIREMENTS

The requirements of civil and military users for radionavigation services are based upon the technical and operational performance needed for military missions, transportation safety and economic efficiency. For civil users, and for military users in missions similar to civil users (i.e., en route navigation), the requirements are defined in terms of discrete "phases of navigation." These phases are categorized primarily by the characteristics of the navigational problem as the mobile craft passes through different regions in its voyage. For example, the ship navigational problem becomes progressively more complex and risky as the large ship passes from the high seas, into the coastal area, and finally through the harbor approach and to its mooring. Thus, it is convenient to view each segment separately for purposes of analysis.

Unique military missions and national security needs impose a different set of requirements which cannot be viewed in the same light. Rather, the requirements for military users are more a function of the system's ability to provide services that equal or exceed tactical or strategic mission requirements at all times in relevant geographic areas, irrespective of hostile enemy action.

In the discussion that follows, both sets of requirements (civil and military) are presented in a common format of technical performance characteristics whenever possible. These same characteristics are used to define navigation system performance in Section 3.

### 2.1 CIVIL REQUIREMENTS

The radionavigation requirements of civil users are determined by a DOT process which begins with acknowledgment of a need for service in an area or for a class of users. This need is normally identified in public safety and cost/benefit need analysis generated internally, from other Federal agencies, the user public or as required by Congress. User conferences held during 1986 and 1988 highlighted land user needs not previously defined.

Radionavigation services provide civil users with the following:

- o Service adequate for safety
- o Economic performance/benefit enhancement.

### 2.2 REQUIREMENTS DETERMINATION

Radionavigation system replacement candidates must be subjected to a total system analysis in terms of safety and economic performance. This involves the evaluation of a number of complex factors. Replacement decisions will not be made on the basis of a simple comparison of one performance characteristic such as system accuracy.

### 2.2.1 Process

The requirements for an area or class of users are not absolutes. The process to determine requirements involves:

- o Evaluation of the acceptable level of safety risks to the Government, user and general public as a function of the service provided.
- o Evaluation of the economic needs in terms of service needed to provide cost effective benefits to commerce and the public at large. This involves a detailed study of the desired service by user group measured against the benefits obtained.
- o Evaluation of the total cost impact of any Government decision on radionavigation users.

This process leads to Government selection of a system. The decision is driven primarily by considerations of safety and economic benefit.

### 2.2.2 User Factors

User factors requiring consideration are:

- o Vehicle size and maneuverability
- o Regulated and unregulated traffic flow
- o User skill and workload
- o Process and display requirements for navigational information
- o Environmental constraints; e.g., weather, terrain, man-made obstructions
- o Operational constraints inherent to the system
- o Economic benefits.

For most users, cost is generally the driving consideration. The price users are willing to pay for equipment is influenced by:

- o Activity of the user; e.g., recreational boaters, air taxi, general aviation, mineral exploration, helicopters, and commercial shipping.
- o Vehicle performance variables such as fuel consumption, operating costs, and cargo value.
- o Cost/performance tradeoffs of radionavigation equipment.

Thus, in the civil sector, evaluation of a navigation system against requirements involves more than a simple comparison of accuracy and equipment performance characteristics. These evaluations must involve the operational, technical, and

cost elements discussed above. Performance requirements are defined within this framework.

## 2.3 PHASES OF NAVIGATION

Each mode of transportation has various phases with different requirements to provide safe and cost-effective operation during each phase.

### 2.3.1 Air

The two basic phases of air navigation are approach/landing and en route/terminal.

#### A. Approach/Landing

The approach/landing phase is that portion of flight conducted immediately prior to touchdown. It is generally conducted within 10 nm of the runway. Two sub-phases may be classified as non-precision approach and precision approach and landing.

#### B. En Route/Terminal

The en route/terminal phase includes all portions of flight except that within the approach/landing phase. It contains five sub-phases which are categorized by differing geographic areas and operating environments as follows:

- o Oceanic En Route

This sub-phase covers operations over ocean areas generally characterized by low-traffic density and no independent surveillance coverage.

- o Domestic En Route (High Altitude and Low Altitude Routes)

Operations in this sub-phase are typically characterized by moderate to high traffic densities. This necessitates narrower route widths than in the oceanic en route sub-phase. Independent surveillance is generally available to assist in ground monitoring of aircraft position.

- o Terminal

The terminal sub-phase is typically characterized by moderate to high traffic densities, converging routes and transitions in flight altitudes. Narrow route widths are required. Independent surveillance is generally available to assist in ground monitoring of aircraft position.

- o Remote Areas

Remote areas are special geographic or environmental areas characterized by low-traffic density and terrain where it has been difficult to cost-effectively implement comprehensive navigation coverage. Typical of remote areas are mountainous terrain, offshore areas, and large portions of the state of Alaska.

- o Operations Between Ground Level and 5000 feet Above Ground Level (AGL)

This sub-phase is characterized by en route flights between ground level and 5,000 feet AGL. Most rotorcraft operations are conducted in this sub-phase as well as some fixed wing operations. This sub-phase typically has limited communication, navigation, and surveillance service because radio signals are easily blocked by terrain and buildings. Traffic density is increasing which may require Air Traffic Control (ATC) services and structure.

### 2.3.2 Marine

Marine navigation in the U.S. consists of five distinct phases, identified as ocean, coastal, harbor approach, harbor, and inland waterway navigation. Standards or requirements for safety of navigation and reasonable economic efficiency can be developed around these five phases. Specialized requirements, which may be generated by the specific activity of a ship, must be addressed separately.

#### A. Ocean Navigation

Ocean navigation is that phase in which a ship is beyond the Continental Shelf (200-meter depth), and more than 50 nm from land, in waters where position fixing by visual reference to land or to fixed or floating aids to navigation is not practical. Ocean navigation is sufficiently far from land masses so that the hazards of shallow water and of collision are comparatively small.

#### B. Coastal Navigation

Coastal navigation is that phase in which a ship is within 50 nm from shore or the limit of the Continental Shelf (200-meter depth), whichever is greater, where a safe path of water at least one mile wide, if a one-way path, or two miles wide, if a two-way path, is available. In this phase, a ship is in waters contiguous to major land masses or island groups where transoceanic traffic patterns tend to converge in approaching destination areas; where interport traffic exists in patterns that are essentially parallel to coastlines; and within which ships of lesser range usually confine their operations. Traffic-routing systems and scientific or industrial activity on the Continental Shelf are encountered frequently in this phase of navigation. Ships on the open waters of the Great Lakes also are considered to be in the coastal phase of navigation.

The boundary between coastal and ocean navigation is defined by one of the following which is farthest from land:

- o 50 miles from land
- o The outer limit of offshore shoals, or other hazards on the Continental Shelf
- o Other waters where traffic separation schemes have been established, and where requirements for the accuracy of navigation are thereby made more rigid than the safety requirements for ocean navigation.

### C. Harbor and Harbor Approach

Harbor and harbor approach navigation are conducted, in general terms, in waters inland from those of the coastal phase. For a ship entering from the sea or the open waters of the Great Lakes, the harbor approach phase begins generally with a transition zone between the relatively unrestricted waters where the navigational requirements of coastal navigation apply, and narrowly restricted waters near and/or within the entrance to a bay, river, or harbor, where the navigator enters the harbor phase of navigation. Usually the harbor phase requires navigation of a well defined channel which, at the seaward end, is typically from 180 to 600 meters in width if it is used by large ships, but may narrow to as little as 120 meters farther inland. Channels used by smaller craft may be as narrow as 30 meters.

From the viewpoint of establishing standards or requirements for safety of navigation and promotion of economic efficiency, there is some generic commonality between the harbor approach and harbor phases. In each case, the nature of the waterway, the physical characteristics of the vessel, the need for frequent maneuvering of the vessel to avoid collision, and the closer proximity to grounding danger impose more stringent requirements for accuracy and for real-time guidance information than for the coastal phase. For analytical purposes, the phases of harbor approach and harbor navigation are built around the problems of precise navigation of large seagoing and Great Lakes ships in narrow channels between the transition zone and the intended mooring.

### D. Inland Waterways

Inland waterway navigation is conducted in restricted areas similar to those for harbors or harbor approaches. However, in the inland waterway case, the focus is on non-seagoing ships and their requirements on long voyages in restricted waterways, typified by tows and barges in the U.S. Western Rivers System and the U.S. Intracoastal Waterway System.

In some areas, seagoing craft in the harbor phase of navigation and inland craft in the inland waterway phase share the use of the same restricted waterway. The distinction between the two phases depends primarily on the type of craft. It is made because seagoing ships and typical craft used in inland commerce have differences in physical characteristics, manning, and equipment. These differences have a significant impact upon their requirements for aids to navigation. Recreational and other relatively small craft are found in large numbers in waters used by both seagoing and inland commercial traffic and generally have less rigid requirements in either case.

#### 2.3.3 Land

In-vehicle land navigation applications using radionavigation systems are still in development. It appears that more extensive use of land navigation systems may come about as the result of systems with digitized map displays. These are being developed by industry for automobiles and commercial vehicles. Land navigation could also take the form of a portable radionavigation receiver used by a person traversing remote areas on foot. In comparison with the air and marine communities, there are no well-defined phases of land navigation, and no attempt will be made to define any phases until user requirements are more precisely known.

#### 2.3.4 Space

For earth-orbiting space activities, the mission phases can be generally categorized as launch phase, in-flight/in-orbit phase, and reentry and landing phase.

##### A. Launch Phase

This phase is defined as that portion of the mission from the point at which the Space Shuttle or expendable launch vehicle leaves the launch pad to the point wherein the Space Shuttle (or the payload launched by the expendable launch vehicle) is inserted into earth orbit.

##### B. In-Flight/In-Orbit Phase

This is the phase wherein key operations or data gathering from an experiment to meet the primary mission objectives is performed. During this phase, the Space Shuttle may deploy a satellite, perform positional maneuvers in support of onboard experiments, or retrieve a satellite for return to earth. This phase essentially ends when the Space Shuttle initiates de-orbit maneuvers. In this phase, free-flying spacecraft perform their experiments and/or operations in their required orbits. In those cases where the spacecraft will not be returned to earth, this operational phase continues until such time as the spacecraft is shut down or can no longer perform its functions. For those spacecraft to be returned to earth, this phase essentially ends when the spacecraft is retrieved by the Space Shuttle.

##### C. Reentry and Landing Phase

This phase begins when the Space Shuttle, possibly with onboard experiments and/or a retrieved spacecraft in the payload bay, initiates de-orbit maneuvers. The Space Shuttle goes through atmospheric entry and makes an unpowered landing. This phase ends when the Space Shuttle comes to a full stop.

#### 2.3.5 Applications Other than Navigation

Use of radionavigation systems for functions other than navigation is rapidly increasing. While there may be many diverse uses, the majority fall into the following categories:

- o Radiolocation in the form of surveying and site registration: Noting the location of a place or event for record purposes, or to return to it at a later time.
- o Radiolocation in the form of Automatic Vehicle Monitoring/Location (AVM/AVL): Utilizing radionavigation systems to track or locate vehicles.
- o Time/Frequency Dissemination: Using radionavigation system signals to accurately time non-associated electronic systems.

## 2.4 CIVIL AIR RADIONAVIGATION REQUIREMENTS

Aircraft navigation is the process of conducting aircraft from one place to another and includes position determination, establishment of course and distance to the desired destination, and determination of deviation from the desired track. Requirements for navigational performance are dictated by the phase of flight operations and their relationship to terrain, to other aircraft, and to the air traffic control process. Aircraft navigation may be achieved through the use of visual procedures during Visual Flight Rules (VFR) operations but requires use of electronic or other non-visual aids under low-visibility conditions and above FL 180.

Aircraft separation criteria, established by the Federal Aviation Administration (FAA), take into account limitations of the navigational service available, and in some airspace, the Air Traffic Control (ATC) surveillance service. Aircraft separation criteria are influenced by the quality of navigational service, but are strongly affected by other factors as well. The criteria relative to separation require a high degree of confidence that an aircraft will remain within its assigned volume of airspace. The dimensions of the volume are determined by a stipulated probability that performance of the navigational system will not exceed a specified error.

Since navigation is but one function performed by the pilot, the workload for navigation in conjunction with communications, flight control, and engine monitoring must be small enough so that the pilot has time to see adequately and avoid other aircraft when operating using see-and-avoid rules.

### 2.4.1 Aviation Requirements

The following are basic requirements for the current and future aviation navigation system. The words "navigation system" mean all of the elements to provide the necessary navigation services to each phase of flight. While navigation systems are expected to be able to meet these requirements, implementation of specific capabilities is to be determined by the users, and where appropriate, regulatory authorities.

No single set of navigational and operational requirements, even though they meet the basic requirement for safety, can adequately reflect the many different combinations of operating conditions encountered in various parts of the world, in that the requirements applicable to the most exacting region may be extravagant when applied to others.

- A. The navigation system must be suitable for use in all aircraft types which may require the service without limiting the performance characteristics or utility of those aircraft types; e.g., maneuverability and fuel economy.
- B. The navigation system must be safe, reliable, available and appropriate elements must be capable of providing service over all the used airspace of the world, regardless of time, weather, terrain and propagation anomalies.

- C. The integrity of the navigation system, including the presentation of information in the cockpit, shall be as near 100 percent as is achievable and, to the extent feasible, should provide flight deck warnings in the event of failure, malfunction, or interruption.
- D. The navigation system must have a capability of recovering from a temporary loss of signal in such a manner that the correct current position will be indicated without the need for complete resetting.
- E. The navigation system must automatically present to the pilot adequate warning in case of malfunctioning of either the airborne or source element of the system, and assure ready identification of erroneous information which may result from a malfunctioning of the whole system or from incorrect setting.
- F. The navigation system must provide in itself maximum practicable protection against the possibility of input blunder, incorrect setting, or misinterpretation of output data.
- G. The navigation system must provide adequate means for the pilot to check the accuracy of airborne equipment.
- H. The navigation systems must provide information indications which automatically and radically change the character of its indication in case a divergence from accuracy occurs outside safe tolerance.
- I. The navigation system signal source element must provide timely and positive indication of malfunction.
- J. The navigational information provided by the systems must be free from unresolved ambiguities of operational significance.
- K. Any source-referenced element of the total navigation systems shall be capable of providing operationally acceptable navigational information simultaneously and instantaneously to all aircraft which require it within the area of coverage.
- L. In conjunction with other flight instruments, the navigation system must in all circumstances provide information to the pilot and aircraft systems for performance of the following functions:
  - o Continuous tracking guidance
  - o Continuous determination of distance along track
  - o Continuous determination of position of aircraft
  - o Position reporting
  - o Manual or automatic flight

The information (signals) provided by the navigation system must permit the design of indicators and controls which can be directly interpreted or operated by the pilot at his normal station aboard the aircraft.

- M. The navigation system must be capable of being integrated into the overall ATC (communications, surveillance and navigation) system.
- N. The navigation system should be capable of integration with all phases of flight, including the precision approach and landing system. It should provide for transition from long range (overwater) flight to short range (domestic) flight with minimum impact on cockpit procedure/displays and workload.
- O. The navigation system must permit the pilot to determine the position of the aircraft with an accuracy and frequency that will (a) ensure that the separation minima used can be maintained at all times, (b) execute properly the required holding and approach patterns, and (c) maintain the aircraft within the area allotted to the procedures.
- P. The navigation system must permit the establishment and the servicing of any practical defined system of routes for the appropriate phases of flight.
- Q. The system must have sufficient flexibility to permit changes to be made to the system of routes and siting of holding patterns without imposing unreasonable inconvenience or cost to the providers and the users of the system.
- R. The navigation system must be capable of providing the information necessary to permit maximum utilization of airports and airspace.
- S. The navigation system must be cost-effective to both the Government and the users.
- T. The navigation system must employ equipment to minimize susceptibility to interference from adjacent radio-electronic equipment and shall not cause objectionable interference to any associated or adjacent radio-electronic equipment installation in aircraft or on the ground.
- U. The navigation system must be free from signal fades or other propagation anomalies within the operating area.
- V. The navigation system avionics must be comprised of the minimum number of elements which are simple enough to meet, economically and practically, the most elementary requirements, yet be capable of meeting, by the addition of suitable elements, the most complex requirements.
- W. The navigation system must be capable of furnishing reduced service to aircraft with limited or partially inoperative equipment.
- X. The navigation system must be capable of integration with the flight control system of the aircraft to provide automatic tracking.
- Y. The navigation system must be able to provide indication of a failure or out-of-tolerance condition of the system within ten seconds of occurrence during a non-precision approach.

## 2.4.2 Navigation Signal Error Characteristics

The unique signal characteristics of a navigation system have a direct effect on determining minimum route widths. The distribution and rate of change, as well as magnitude of the errors, must be considered. Error distributions may contain both bias and random components. The bias component is generally easily compensated for when its characteristics are constant and known. For example, VOR radials can be flight-checked and the bias error reduced or eliminated through correction of the radial used on aeronautical charts.

The Loran-C and Omega seasonal and diurnal variations can also be compensated for by implementing correction algorithms in aircraft equipment logic and by publishing corrections periodically for use in air equipment.

The distribution of the random or non-predictable varying error component becomes the critical element to be considered in the design of navigation systems. For any selected route width and system accuracy, those systems which have a broad error distribution tend to produce a higher risk of collision than those with a narrow distribution. The rate of change of the error within the distribution is also an important factor, especially when the system is used for approach and landing.

Errors varying at a very high frequency can be readily integrated or filtered out in the aircraft equipment. Errors occurring at a slower rate can, however, be troublesome and result in disconcerting indications to the pilot. An example of one of these would be a "scalped" VOR signal that causes the Course Deviation Indicator (CDI) to vary. If the pilot attempts to follow the CDI closely, the plane will start to "S" turn frequently. The maneuvering will cause unnecessary pilot workload and degrade pilot confidence in the navigation system. This indication can be further aggravated if navigation systems exhibit different error characteristics during different phases of flight or when the aircraft is maneuvering. The method of determining the total system error is affected by the navigation signal error characteristics. In most current systems the error components are ground system errors, airborne receiver errors, and flight technical errors. These errors are combined using the Root-Sum-Square (RSS) method. In analyzing new systems, it may be necessary to utilize alternative methods of combining errors, but each element must be properly considered.

In summary, the magnitude, nature, and distribution of errors as a function of time, terrain, aircraft type, aircraft maneuvers, and other factors must be considered. The evaluation of errors is a complex process, and the comparison of systems based upon a single error number will be misleading.

## 2.5 CURRENT AVIATION NAVIGATION REQUIREMENTS

### 2.5.1 En Route/Terminal Phase

The en route/terminal phase of air navigation (as defined in Section 2.3) includes the following subphases:

- o Oceanic En Route

- o Domestic En Route
- o Terminal
- o Remote Area
- o Operations Between Ground Level and 5,000 feet AGL

The general requirements in Section 2.4 are applicable to the en route/terminal phase of navigation. In addition, to facilitate aircraft operations in this phase, the system must be capable of being operationally integrated with the system used for approach and landing.

Federal Aviation Regulations (FAR) paragraphs 91.109 and 91.121 specify the vertical separation required below and above Flight Level (FL) 290. The current separation requirement is 1,000 feet below FL 290, and 2,000 feet at and above FL 290. In order to justify the 1,000 foot vertical separation below FL 290, the RSS altitude keeping requirement is  $\pm 350$  feet (3 sigma). This error is comprised of  $\pm 250$  feet (3 sigma) aircraft altimetry system error, of which the altimeter error is limited to  $\pm 125$  feet by Technical Standard Order (TSO) C-10B below Flight Level 290.

The minimum performance criteria currently established to meet requirements for the en route/terminal phase of navigation are presented in the following sections.

#### A. Oceanic En Route

The system must provide navigational capability commensurate with the need in specific areas in order to permit safe navigation and the application of lateral separation criteria. An organized track system has been implemented in the North Atlantic to gain the benefit of optimum meteorological conditions. Since an independent surveillance system such as radar is not available, separation is maintained by procedural means; i.e., position reports and timing.

A 60 nm lateral separation standard has gone into effect on the North Atlantic organized track system. The following system performance is required to achieve this separation:

- o The standard deviation of the lateral track errors shall be less than 6.3 nm, 1 sigma (12.6 nm, 2 sigma).
- o The proportion of the total flight time spent by aircraft 30 nm or more off track shall be less than  $5.3 \times 10^{-4}$ ; i.e., less than 1 hour in about 2000 flight hours.
- o The proportion of the total flight time spent by aircraft between 50 nm and 70 nm off track shall be less than  $1.3 \times 10^{-4}$ ; i.e., approximately 1 hour in about 8000 flight hours.

B. Domestic En Route

Domestic air routes are designed to provide as nearly direct airways as practical between city pairs that have significant air traffic. For altitudes below FL 180 (18,000 feet), the airways are defined as 8 nm in width out to 51 nm from the VOR facility. Beyond 51 nm the airway increases uniformly in width on either side of the centerline  $\pm 4.5$  degrees, with the apex of the angle at the VOR facility.

For altitudes above FL 180, the airways consist of jet routes which have the same protected airspace as the low-altitude structure except the VOR stations may be spaced farther apart and the route width may be as large as 20 nm.

Current accuracy requirements for domestic en route navigation are based on the characteristics of the VOR/DME/VORTAC system and therefore relate to the angular characteristics of the VOR and TACAN azimuth systems and range characteristics of the DME/TACAN range systems. "System Use Accuracy," as defined by ICAO, is the RSS of the ground station error contribution, the airborne receiver error, the display system contribution and the Flight Technical Error (FTE). Flight Technical Error is the contribution of the pilot (or autopilot) in using the presented information to control aircraft position. Error values on which the current system is based are as follows:

1. Azimuth Accuracy in Degrees:

<u>ERROR COMPONENT</u>	<u>2 SIGMA DEVIATION VALUES</u>	<u>SOURCE</u>
VOR Ground	$\pm 1.4^{\circ}$	Semi-Automatic Flight Inspection (SAFI) System
VOR Air	$\pm 3.0^{\circ}$	Equipment Manufacturer
Course Selection (CSE)	$\pm 2.0^{\circ}$	FAA Tests
Flight Technical (FTE)	$\pm 2.3^{\circ}$	FAA Tests
<hr/>		
System Use Accuracy Error (95% Confidence)	$\pm 4.5^{\circ}$	(RSS derived)

## 2. Range Accuracy

Where DME service is used, the system use accuracy is defined as  $\pm 0.5$  nm or 3 percent of distance (2 sigma), whichever is greater. This value covers all existing DME avionics. When DME is used with an RNAV system the range accuracy must be at least  $\pm 0.2$  nm plus 1 percent of the distance (2 sigma).

## 3. Area Navigation (RNAV)

When RNAV computation equipment is used, an additional error contribution is specified and combined in RSS fashion with the basic VOR/DME system error. The additional maximum RNAV equipment error allowed, per FAA Advisory Circular AC 90-45A, is  $\pm 0.5$  nm. RNAV system performance and route design are based on the following error budget:

<u>ERROR COMPONENT</u>	<u>2 SIGMA DEVIATION VALUES</u>	<u>SOURCE</u>
VOR Ground	$\pm 1.4^\circ$	SAFI
VOR Air	$\pm 3.0^\circ$	Equipment Manufacturer and FAA Tests
DME Ground	$\pm 0.1$ nm	SAFI

The VOR/DME and RNAV error values identified below result in 95 percent of the aircraft remaining within  $\pm 4$  nm of the airway centerline out to 51 nm from a VOR facility and within  $\pm 4.5$  degrees (originating at the VOR facility) of the airway centerline when beyond 51 nm from a VOR facility.

<u>ERROR COMPONENT</u>	<u>2 SIGMA DEVIATION VALUES</u>	<u>SOURCE</u>
DME Air	$\pm 0.2$ nm + 1% of Range	Equipment Manufacturer*
FTE	$\pm 1.0$ nm	FAA Tests**
CSE	$\pm 2.0^\circ$	FAA Tests
RNAV System	$\pm 0.5$ nm	Equipment Manufacturer and FAA Tests

\*Only DME aircraft equipment with this accuracy or better is used.

\*\*FTE-0.5 nm in the approach phase.

### C. Terminal

Terminal routes are transitions from the en route phase to the approach phase. The accuracy capability of navigation systems using the VOR/DME in terms of bearing and distance to the facility is defined in the same manner as described for en route navigation. However, the usually closer proximity to facilities provides greater effective system use accuracy, since both VOR and FTE are angular in nature and are related to the distance to the facility. The DME distance error is also reduced, since it is proportional to distance from the facility, down to the minimum error capability. Thus the minimum terminal route width is  $\pm 2$  nm within 25 nm of the facility, based on RSS combination of error elements.

### D. Remote Areas

Remote areas are defined as regions which do not meet the requirements for installation of VOR/DME service or where it is impractical to install this system. These include offshore areas, mountainous areas and a large portion of the State of Alaska. Thus the minimum route width varies and can be greater than  $\pm 10$  nm. The minimum requirements are shown in Table 2-1.

### E. Operations Between Ground Level and 5,000 feet AGL

Operations between ground level and below 5,000 feet AGL occur in offshore, mountainous, and high density metropolitan areas as well as on domestic routes. For operations from U.S. coastline to offshore points, the following requirements must be met:

- o Range from shore to 300 nm
- o Minimum en route altitude of 500 feet above sea level or above obstructions
- o Accuracy adequate to support routes  $\pm 4$  nm wide or narrower with 95 percent confidence
- o Minimum descent altitude to 100 feet in designated areas.

For helicopter operations over land, the following requirements must be met:

- o Accuracy adequate to support  $\pm 2$  nm route widths in both en route and terminal areas with 95 percent confidence
- o Minimum en route altitudes of 1,200 feet
- o Navigational signal coverage adequate to support approach procedures to minimums of 250 feet above obstruction altitudes at heliports and airports.

#### 2.5.2 Approach/Landing Phase

This phase of flight is one of two types: (1) non-precision approach, or (2) precision approach and landing.

The general requirements of Section 2.4 apply to the approach/landing phase. In addition, specific procedures and clearance zone requirements are specified in

**TABLE 2-1. CONTROLLED AIRSPACE AVIATION NAVIGATION ACCURACY TO MEET CURRENT REQUIREMENTS**

PHASE	SUB-PHASE	ALTITUDE (Flight Level)	TRAFFIC DENSITY	ROUTE WIDTH (nm)	SOURCE ACCURACY 2drms (Meters)	SYSTEM USE ACCURACY 2drms (Meters)
EN ROUTE/ TERMINAL	Oceanic	FL 275 to 400	Normal	60	N/A	12.6nm*
	Domestic	FL 180 to 600	Low	16	2,000	7,200
			Normal	8	1,000	3,600
	Terminal	500 to FL 180	High	8	1,000	3,600
			High	4	500	1,800
	Remote	500 to FL 600	Low	8 to 20	1,000 to 4,000	3,600 to 14,400
	Special helicopter operations	500 to 5,000 ft	Low (off-shore)	Not determined	1,000 to 2,000	3,600 to 7,200
		500 to 3,000 ft	High (land)	4	500	1,800
	Non-precision	250 to 3,000 ft above surface	Normal	N/A	100	150
			Normal	N/A	± 17.1 **    ± 4.1 ***	N/A
APPROACH AND LANDING	CAT I	N/A	Normal	N/A	CAT I Decision Height Point ****	N/A
					± 5.2 **    ± 1.7 ***	N/A
	Precision	N/A	Normal	N/A	CAT II Decision Height Point ****	N/A
					± 4.0 **    ± 0.6 ***	N/A
CAT III	N/A	Normal	N/A	At Runway Threshold ****	N/A	

\* The distribution of this error is detailed in the "Report of the Limited North Atlantic Regional Air Navigation Meeting," dated 1976; ICAO Montreal, Canada.

\*\* Lateral position ground equipment (2 sigma) accuracy in meters for Precision Approach and Landing.

\*\*\* Vertical position ground equipment (2 sigma) accuracy in meters for Precision Approach and Landing.

\*\*\*\* Assumes a 3° glideslope and 8,000 ft distance between runway threshold and localizer antenna.

TERPS (United States Standard for Terminal Instrument Procedures, FAA Handbook 8260.3B).

Altimetry accuracy requirements are established in accordance with FAR 91.170 and are the same as those for the en route/terminal phase.

The minimum performance criteria currently established to meet requirements for the approach/landing phase of navigation vary between precision and non-precision approaches.

#### A. Non-Precision Approach

Non-precision approaches are based on any navigational system that meets the criteria established in TERPS. Minimum safe altitude, obstacle clearance area, visibility minimum, final approach segment area, etc., are all functions of the navigational accuracy available and other factors. The unique features of Area Navigation (RNAV) for non-precision approaches are specified in FAA Advisory Circulars No. 90-45A, "Approval of Area Navigation Systems for Use in the U.S. National Airspace System"; No. 20-130, "Airworthiness Approval of Multi-Sensor Navigation Systems in U.S. National Airspace System (NAS) and Alaska"; and 20-121A, "Airworthiness Approval of the LORAN-C Navigation System for Use in U.S. National Airspace (NAS) and Alaska".

While the achieved capability for non-precision approaches varies widely, depending on the location of the navigational facility in relation to the fix location and type of navigational system, approximately 30 percent of the non-precision approach fixes based on VOR in the U.S. achieve a cross track navigational accuracy of  $\pm 100$  meters (2 sigma) at the missed approach point (MAP). This accuracy is based upon the  $\pm 4.5$  degrees VOR system use accuracy and the MAP being less than 0.7 nm from the VOR facility.

Currently the integrity requirement for non-precision approaches is to provide the pilot with either a warning or a removal of signal within ten seconds of the occurrence of an out-of-tolerance condition.

#### B. Precision Approach and Landing

Precision approach and landing radio aids provide vertical and horizontal guidance and position information. The Instrument Landing System (ILS) and Microwave Landing System (MLS) are of this type. International agreements have been made to achieve an all-weather landing capability through an evolutionary process, reducing landing weather minima on a step-by-step basis as technical capabilities and operational knowledge permit. The performance objectives for the various landing categories are as shown in Table 2-1.

The MLS and ILS system integrities, during precision approaches, warn the pilot of an out-of-tolerance condition by removing these signals from service. The response time for providing these warnings vary from 10 seconds (ILS localizer - Category 1) to 1 second (MLS) depending on the system and category of operation.

#### C. Current System Requirements Summary

The system use accuracy criteria to meet the current route requirements are summarized in Table 2-1. These route widths are based upon present capacities, separation requirements, and obstruction clearance requirements.

## 2.6 FUTURE AVIATION RADIONAVIGATION REQUIREMENTS

Altimetry requirements for vertical separation of 1,000 feet, below FL 290, are not expected to change. Increased altimetry accuracy is needed at and above FL 290 to permit 1,000 feet separation. The required future 3 sigma value of the aircraft altimetry system error has not been specified, but it must be accurate enough to support the 1,000 feet vertical separation at all flight levels.

### 2.6.1 En Route/Terminal Phase

#### A. Oceanic

Lateral separation specifications have been designed to allow a lateral separation of 60 nm. This was put into effect for certain areas of the North Atlantic in early 1981. The 60 nm separation requires a lateral track error of less than  $\pm 12.6$  nm (2 sigma). Further lateral separation reductions are desirable.

#### B. Domestic En Route

At the present time, the number of VOR/DMEs is sufficient to allow most routes to have widths of  $\pm 4$  nm. This is possible as most VOR facilities are spaced less than 100 nm apart on the route. However, greater spacings are used in low traffic density areas, remote areas, and on most of the high-altitude route structure. Parts of the high-altitude route structure have a distance between VOR facilities resulting in route widths up to 20 nm.

Traffic increases are causing route capacity problems. More use of RNAV will allow the implementation of random and parallel routes than with the use of current VOR/DME facilities. No increase in VOR/DME ground accuracy is required to meet the navigational requirements imposed by the air traffic levels estimated for the Year 2000. The current nominal VOR system signal-in-space accuracy that permits 8 nm route widths is  $\pm 1,000$  meters (2 drms). Any replacement system must have an equivalent accuracy.

#### C. Terminal

The major change forecasted for the terminal area is the increased use of RNAV and time control to achieve optimum runway utilization and noise abatement procedures. Some current multi-DME RNAV and VOR avionics can provide system use RSS cross track navigational accuracies better than  $\pm 500$  meters (2 sigma) in terminal areas using the current VOR/DME facilities. A  $\pm 500$  meter (2 sigma) cross track navigational accuracy is expected to meet the terminal requirements through the Year 2000.

#### D. Remote Areas

Many areas, such as Alaska, the Rocky Mountains and other mountainous areas, and some offshore locations, cannot be served easily or at all by VOR/DME. Presently, Non-Directional Beacon (NDB), OMEGA, and privately-owned systems such as TACAN are being used in combination to meet the user navigational needs in these areas. OMEGA and LORAN-C are being used as supplements to VOR/DME to meet

these needs. The accuracy and coverage of these systems seem adequate to handle the traffic densities projected for the different areas. For all-weather operations, a system signal in space accuracy of 4,000 meters (2 drms) is proposed, with 1,000 meters (2 drms) or higher accuracy in specific areas.

#### E. Low Altitude Operations

Both offshore and onshore low-altitude operations will have navigational requirements at least as stringent as those shown on page 2-14, paragraph E, and coverage extended from 300 nm to 500 nm from shore. Area navigation should be implemented for low traffic density operations. As traffic density increases, the establishment of low altitude routes may be necessary. Operations in metropolitan areas will require integration of the enroute/terminal phase with non-precision and precision approaches.

#### 2.6.2 Approach/Landing Phase

##### A. Non-Precision Approach

Changes in navigational requirements for non-precision approaches are expected due to new and/or modified noise abatement procedures and encroachment on obstacle clearance zones by urban development.

The current estimate of the future requirements for the non-precision approach navigation system accuracy of 100 meters (2drms) is that it be able to perform as well as an on-airport VOR. This requirement has been selected for the following reasons:

- o Approximately 30 percent of the runways with non-precision approaches use on-airport VOR.
- o These are typically used at the busiest airports. Since they are in urban areas, they have had the most pressure for reduction of clearance areas for additional noise abatement and obstacle encroachment problems.
- o Any replacement navigation system must satisfy operational requirements of the function it performs for applicable phases of flight at least as well in all navigational phases as the system it is replacing.

The critical factor in the final approach segment of a non-precision approach is the size of the obstacle clearance area. The basic VOR obstacle clearance area is a trapezoid beginning at the facility with a width of two nautical miles (nm) ( $\pm 1$  nm each side of the facility) and expanding linearly to a width of five nm ( $\pm 2.5$  nm each side of course) at a distance of 30 nm. A triangular secondary area is attached to each side of the trapezoid. The apex of the secondary area is at the end of the trapezoid nearest the facility and the area expands to a width of 1 nm at 30 nm. This is illustrated in Figure 2-1.

The  $\pm 100$  m (2 sigma) system accuracy requirement is based on the VOR system accuracy at a distance of 0.7 nm from the VOR. Current RNAV equipments cannot meet this requirement; however, it seems feasible to provide improved RNAV systems that can meet this requirement.

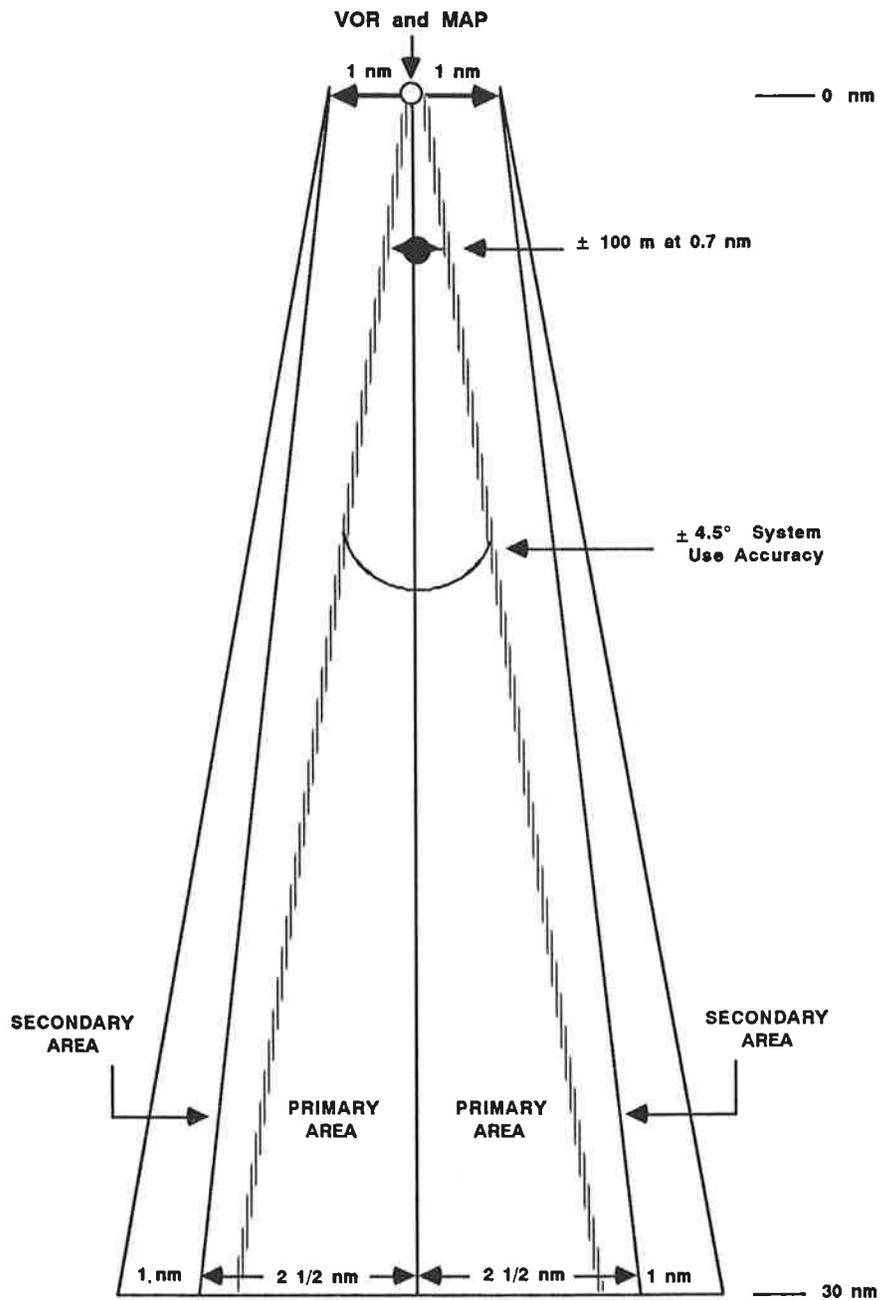


FIGURE 2-1. NON-PRECISION APPROACH OBSTACLE CLEARANCE AREA FOR CURRENT VOR WITH MAP AT VOR FACILITY

VORs also meet the integrity criteria for non-precision approaches by warning the pilot of an out-of-tolerance condition through the removal of the signal from service within ten seconds after the condition begins. This is not intended to exclude methods meeting the ten-second criteria with other systems.

## B. Precision Approach and Landing

The requirements for precision approaches and landings are not expected to change by the Year 2020 and are presented in Table 2-2.

In order to enhance all-weather operations, a uniform guidance accuracy requirement is proposed as follows:

### Accuracy (2 sigma) at the Approach Reference Datum

Lateral	$\pm 13.0$ feet ( $\pm 4.0$ meters)
Vertical	$\pm 2.0$ feet ( $\pm 0.6$ meters)

### 2.6.3 Future System Performance Requirements Summary

Table 2-2 represents the best estimate of future minimum accuracy and route criteria to meet the aviation navigational requirements up to the Year 2000.

The effectiveness of meeting one or more of these requirements with a combination of subsystems and alternatively with a minimum number of subsystems should be assessed and fully coordinated among Government agencies and users.

Due consideration should be given to the situation that not all users need all services. Pending the results of this assessment there is no compelling argument from the aviation user's standpoint for a single source of navigation information.

The life-cycle costs of each subsystem to the Government and each category of user must be an important element of this continuing assessment.

## 2.7 CIVIL MARINE RADIONAVIGATION REQUIREMENTS

The navigational requirements of a vessel depend upon its general type and size, the activity in which the ship is engaged (e.g., point-to-point transit, fishing) and the geographic region in which it operates (e.g., ocean, coastal), as well as other factors. Safety requirements for navigation performance are dictated by the physical constraints imposed by the environment and the vessel, and the need to avoid the hazards of collision, ramming, and grounding.

The foregoing discussion of phases of marine navigation sets the framework for defining safety of navigation requirements. However, the economic and operational dimensions also need to be considered for the wide diversity of vessels that traverse the oceans and U.S. waters. For example, accurate worldwide navigation (beyond that needed for safety) is important particularly to the economy of large seagoing ships having high hourly operating costs. For fishing and oil exploration vessels, the ability to locate precisely and return to productive or promising areas

**TABLE 2-2. CONTROLLED AIRSPACE AVIATION NAVIGATION ACCURACY TO MEET PROJECTED FUTURE REQUIREMENTS**

PHASE	SUB-PHASE	ALTITUDE (Flight Level)	TRAFFIC DENSITY	ROUTE WIDTH (nm)	SOURCE ACCURACY 2 drms (Meters)	SYSTEM USE ACCURACY 2 drms (Meters)
EN ROUTE/ TERMINAL	Oceanic	FL 275 to 400	Normal	Less than 60	N/A	Better than 12.6nm*
	Domestic	FL 180 to 600	Normal	8	1,000	3,600
			High	8	1,000	3,600
	Terminal	500 ft to FL 180	Normal	8	1,000	3,600
			High	4	500	1,800
			Normal	8 to 20	1,000 to 4,000	3,600 to 14,400
	Remote	500 ft to FL 600	Normal	8	1,000	3,600
	Special helicopter operations	500 ft to 5,000 ft	Low (off-shore)	8	1,000	3,600
		500 ft to 3,000 ft	High (land)	4	500	1,800
	APPROACH AND LANDING	Non-precision	250 to 3,000 ft above surface	Normal	N/A	100
Precision		At runway threshold	Normal	N/A	± 4.0** ± 0.6***	N/A

\* The distribution of this error is detailed in the "Report of the Limited North Atlantic Regional Air Navigation Meeting," dated 1976; ICAO Montreal, Canada.

\*\* This value is the ground equipment (2 sigma) azimuth accuracy in meters at the approach reference datum.

\*\*\* This value is the ground equipment (2 sigma) elevation accuracy in meters at the approach reference datum.

and avoid underwater obstructions provides important economic benefits. Search and Rescue (SAR) effectiveness is similarly dependent on accurate navigation in the vicinity of a maritime distress incident.

For purposes of system planning, the Government seeks to satisfy minimum safety requirements for each phase of navigation and to maximize the economic utility of the service for users. Since the vast majority of marine users are not required to carry any navigational equipment, and will do so only if persuaded by individual cost/benefit analysis, this Governmental policy helps to promote maritime safety through a simultaneous economic incentive.

Tables 2-3, 2-4 and 2-5 identify system performance needed to satisfy current maritime user requirements or to achieve special benefits in four of the five phases of marine navigation. The tables are divided into two categories. The upper half are those related to safety of navigation. The Government recognizes an obligation to satisfy these requirements for the overall national interest. The lower half are specialized requirements or characteristics needed to provide special benefits to discrete classes of maritime users (and additional public benefits which may accrue from services provided by users). The Government does not recognize an absolute commitment to satisfy these requirements, but does endeavor to meet them if their cost can be justified by benefits which are in the national interest. For the purpose of comparing the performance of systems, the requirements are categorized in terms of system performance characteristics representing the minimum performance considered necessary to satisfy the requirements or achieve special benefits.

## 2.8 OCEAN PHASE

The requirements for safety of navigation in the ocean phase for all ships are given in Table 2-3. These requirements must provide the Master with a capability to avoid hazards in the ocean (e.g., small islands, reefs) and to plan correctly the approach to land or restricted waters. For many operational purposes, repeatability is necessary to locate and return safely to the vicinity of a maritime distress, as well as for special activities such as hydrography, research, etc. Economic efficiency in safe transit of open ocean areas depends upon the continuous availability of accurate position fixes to enable the vessel to follow the shortest safe route with precision, minimizing transit time.

### 2.8.1 Requirements

For safe general navigation under normal circumstances, the requirements for the accuracy and frequency of position fixing on the high seas are not very strict. As a minimum, these requirements include a predictable accuracy of 2 to 4 nm coupled with a maximum fix interval of two hours or less. These minimum requirements would permit reasonably safe oceanic navigation, provided that the navigator understands and makes allowances for the probable error in navigation, and provided that more accurate navigational service is available as land is approached. While these minimum requirements would permit all vessels to navigate with relative safety on the high seas, more desirable requirements would be predictable accuracy of 1 to 2 nm and a fix interval of 15 minutes or less. The navigation signal should be available 95 percent of the time. Further, in any 12-hour period, the probability of obtaining a fix from the system should be at least 0.99.

**TABLE 2-3. CURRENT MARITIME USER REQUIREMENTS/BENEFITS  
FOR PURPOSES OF SYSTEM PLANNING AND DEVELOPMENT - OCEAN PHASE**

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS										
	ACCURACY (2 drms)		REPEATABLE	RELATIVE	COVERAGE	AVAILABILITY	RELIABILITY	FIX INTERVAL	FIX DIMENSION	CAPACITY	AMBIGUITY
	PREDICTABLE	REPEATABLE									
SAFETY OF NAVIGATION - ALL CRAFT	2-4nm (3.7-7.4km) minimum 1-2nm (1.8-3.7km) Desirable	-	-	-	Worldwide	99% fix at least every 12 hours	**	15 minutes or less desired; 2 hours maximum	Two	Unlimited	Resolvable with 99.9% confidence

BENEFITS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO ACHIEVE BENEFITS											
	LARGE SHIPS MAXIMUM EFFICIENCY	RERESOURCE EXPLORATION	SEARCH OPERATIONS	REPEATABLE	RELATIVE	COVERAGE	AVAILABILITY	RELIABILITY	FIX INTERVAL	FIX DIMENSION	CAPACITY	AMBIGUITY
LARGE SHIPS MAXIMUM EFFICIENCY	0.1-0.25nm* (185-460m)	-	-	-	Worldwide, except Polar regions	99%	**	5 minutes	Two	Unlimited	Resolvable with 99.9% confidence	
RERESOURCE EXPLORATION	10-100m*	10-100m*	-	-	Worldwide	99%	**	1 minute	Two	Unlimited	Resolvable with 99.9% confidence	
SEARCH OPERATIONS	0.1-0.25nm (460m)	0.25nm	185m	-	National maritime SAR regions	99%	**	1 minute	Two	Unlimited	Resolvable with 99.9% confidence	

\* Based on stated user need.  
\*\* Dependent upon mission time.

**TABLE 2-4. CURRENT MARITIME USER REQUIREMENTS/BENEFITS  
FOR PURPOSES OF SYSTEM PLANNING AND DEVELOPMENT - COASTAL PHASE**

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS									
	ACCURACY (2 dirms)		COVERGE	AVAILABILITY	RELIABILITY	FIX INTERVAL	FIX DIMENSION	CAPACITY	AMBIGUITY	
	PREDICTABLE	REPEATABLE								RELATIVE
SAFETY OF NAVIGATION - ALL SHIPS	0.25nm (460m)	-	U.S. coastal waters	99.7%	**	2 minutes	Two	Unlimited	Resolvable with 99.9% confidence	
SAFETY OF NAVIGATION - RECREATION BOATS & OTHER SMALLER VESSELS	0.25nm-2nm (460-3,700m)	-	U.S. coastal waters	99%	**	5 minutes	Two	Unlimited	Resolvable with 99.9% confidence	

BENEFITS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO ACHIEVE BENEFITS									
	PREDICTABLE	REPEATABLE	RELATIVE	COVERGE	AVAILABILITY	RELIABILITY	FIX INTERVAL	FIX DIMENSION	CAPACITY	AMBIGUITY
COMMERCIAL FISHING (Including Commercial Sport Fishing)	0.25nm (460m)	50-600 ft (15-180m)	-	U.S. coastal/ fisheries areas	99%	**	1 minute	Two	Unlimited	Resolvable with 99.9% confidence
RESOURCE EXPLORATION	1.0-100m*	1.0-100m*	-	U.S. coastal areas	99%	**	1 second	Two	Unlimited	Resolvable with 99.9% confidence
SEARCH OPERATIONS, LAW ENFORCEMENT	0.25nm (460m)	300-600 ft (90-180m)	300 ft (90m)	U.S. coastal/ fisheries areas	99.7%	**	1 minute	Two	Unlimited	Resolvable with 99.9% confidence
RECREATIONAL SPORTS FISHING	0.25nm (460m)	100-600 ft (30-180m)	-	U.S. coastal areas	99%	**	5 minutes	Two	Unlimited	Resolvable with 99.9% confidence

\* Based on stated user need.

\*\* Dependent upon mission time.

**TABLE 2-5. CURRENT MARITIME USER REQUIREMENTS/BENEFITS  
FOR PURPOSES OF SYSTEM PLANNING AND DEVELOPMENT - HARBOR AND HARBOR APPROACH PHASES**

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS										
	ACCURACY (2 dirms)			RELATIVE	COVERAGE	AVAILABILITY	RELIABILITY	FIX INTERVAL	FIX DIMENSION	CAPACITY	AMBIGUITY
	PREDICTABLE	REPEATABLE	RELATIVE								
SAFETY OF NAVIGATION - LARGE SHIPS & TOWS	25-65 ft*** (8-20m)	-	-	U.S. harbors & harbor approaches	99.7%	**	6-10 seconds	Two	Unlimited	Resolvable with 99.9% confidence	
SAFETY OF NAVIGATION - SMALLER SHIPS	***	***		U.S. harbors & harbor approaches	99.7%	**	***	Two	Unlimited	Resolvable with 99.9% confidence	
RESOURCE EXPLORATION	1-5m*	1-5m*		U.S. harbors & harbor approaches	99%	**	1 second	Two	Unlimited	Resolvable with 99.9% confidence	

BENEFITS		MEASURES OF MINIMUM PERFORMANCE CRITERIA TO ACHIEVE BENEFITS									
FISHING, RECREATIONAL AND OTHER SMALL VESSELS	***	***	-	U.S. harbors & harbor approaches	99.7%	**	***	Two	Unlimited	Resolvable with 99.9% confidence	

\* Based on stated user need.  
 \*\* Dependent upon mission time.  
 \*\*\* Varies from one harbor to another.

Larger recreational craft and smaller commercial fishing vessels which sail beyond the range of coastal navigation systems require, for a reasonable level of safety, some means of establishing their position reliably at intervals of a few hours at most. Even more so than with larger ships, this capability is particularly important in time of emergency or distress. Many operators of these craft, however, will accept the risk of ocean sailing without reliable radionavigation unless that capability is available at relatively low cost.

### 2.8.2 Minimum Performance Criteria

Economic efficiency in trans-oceanic transportation, special maritime activities and safety in emergency situations require or benefit from navigational accuracy higher than that needed for safety in routine, point-to-point ocean voyages. These requirements are summarized in Table 2-3. The predictable accuracy requirements may be as stringent as 10 meters for special maritime activities, and may range to 0.25 nm for large, economically efficient vessels, including search operations. Search operations must also have a repeatable accuracy of at least 0.25 nm. As indicated in Table 2-3, the required fix interval may range from as low as once per five minutes to as high as once per minute. Signal availability must be at least 95 percent and approach 99 percent for all users. These requirements are based on current estimates and are to be used for the purposes of system planning. There has not been sufficient analysis to establish quantitative relationships between navigational accuracy and economic efficiency. The expensive, satellite-based navigation systems used by ships engaged in science and resource exploration, and the increasing use of relatively expensive satellite navigation by merchant ships and larger, ocean-going fishing vessels are evidence of the perceived value attached to highly accurate ocean navigation by the vessel owners.

## 2.9 COASTAL PHASE

There is need for continuous, all-weather radionavigation service in the coastal area to provide, at the least, the position fixing accuracy to satisfy minimum safety requirements for general navigation. These requirements are delineated in Table 2-4. Furthermore, the total navigational service in the coastal area must provide service of useful quality and be within the economic reach of all classes of mariners. It should be sufficient to assure that no boat or ship need be lost or endangered, or that the environment and public safety not be threatened, because a vessel could not navigate safely with reasonable economic efficiency.

### 2.9.1 Requirements

Requirements on the accuracy of position fixing for safety purposes in the coastal phase are established by:

- o The need for larger vessels to navigate within the designated one-way traffic lanes at the approaches to many major ports, in fairways established through offshore oil fields, and at safe distances from shallow water.
- o The need to define accurately, for purpose of observing and enforcing U.S. laws and international agreements, the boundaries of the Fishery Conservation Zone, the U.S. Customs Zone, and the territorial waters of the U.S.

## 2.9.2 Minimum Performance Criteria

Government studies have established that a navigation system providing a capability to fix position to an accuracy of 0.25 nm will satisfy the minimum safety requirements if a fix can be obtained at least every 15 minutes. As a secondary economic factor, it is required that relatively higher repeatable accuracy be recognized as a major advantage in the consideration of alternative candidate radionavigation systems for the coastal area. As indicated in Table 2-4, these requirements may be relaxed slightly for the recreational boat and other small vessels.

In such activities as marine scientific research, hydrographic surveying, commercial fishing, and petroleum or mineral exploration, as well as in Navy operations, there may be a need to establish position in the coastal area with much higher accuracy than that needed for safety of general navigation. In many of these special operations which require highly accurate positions, the use of radiodetermination would be classified as radiolocation rather than radionavigation. As shown in Table 2-4, the most rigid requirement of any of this general group of special operations is for seismic surveying with a repeatable accuracy on the order of 1 to 100 meters (2 drms), and a fix rate of once per second for most applications.

## 2.10 HARBOR AND HARBOR APPROACH PHASES

The pilot of a vessel in restricted waters must direct its movement with great accuracy and precision to avoid grounding in shallow water, and avoid collisions with other craft in congested waterways. Unable to turn around, and severely limited in the ability to stop to resolve a navigational problem, the pilot of the large vessel (or a tow boat and barge combination) may find it necessary to hold the total error in navigation within limits measured in a few feet while navigating in this environment. It would appear that a major step in maximizing the effectiveness of radionavigation systems in the harbor and harbor approach environment is to present the position information on some form of electronic display. This would allow a ship's captain, pilot, or navigator a continual reference, as opposed to plotting "outdated" fixes on a chart to show the recent past. It is also recognized that the role of the existing radionavigation system decreases in this harbor and harbor approach environment, while the role of visual aids and radar escalates.

### 2.10.1 Requirements

To navigate safely, the pilot needs highly accurate verification of position almost continuously, together with information depicting any tendency for the vessel to deviate from its intended track and a nearly continuous and instantaneous indication of the direction in which the pilot should steer. Table 2-5 was developed to present estimates of these requirements. To effectively utilize the requirements stated in the table, however, a user must be able to relate the data to immediate positioning needs. This is not practical if one attempts to plot fixes on a chart in the traditional way. To utilize radionavigation information that is presented at 6 to 10 second intervals on a moving vessel, some form of an automatic display is required. Technology is available which presents radionavigation information along with other data.

## 2.10.2 Minimum Performance Criteria

The radionavigation system accuracy required to provide useful information in the harbor and harbor approach phase of marine navigation varies from harbor to harbor, as well as with the size of the vessel. In the more restricted channels, accuracy in the range of 8 to 20 meters 2 drms relative to the channel centerline may be required for the largest vessels. A need exists to more accurately determine these radionavigation requirements for various-sized vessels while operating in such restricted confines. Radionavigation users' conferences have indicated that for many mariners, the radionavigation system becomes a secondary tool when they enter the harbor and harbor approach environment.

Further efforts will be directed toward verifying user requirements and desires for radionavigation systems in the harbor and harbor approach environment. The USCG, through its R,E&D program, is initiating a study to analyze and model the navigation requirements for major U.S. harbors. The requirements for smaller vessels in the harbor and harbor approach phase of navigation are less stringent than for large ships. The users' conferences mentioned above indicated that the smaller vessel operator is also less likely to depend on a radionavigation system in the harbor and harbor approach environment than he is on radar or visual means.

## 2.11 INLAND WATERWAY PHASE

Very large amounts of commerce move on the U.S. inland waterway system, much of it in slow-moving, comparatively low-powered tug and barge combinations. Tows on the inland waterways, although comparatively shallow in draft, may be longer and wider than large seagoing ships which call at U.S. ports. Navigable channels used by this inland traffic are often narrower than the harbor access channels used by large ships. Restricted visibility and ice cover present problems in inland waterway navigation, as they do in harbor and harbor approach navigation. The long, ribbon-like nature of the typical inland waterway presents special problems to the prospective use of precise, land-based area navigation systems. Continual shifting of navigable channels in some unstable waters creates additional problems to the prospective use of any radionavigation system which provides position measurements in a fixed coordinate system.

### 2.11.1 Requirements

Requirements based on the consideration of practically achievable performance and expected benefits have not been defined. However, R,E&D in harbor and harbor approach navigation is expected to produce results which will have some application to inland waterway navigation.

### 2.11.2 Minimum Performance Criteria

These criteria have not been determined. The R,E&D plans in Section 4 discuss the current and future efforts in the area of inland waterway navigation.

## 2.12 FUTURE MARINE RADIONAVIGATION REQUIREMENTS

The marine navigation requirements presented in the preceding discussions and tables are based on a combination of requirements studies, user inputs, and estimates. However, they are the product of current technology and operating practices, and are therefore subject to revision as technologies and operating techniques evolve. The USCG, through an R,E&D effort, is attempting to further refine the harbor and harbor approach requirements. This effort may also have some application in the inland waterway phase of marine navigation. The principal factors which will impact future requirements are safety, economics, energy conservation, environment and evolving technologies.

### 2.12.1 Safety

#### A. Increased Risk from Collision, Grounding and Ramming

Cargoes of particular hazard (petroleum, chemicals, etc.) are carried in great volumes in U.S. coastal and inland waterways. Additionally, the ever-increasing volume of other shipping and the increasing numbers of smaller vessels act to constantly increase the risk of collision, grounding and ramming. Economic constraints also cause vessels to be operated in a manner which, although not unsafe, places more stringent demands on all navigation systems.

#### B. Increased Size and Decreased Maneuverability of Marine Vessels

The desire to minimize costs and to capture economies of scale in marine transportation have led to design and construction of larger vessels and unitized tug/barge combinations, both of which are relatively less powerful and maneuverable than their predecessors. Consequently, more demanding navigational requirements are needed to compensate for these drawbacks.

#### C. Greater Need for Traffic Management/Navigational Surveillance Integration

The foregoing trends further strengthen the need for Governmental involvement in marine vessel traffic management to assure reasonable safety in U.S. waters. Radionavigation systems may become an essential component of traffic management systems. Differential GPS and LORAN-C are expected to play an increasingly important role in such areas as Vessel Traffic Services (VTS).

### 2.12.2 Economics

#### A. Greater Congestion in Harbor Approaches and Inland Waterways

In addition to the safety penalty implicit in greater congestion in restricted waterways, there are economic disadvantages if shore facilities are not used effectively and efficiently. Accurate radionavigation systems can contribute to better productivity and decreased delay in transit.

#### B. All Weather Operations

Low visibility and ice-covered waters presently impede full utilization of the marine transportation mode. Evolving radionavigation systems may eventually alleviate the impact of these restrictions.

### 2.12.3 Environment

As onshore energy supplies are depleted, resource exploration and exploitation will move further offshore to the U.S. Outer Continental Shelf and to harsher and more technically demanding environments. In addition, more intensive U.S. fishing activity is anticipated as the result of legislative initiatives and the creation of the U.S. Fishery Conservation Zone. In sum, both sets of activities may generate demands for navigational services of higher quality and for broadened geographic coverage in order to allow environmentally-sound development of resources.

### 2.12.4 Energy Conservation

The need to conserve energy resources and to reduce costs provides powerful incentives for increased transportation efficiency, some of which could come from better navigation systems.

## 2.13. CIVIL LAND RADIONAVIGATION REQUIREMENTS

Civil land radionavigation applications are still primarily in the developmental stage, and vehicular radionavigation systems are being developed and tested by state and Federal government agencies and private industry. While development of civil land radionavigation systems appears at this time to be concentrated in the transportation community, electronic chart development and receiver miniaturization may lead to the development of a portable land navigator for the camper or backwoods sports enthusiast. Such a device conceivably could be a multipurpose unit plugging into the boat or car when needed to navigate those vehicles.

### 2.13.1 Requirements

Currently there is no definitive statement of requirements for land vehicle radionavigation. However, comments made by automobile manufacturers' representatives at the users' conferences held by DOT indicated that users need accuracy on the order of 5 to 15 meters. Requirements to achieve costs benefits are also undefined at this time. It appears, however, that significant safety benefits and possible economic benefits can be derived by users traversing long distances, especially during inclement winter weather. The ability to more closely coordinate air and land search parties following accidents or disasters could save time, resulting in the saving of lives as well as search and rescue costs.

### 2.13.2 Minimum Performance Criteria

Since no definitive statement of requirements exists for land radionavigation, the minimum performance criteria can only be estimated. Comments made at the users' conferences held by the DOT indicated that some prospective users desire accuracy in the order of 5 to 15 meters. For other users, less accuracy appears to be acceptable.

## 2.14 MILITARY RADIONAVIGATION REQUIREMENTS

Military forces must be prepared to conduct operations anywhere in the world, in the air, on and under the sea, on land, and in space. During peacetime, military platforms must conform to applicable national and international rules in controlled airspace, on the high seas, and in coastal areas. Military planning must also consider operations in hostile environments.

### 2.14.1 General Requirements

Military navigation systems should have the following characteristics:

- o Worldwide coverage
- o User-passive
- o Capable of denying use to the enemy
- o Support unlimited number of users
- o Resistant to meaconing,\* interference, jamming and intrusion
- o Resistant to natural disturbances and hostile attacks
- o Effective real-time response
- o Available for combined military operations with allies
- o Free from frequency allocation problems
- o Common grid for all users
- o Position accuracy that is not degraded by changes in altitude for air and land forces or by time of year or time of day
- o Accurate when the user is in high "G" or other violent maneuvers
- o Maintained by operating level personnel
- o Continuously available for fix information
- o Not dependent on externally-generated signals.

No single system or combination of systems currently in existence meets all of the approved military navigation requirements. No known system can provide a common grid for all users, and at the same time be passive, self-contained and

---

\*Meaconing refers to imitative navigational signal deceptions.

yield the worldwide accuracies required. The nature of military operations requires that essential navigation services be available, with the highest possible confidence that these services will equal or exceed mission requirements. This, among other considerations, necessitates a variety of navigational techniques and redundant installations on the various weapon system platforms for military operations.

While general military requirements remain fairly constant, continuous review is required because of the impact of new technology, weapon system modifications, the dynamics of U.S. national policy interests, and the non-military environment to which the military must respond. Current indications are that a navigation concept based on an advanced navigation satellite system with global precision coverage, incorporating supplementary self-contained navigation systems, will be the most widely-used combination of systems over the next decade.

#### 2.14.2 Service Requirements

The JCS MNP provides specific DOD requirements for navigation, positioning and timing accuracy organized by primary missions and functions with specifically related accuracy requirements. These requirements are used for information and guidance in the development and procurement of military navigation systems.

### 2.15 SPACE RADIONAVIGATION REQUIREMENTS

Several program areas within NASA are engaged in the evaluation of GPS for precise position determination as a means of meeting space needs, for scientific studies, and for effecting economies in the use of space. These include the following uses of GPS which are discussed herein:

- o Control and navigation of space missions, such as the Space Shuttle and automated spacecraft.
- o Determination (in real time) of a position reference system for space platforms for in-orbit pointing of remote sensing devices.
- o Incorporation of real-time spacecraft position data to  $\pm 1$  km in the telemetered data stream of geophysical (solar-terrestrial) spacecraft or Spacelab payloads.
- o Refinement of further post-pass orbit data for data analysis when greater accuracy is required.

### 2.16 REQUIREMENTS FOR APPLICATIONS OTHER THAN NAVIGATION

Many non-navigation uses for radionavigation systems have developed over the years. Previous Government studies and inputs from users had given a preliminary indication of such usage, and at recent users' conferences, the extent of these non-navigation uses was emphasized. They included such uses as wildlife migratory studies; forestry conservation; AVM/AVL systems for cars, trucks and trains; communications timing systems and site registration systems. An extensive study

initiated by the Association of American Railroads and the Railway Association of Canada investigated the use of a radionavigation system in an automatic train control system. At least one railroad company is independently developing an automatic train control system which will use a radionavigation system.

While the Government has no statutory responsibility to provide radionavigation services for such applications, their existence and requirements are recognized. Table 2-6 provides a preliminary assessment of these requirements. Additionally, the FRP process attempts to accommodate such users as radionavigation plans and changes are instituted.

#### 2.16.1 Radiolocation (Site Registration and AVM/AVL)

Study efforts and field measurements to date have led to some preliminary estimates of accuracies required to make radiolocation services beneficial to various user groups. No other characteristics have been determined.

#### 2.16.2 Timing/Frequency Offset Applications

There are currently no definitive statements of these requirements since timing/frequency offset applications are a new area in the FRP. One national telephone company uses LORAN-C extensively for communication network synchronization.

TABLE 2-6. REQUIREMENTS FOR APPLICATIONS OTHER THAN NAVIGATION

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS									
	ACCURACY (2 drms)			COVERAGE	AVAILABILITY	FIX INTERVAL	FIX DIMENSION	CAPACITY	AMBIGUITY	
	PREDICTABLE	REPEATABLE	RELATIVE							
RADIOLLOCATION										
AVM/AVL	30m	-	30m	Nationwide	99.7%	1 second	Two	Unlimited	Resolvable with 99.9% confidence	
SITE REGISTRATION	30m	30m	-	Nationwide	99.7%	1 second	Two	Unlimited	Resolvable with 99.9% confidence	
RESOURCE MANAGEMENT	30m	30m	30m	National Economic Zone	99.7%	1 second	Two	Unlimited	Resolvable with 99.9% confidence	
GEOPHYSICAL SURVEY	5m	<1m	<1m	Worldwide	99.7%	1 second	Three	Unlimited	Resolvable with 99.9% confidence	
GEODETTIC CONTROL	1m	-	5mm + 1 part in 10 <sup>6</sup>	Worldwide	99.7%	1 second	Three	Unlimited	Resolvable with 99.9% confidence	
TIMING/PTTI										
COMMUNICATIONS NETWORK SYNCHRONIZATION	-	1 part in 10 <sup>11</sup> (freq)*	-	Nationwide	99.7%	Continuous	N/A	Unlimited	N/A	
SCIENTIFIC COMMUNITY	-	1 part in 10 <sup>14</sup> (freq)	-	Worldwide	99.7%	Continuous	N/A	Unlimited	N/A	

\* Proposed ITU Standard based on American Telephone and Telegraph "Stratum 1 Requirement".

### 3. RADIONAVIGATION SYSTEMS USED IN PHASES OF NAVIGATION

This section summarizes the plans of the Federal Government to provide general purpose and special purpose radio aids to navigation for use by the civil and military sectors. It focuses on three aspects of planning: (1) the efforts needed to maintain existing systems in a satisfactory operational configuration, (2) the development needed to improve existing system performance or to meet unsatisfied user requirements in the near term, and (3) the evaluation of existing and proposed radionavigation systems to meet future user requirements. Thus, the plan provides the framework for operation, development and evolution of systems.

The Government operates existing radionavigation systems which meet most of the current and projected civil user requirements for safety of navigation and promotion of reasonable economic efficiency. These systems are adequate for the general navigation of military craft as well, but none completely satisfies all the needs of military missions nor provides highly accurate, three-dimensional, worldwide navigation capability. GPS is being developed to satisfy many of these general and special military requirements. GPS may have broad potential for satisfying current civil user needs or for responding to new requirements that present systems do not satisfy. Thus, it could ultimately become the primary worldwide system for military and civil navigation and position location. Likewise civil development of MLS promises to provide the technology required to satisfy unfilled military requirements for a highly mobile precision approach system.

#### 3.1 EXISTING SYSTEMS USED IN THE PHASES OF NAVIGATION

It is generally accepted that the needs for navigation services derive from the activities in which the users are engaged, the locations in which these activities occur, the relation to other craft and physical hazards, and - to some extent - the type of craft. Because these differences exist, navigation services are divided by classes or types of users and the phases of navigation. These divisions are summarized in Tables 3-1 through 3-3. These tables also show current application of the existing radionavigation systems in the various phases of navigation. Detailed descriptions of the existing and proposed radionavigation systems are given in Appendix A.

The systems listed in Table 3-1 are used singly or in combination to support functions of the various phases of civil navigation. Tables 3-2 and 3-3 compare common use systems to mission applications for military use. The following sections describe the approach employed to define the needs, requirements, and degree to which existing systems satisfy these needs.

##### 3.1.1 Air Navigation

VOR/DME forms the basis of a safe, adequate, and trusted international air navigational system, and there is a large investment in ground equipment and avionics by both the Government and users. In view of this, it is intended to maintain the VOR/DME system at its present capability into the next century. The current ICAO protection date extends through 1995.

**TABLE 3-1. RADIONAVIGATION SYSTEM CIVIL APPLICATIONS**

APPLICATIONS	SYSTEMS								
	LORAN-C	OMEGA	VOR/DME	TACAN	MLS/ILS	TRANSIT	RADIO-BEACONS	GPS	RDSS
<b>AIR</b>									
<b>EN ROUTE/TERMINAL</b>									
Remote Areas	X	X	E	X	-	-	X	X	-
Special Helicopter	X	E	E	-	-	-	X	X	-
Oceanic En Route	-	X	-	-	-	-	-	X	-
Domestic En Route	X	X	X	X	-	-	X	X	-
Terminal	X	-	X	X	-	-	X	X	-
<b>APPROACH/LANDING</b>									
Non Precision	X	-	X	X	-	-	X	E	-
Precision	-	-	-	-	X	-	-	-	-
<b>MARINE</b>									
Oceanic	X	X	-	-	-	X	X	X	-
Coastal	X	-	-	-	-	-	X*	X	-
Harbor & Harbor Approach	E	-	-	-	-	-	X*	E	-
Inland Waterways	-	-	-	-	-	-	-	-	-
<b>LAND</b>									
Navigation	X	X	-	-	-	X	-	E	E
<b>SPACE</b>									
Navigation/Tracking	-	-	-	-	-	-	-	X	-
Terminal Approach	-	-	-	X	-	-	-	X	-
Terminal Landing	-	-	-	-	X	-	-	X	-
<b>OTHER</b>									
AVM/AVL	X	X	-	-	-	-	-	E	E
Site Registration	E	-	-	-	-	X	-	E	E
Surveying	-	-	-	-	-	X	-	X	X
Timing/Frequency	X	X	-	-	-	X	-	X	-

**LEGEND**

- E* = System in Evaluation
- X* = Current or Planned Application
- \** = Includes Racons
- = System Not Used

**TABLE 3-2. DOD RADIONAVIGATION SYSTEM APPLICATIONS - AVIATION, LAND**

AVIATION MISSIONS	SYSTEMS							
	LORAN-C	OMEGA	VOR/DME	TACAN	MLS/ILS	TRANSIT	RADIO-BEACONS	GPS
<b>EN ROUTE</b>								
Foreign Domestic	X	X	X	X	-	-	X	X
Domestic	X	X	X	X	-	-	X	X
Combat Theatre	X	X	-	X	-	-	X	X
Overwater	X	X	-	-	-	-	X	X
Remote Area	X	X	-	X	-	-	X	X
<b>TERMINAL</b>	-	-	X	X	-	-	X	X
<b>APPROACH/LANDING</b>								
Non-Precision	-	-	X	X	-	-	X	X
Precision Landing	-	-	-	-	X	-	-	-
<b>SPACE</b>								
Launch/Abort	-	-	-	X	X	-	-	X
Orbital	-	-	-	-	-	-	-	X
Re-Entry	-	-	-	-	-	-	-	X
<b>SURVEYING</b>	X	-	-	X	-	-	-	X
<b>TARGET ACQUISITION</b>	X	X	-	X	-	-	X	X
<b>AERIAL RENDEZVOUS</b>	-	-	-	X	-	-	X	X

LAND MISSIONS	SYSTEMS							
	LORAN-C	OMEGA	VOR/DME	TACAN	MLS/ILS	TRANSIT	RADIO-BEACONS	GPS
<b>LAND WARFARE</b>								
General Navigation	-	-	-	-	-	-	-	X
Surveillance & Reconnaissance	-	-	-	-	-	-	-	X
Indirect Fire Supt.								
Fwd Observers	-	-	-	-	-	-	-	X
Fwd Air Contr	-	-	-	-	-	-	-	X
Artillery	-	-	-	-	-	-	-	X
Surveying	-	-	-	-	-	-	-	X
<b>TIME TRANSFER</b>	X	-	-	-	-	-	-	X

**LEGEND**

X = Current or Planned Application  
 - = System Not Used

TABLE 3-2. DOD RADIONAVIGATION SYSTEM APPLICATIONS - NAVAL

NAVAL MISSIONS	SYSTEMS							
	LORAN-C	OMEGA	VOR/DME	TACAN	MLS/ILS	TRANSIT	RADIO-BEACONS	GPS
EN ROUTE, GENERAL PURPOSE								
Ship	X	X	-	-	-	X	X	X
Submarine	X	X	-	-	-	X	-	X
SEARCH & RESCUE								
Ship	-	-	-	-	-	X	-	X
Air	-	-	-	X	-	-	-	X
MINE COUNTERMEASURES								
Ship	X	X	-	-	-	X	-	X
Air	-	-	-	X	-	X	-	X
MINE LAYING								
Ship	X	-	-	-	-	X	-	X
Submarine	-	X	-	-	-	-	-	X
Air	-	X	-	X	-	-	-	X
AMPHIBIOUS WARFARE								
Ship	-	X	-	-	-	X	X	X
Air	-	-	-	X	-	-	-	X
ANTI AIR WARFARE								
Ship	X	X	-	-	-	X	-	X
Air	-	-	-	X	-	-	-	X
SURFACE WARFARE								
Ship	X	X	-	-	-	X	-	X
Submarine	X	X	-	-	-	X	-	X
Air	-	X	-	X	-	-	-	X
ANTI SUBMARINE WARFARE								
Ship	-	X	-	-	-	X	-	X
Submarine	-	X	-	-	-	X	-	X
Air	X	X	X	X	X	-	X	X
LOGISTICS								
Surface	X	X	-	-	-	X	-	X
Submarine	X	X	-	-	-	X	-	X
Air	X	X	X	X	X	-	X	X
SURVEYING								
Surface	X	X	-	-	-	X	-	X
Submarine	X	X	-	-	-	-	-	X
Air	X	X	X	X	-	-	X	X

LEGEND

X = Current and Planned Application  
 - = System Not Used

**TABLE 3-3. DEFENSE MAPPING AGENCY RADIONAVIGATION SYSTEM APPLICATIONS**

	SYSTEMS			
	LORAN-C	OMEGA	TRANSIT	GPS
<b>WORLDWIDE POSITIONING OF SATELLITE (ORBITAL TRACKING)</b>				
Low Altitude	-	-	X	X
Medium Altitude	-	-	X	X
High Altitude	-	-	X	X
<b>GEODETTIC POSITIONING BY SATELLITE (RELATIVE)</b>	-	-	X	X
<b>GEODETTIC POSITIONING (CONVENTIONAL)</b>	-	-	X	X
<b>DEEP OCEAN BATHYMETRIC SURVEY</b>	X	X	X	X
<b>COASTAL HYDROGRAPHIC</b>	X	-	X	X

**LEGEND**

- X = Current and Planned Application*
- = System Not Used*

As evidenced by the users' conferences in 1986 and 1988, there is increasing interest and usage of LORAN-C for air navigation. LORAN-C has been certified as a supplemental aid to navigation in certain areas of the U.S. and the system is being expanded.

#### Oceanic En Route

Oceanic en route air navigation is currently accomplished using inertial navigation (INS), OMEGA, or a combination of these two systems. Use of Doppler and celestial navigation is still approved although their use is almost nonexistent. Use of VOR/DME, TACAN and LORAN-C is approved where there is adequate coverage.

#### Domestic En Route

Domestic en route air navigation requirements are presently being met, except in some remote and offshore areas. The basic short-distance aid to navigation in the U.S. is VOR alone, or collocated with either DME or TACAN to form a VOR/DME or a VORTAC facility. This system is used for en route and terminal navigation for flights conducted under Instrument Flight Rules (IFR). It is also used by pilots operating on Visual Flight Rules (VFR). The U.S. and all other member states of the ICAO have agreed to provide VOR/DME service to international air carriers up to January 1, 1995. LORAN-C, OMEGA, and inertial are also used for domestic en route navigation. When inertial is used its performance must be monitored through the use of an approved externally-referenced radio aid to navigation.

#### Terminal

Terminal air navigation requirements are met presently using VOR, VOR/DME, VORTAC, TACAN, or LORAN-C.

#### Approach and Landing

Non-precision approach navigation requirements are met presently using VOR, VOR/DME, VORTAC, TACAN, LORAN-C or NDB. Precision approach and landing requirements are met today by ILS and will be met in the future by MLS.

### 3.1.2 Marine Navigation

Marine navigation is comprised of four basic phases: Oceanic, Coastal, Harbor and Harbor Approach and Inland Waterway. The phase of navigation in which a mariner operates determines which radionavigation system or systems will be the most useful. While some radionavigation systems can be used in more than one phase of marine navigation, no current system meets all requirements for the Harbor and Harbor Approach and Inland Waterway phases of marine navigation.

#### Ocean Phase

Navigation on the high seas is now accomplished by the use of dead-reckoning, celestial fixes, self-contained navigation systems (e.g., inertial), LORAN-C, OMEGA, and TRANSIT. Worldwide coverage by most ground-based systems such as LORAN-C is not practicable. The OMEGA system, however, with all eight stations operational, does provide essentially worldwide coverage.

### Coastal Phase

Requirements for operation within the coastal area are now fully met. In 1974 LORAN-C was designated as the Federally-provided primary civil marine radionavigation system for coastal areas of the conterminous 48 states, southern Alaska, and the Great Lakes. This service was fully implemented in 1980.

The marine radiobeacon system provides primary service in the coastal area and Great Lakes for recreational boaters and backup service for all categories of users. Radiodirection finders (RDF), required in some merchant ships by international agreement for search and rescue purposes, are also used with the radiobeacon system for navigation.

### Harbor and Harbor Approach Phases

Navigation in the harbor and harbor approach areas is accomplished currently through use of fixed and floating visual aids to navigation, radar, and audible warning signals. The growing concern for means to reduce the incidence of accidents and to expedite movement of traffic during periods of restricted visibility and ice cover has resulted in the implementation of Vessel Traffic Services (VTS) and investigation of the use of radio aids to navigation. Specific quantitative requirements for navigation in the Harbor and Harbor Approach phases, which will vary somewhat from one harbor to another, have not been developed but are significantly more demanding than for ocean and coastal navigation.

The USCG has studies in progress to better define the maritime navigation requirements in the Harbor and Harbor Approach Phase of navigation. Their R,E&D Harbor Monitor program has characterized the LORAN-C capability in major U.S. harbors and has identified those harbors which could be improved by installing a differential LORAN-C system. RTCM has developed a differential GPS specification, and the USCG and RSPA are testing a differential GPS system to verify the concept. However, during the Radionavigation Users' Conferences held in 1986 and 1988, there was little demand for better harbor and harbor approach accuracy from the radionavigation systems. It was stated, and the USCG recognizes, that radar plays a major role in harbor and harbor approach navigation. There are, however, major bodies of water on the East Coast where shipping channels are relatively confined and shore lines are distant and featureless. In these environments, a radionavigation system capable of providing 8 to 20 meter accuracy could provide significant benefits to the mariner. Operations on connecting waters and in harbors on the Great Lakes are similar to those in the Harbor and Harbor Approach Phase, and generally have more stringent navigational requirements than the Coastal Phase of navigation.

### Inland Waterway Phase

This phase of navigation is concerned primarily with those vessels which are not oceangoing. Specific quantitative requirements for navigation on rivers and other inland waterways have not yet been developed. Visual and audio aids to navigation, radar, and intership communications are presently used to enable safe navigation in those areas. No change in this practice is expected in the immediate future.

### 3.1.3 Land Navigation

The Government does not have a specific responsibility under law to provide radionavigation systems for civil land use. However, under the general provisions for improving the safety and efficiency of transportation, a number of projects have been sponsored by Government and industry to evaluate the feasibility of using existing and proposed radionavigation systems for land navigation. Currently, land navigation is in the developmental stage; however, LORAN-C, GPS/SPS, OMEGA and dead-reckoning map-matching are being evaluated as systems that could improve the safety and efficiency of land navigation.

### 3.1.4 Uses Other Than Navigation

These uses are concerned primarily with the application of LORAN-C, GPS and OMEGA for radiolocation and time and frequency dissemination. As with land navigation, the Government does not have a responsibility under law to provide radionavigation systems for these users. However, during the Radionavigation Users' Conferences held in 1986 and 1988, it was indicated that this is a rapidly-growing segment of the user community.

## 3.2 EXISTING SYSTEMS - STATUS AND PLANS

### 3.2.1 LORAN-C

LORAN-C was developed to provide military users with a radionavigation capability having much greater coverage and accuracy than its predecessor LORAN-A. It was subsequently selected as the Federally-provided radionavigation system for civil marine use in the U.S. coastal areas.

#### A. Operating Plan

LORAN-C was designated as the Federally-provided navigation system for the U.S. coastal areas in 1974. Implementation of the program authorized at that time has been completed. Studies have shown that further expansion to provide coverage to the Caribbean, Eastern Hawaii and Northern Alaska areas is not cost-beneficial at this time. An increase in aviation user demand has prompted action to eliminate the midcontinent gap and to expand coverage in Alaska. Methods have been investigated to make LORAN-C suitable for navigation in harbors and harbor approaches. It has been demonstrated that differential LORAN-C is capable of meeting that requirement in many, but not all, harbor areas. Figure 3-1 outlines the operating plan for the LORAN-C system. The coverage is shown in Appendix A.

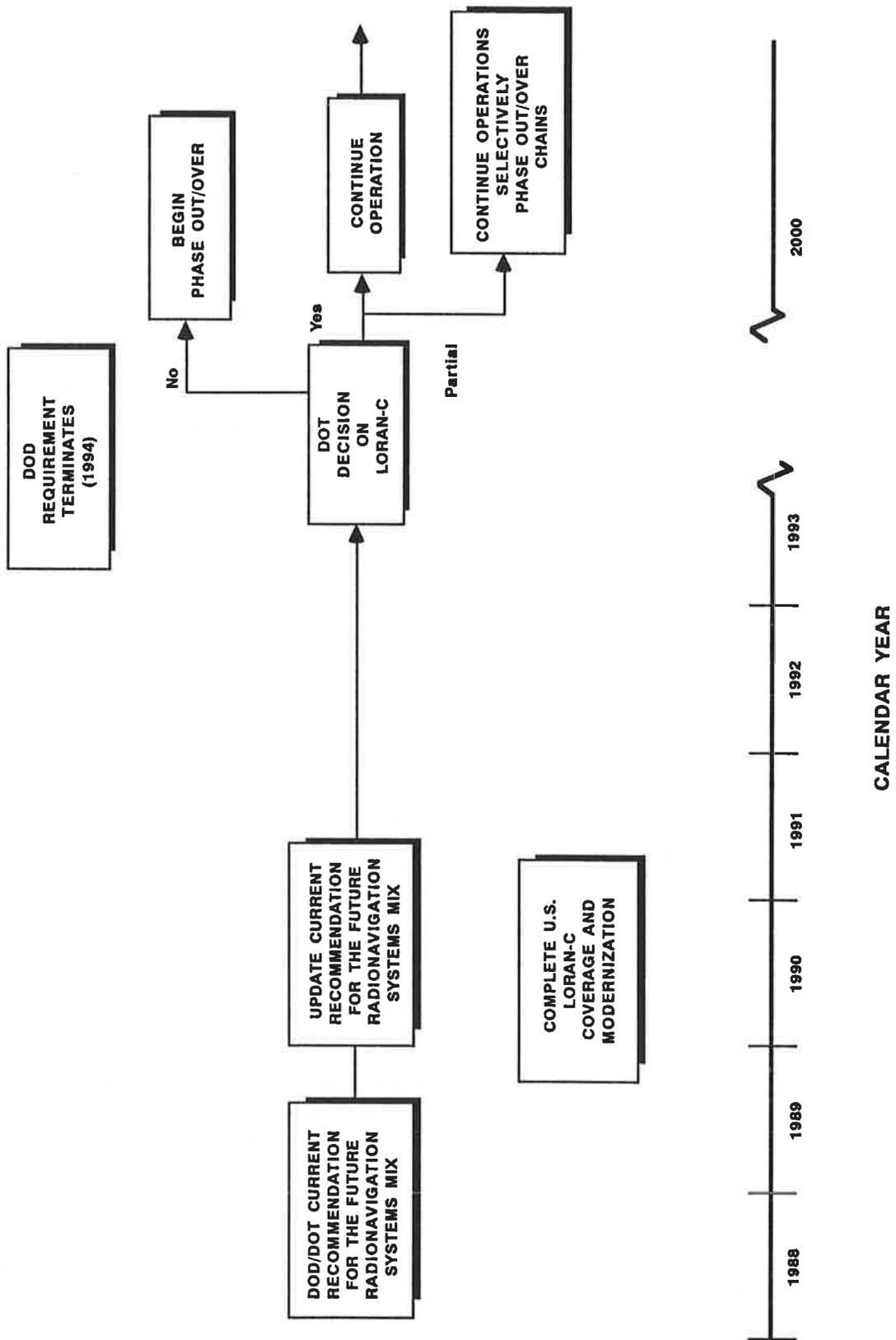


FIGURE 3-1. OPERATING PLAN FOR LORAN-C

## B. User Community

Initially, the major user of LORAN-C was the military, since civil marine use was limited due to the high cost of LORAN-C receivers and the lack of coverage over much of the U.S. coastal areas. Technological advances have rapidly lowered user receiver costs, and coastal coverage limitations have been eliminated by system improvements and expansion. As a result, there is presently extensive civil marine use of LORAN-C. During the last few years, there has also been a tremendous surge of users in the civil aviation community. In addition, there is growing terrestrial use in radiolocation and for precise time and time interval applications. The projected number of civil and military users is shown in Table 3-4.

## C. Acceptance and Utilization

A high degree of user acceptance of LORAN-C has been shown by all user communities. Because of system reliability, as well as accuracy, coverage, and cost factors, continuous growth in user population is anticipated. At the 1986 and 1988 Radionavigation Users' Conferences, strong user support was expressed for continued operation of the LORAN-C system for the foreseeable future.

There are a number of LORAN-C chains in operation overseas to serve U.S. military requirements for navigational service. Some of the stations are operated by the USCG, while others are operated by the host country under bilateral agreement. The service is available to all users, military and civilian, of all nations. Canadian LORAN-C stations include stations in British Columbia at Williams Lake and Port Hardy in the Canadian West Coast LORAN-C Chain, and stations in Newfoundland, Cape Race and Fox Harbour in the Canadian East Coast Chain. Both Canadian LORAN-C chains are partially comprised of USCG-operated stations which are dual-rated with other chains.

The USSR operates a radionavigation system similar to LORAN-C known as CHAYKA. Several chains are known to be in operation, providing coverage mostly over land. Saudi Arabia has installed two LORAN-C chains with six stations to provide coverage over most of the country and parts of the Red Sea, Arabian Gulf and the Gulf of Aden. France operates two stations in the Rho-Rho or ranging mode. The People's Republic of China is currently installing a LORAN-C chain to cover the South China Sea. Norway is also considering extending existing coverage by adding low-powered stations in the North Sea. The United Kingdom and several other European nations are studying possible expansion of the LORAN-C chains in the European area for civil use. Several other nations are known to be using LORAN-C.

Since the LORAN-C stations must be land-based and have a useful range of about 1000 nm, it is not feasible to provide worldwide coverage utilizing this system. The coverage area is limited to areas where adequate geometry and signal-to-noise ratio are available.

## D. Outlook

The LORAN-C system is expected to continue in operation for the foreseeable future. This estimate is based on the adoption and use of this system by a very large user population, and the absence of any near-term prospect for its replacement.

TABLE 3-4. LORAN-C PROJECTIONS

FACILITIES/USERS	CALENDAR YEARS													
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
U.S./CANADIAN FACILITIES	26	30*	30	30	30	30	30	30	30	30	30	30	30	30
U.S. OVERSEAS FACILITIES	16	16	16	16	16	16	0	0	0	0	0	0	0	0
CIVIL USERS (MARITIME) WORLDWIDE	400,000	450,000	**											
CIVIL USERS (AVIATION) WORLDWIDE ***	78,000	84,000	90,000	96,000	100,000	**								
DOD USERS	700	700	500	500	450	250****	**							

\* Increased to provide continuous U.S. coverage.

\*\* Data beyond this year are not available.

\*\*\* Majority are VFR, non-IFR receivers.

\*\*\*\* DOD Requirement for LORAN-C terminated.

The FAA-sponsored midcontinent expansion will result in a substantial addition to continental U.S. LORAN-C coverage. This project will add four stations to fill the midcontinent gap for civil aviation LORAN-C users. The FAA is also sponsoring a project to increase coverage in South Central Alaska by dual-rating the Port Clarence station with the Gulf of Alaska Chain. The increase in LORAN-C coverage is expected to lead to further land use. While no other major changes are anticipated for the continental U.S., some minor changes may be made to improve system performance. The U.S. and USSR have agreed to create a jointly operated LORAN-C/CHAYKA System providing service to areas of the North Pacific Ocean and the Bering Sea. The goal is to conduct a series of joint studies to ensure compatibility between the systems leading to operation of a three station chain in the early 1990's.

The FAA has designated LORAN-C as a supplemental system in the National Airspace System. The FAA will fully implement LORAN-C in the NAS by sponsoring the completion of midcontinent coverage and by approving non-precision approaches at all airports that have adequate LORAN-C coverage. The National Association of State Aviation Officials (NASAO) is working with the FAA in establishing non-precision approaches. Toward this end, the FAA will deploy 197 LORAN-C signal monitors throughout the NAS. The FAA and USCG are also preparing a National Aviation Standard for LORAN-C which will specify LORAN-C system performance. The FAA has prepared an airworthiness Advisory Circular (AC 20-121A), and a Technical Standard Order (TSO-C60b). RTCA Special Committee #137 has issued a MOPS for LORAN-C.

The overseas chains operated in support of DOD will be closed or transferred to the host nation when the DOD requirements are phased out. Based on the currently planned GPS operational date of 1992 and current requirements, the DOD will not have a requirement for the LORAN-C System after December, 1994. The DOD position will not affect civil use of LORAN-C in the U.S.

### 3.2.2 OMEGA

The OMEGA system was developed and implemented by the Department of the Navy, with the assistance of the USCG and with the participation of several partner nations. It provides worldwide all-weather radionavigation capability to air and surface users and was selected by the U.S. to be the Federally-provided radionavigation system for the high seas. The U.S. responsibility for operation of the system rests with the USCG.

#### A. Operating Plan

The permanent eight-station OMEGA configuration has been operational since August 1982, although, in earlier configurations, the system was widely used for more than five years before this date. OMEGA stations are currently located in Norway, Liberia, North Dakota, Hawaii, La Reunion Island, Argentina, Australia, and Japan. The USCG operates the two stations located in the U.S., and bilateral agreements between the USCG and the partner nations govern partner-nation operation of the other six stations. The USCG provides varying amounts of technical and logistic support to the partner nations. Future changes to the system configuration are being studied. They must address a complex set of considerations: plans of partner operating agencies, projections of major recapitalization requirements and the needs of the user population. These issues

will be studied to determine the cost/benefit of current versus alternative configurations and may lead to reduction or elimination of coverage in some areas. This makes current planning highly speculative and leads to a dynamic planning outlook for about the next five years. Discussions of available options have been initiated with applicable U.S. agencies and partner nations. Figure 3-2 outlines the operating plan for the OMEGA system.

#### B. User Community

In addition to the DOD air and marine users, civil ships and aircraft are using the OMEGA system. A number of air carriers and general aviation aircraft operators have received approval to use OMEGA as an update for their self-contained systems or as a sole means of navigation on oceanic routes. The system is popular because it provides moderate accuracy coverage where no other continuous-fix systems are available. Receiver innovations have led to the use of VLF communications transmissions to augment the Omega network and improve overall system redundancy and reliability. Receivers designed to use VLF communication signals as part of the navigation solution should be capable, using OMEGA signals only, of meeting performance standards contained in Advisory Circular 20-101C and Technical Standard Order TSO-C120. The projected numbers of civil and military users are shown in Table 3-5.

#### C. Acceptance and Utilization

Because of OMEGA's extensive coverage, civil use involves ships crossing the high seas and aircraft operating in oceanic airspace. It is also used as a supplement for high altitude domestic enroute airspace. Foreign ships and aircraft use this international system.

Current information indicates that the present permanent OMEGA system covers nearly 100 percent of the earth's surface. The coverage and accuracy of the system are being validated on a regional basis. This program includes collecting data from: fixed monitor receiver sites, shipboard monitor receivers and aircraft receivers. These data are used to correct and update propagation models and tables, and to confirm propagation parameters affecting coverage and availability. The validations begun in the mid-1970's, have been completed in the North Atlantic, North Pacific, South Atlantic and Indian Oceans. Data collection for the final validation area, the Mediterranean Sea, was completed in 1988. Besides showing the Omega system is meeting the advertised performance, the validations have documented considerable redundancy in system coverage. Together with the coverage redundancy provided by the use of VLF communications augmentation, this information will be used in studies to determine future configuration options.

Use of Omega has been certified by the FAA for use on the North Atlantic (since 1977) and as a supplemental means of navigation for high-altitude domestic enroute airspace.

The OMEGA system is limited in accuracy due to propagation effects, and restrictions on use of the signals when close to a station. For these reasons, OMEGA cannot meet the requirements for maritime navigation in U.S. coastal areas or for aircraft flying in U.S. terminal airspace.

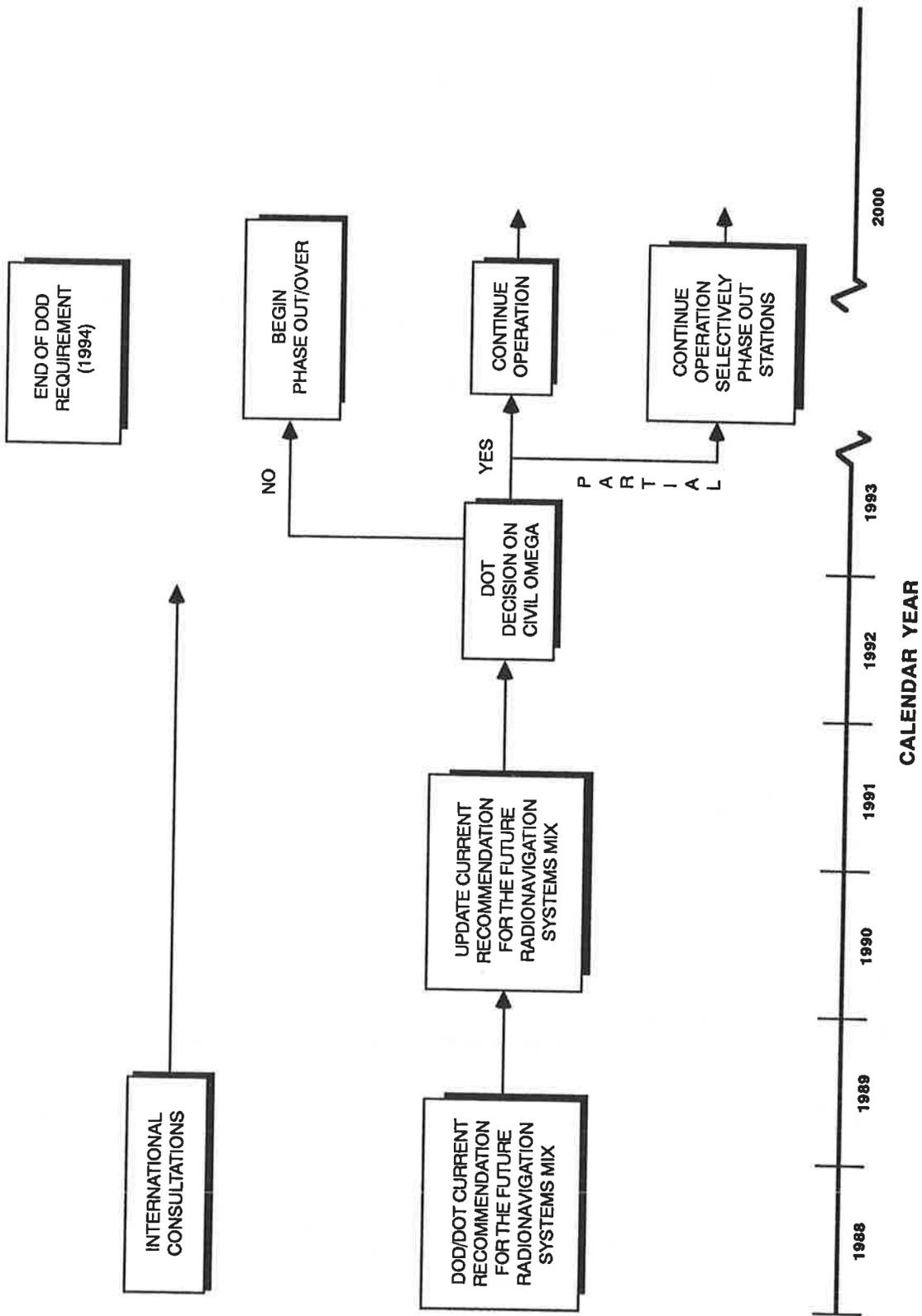


FIGURE 3-2. OPERATING PLAN FOR OMEGA

TABLE 3-5. OMEGA PROJECTIONS

FACILITIES/USERS	CALENDAR YEARS													
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
U.S. FACILITIES	2	2	2	2	2	2	2	2	2	2	2	2	2	2
PARTNER NATION FACILITIES	6	6	6	6	6	6	6	6	6	6	6	6	6	6
CIVIL USERS (AIR) WORLDWIDE	11,500	11,880	12,270	12,270	*									
CIVIL USERS (SURFACE) WORLDWIDE	7,500	7,500	7,500	7,000	*									
DOD USERS	2,100	2,100	1,500	1,000	1,000	500	*							

\* Data beyond this year are not available.

#### D. Outlook

Changes in configuration will be determined by the findings of on-going recapitalization studies and the impact of GPS. No changes are anticipated until the mid-1990's. The dominant recapitalization expenses involve the transmitting antennas, particularly the valley-span configurations at Norway and Hawaii. Continued efforts by the USCG to further refine the propagation prediction model for the system may result in improvements in system accuracy.

Because of the international character of the system and international user acceptance, operational decisions regarding system life must be coordinated with the partner nations. DOD will phase out military air use of OMEGA by December, 1994; however, some naval receivers may continue in operation after that date.

#### 3.2.3 VOR, VOR/DME, VORTAC

VHF Omnidirectional Range (VOR) was developed as a replacement for the Low-Frequency Radio Range to provide a bearing from an aircraft to the VOR transmitter. A collocated DME provides the distance from the aircraft to the DME transmitter. At most sites the DME function is provided by the TACAN system which also provides azimuth guidance to military users. Such combined facilities are called VORTAC stations.

##### A. Operating Plan

The FAA operates 950 VOR, VOR/DME and VORTAC stations including 150 VOR-only stations. A small increase in the number of stations is planned during the next 5 to 10 years, to meet the requirements in specified areas. The DOD also operates a few stations in the U.S. and overseas. These are available to all users. The operating plan for VOR, VOR/DME, and VORTAC is shown in Figure 3-3.

##### B. User Community

Approximately 80 percent of the general aviation aircraft are equipped with at least one VOR receiver and over 50 percent of the aircraft have two or more VOR receivers. All air carrier aircraft depend on it for bearing information. DME is used to provide distance information for all U.S. air carrier aircraft and for a large number of general aviation and military aircraft operating in U.S. airspace. The projected civil and military user population is shown in Table 3-6.

##### C. Acceptance and Utilization

VOR is part of a National Airspace System and is also the internationally designated standard short-distance radionavigation aid in air carrier and general aviation IFR operations. It is easy to use and is generally liked by pilots. Because it forms the basis for defining the airways, its use is an integral part of the air traffic control procedures.

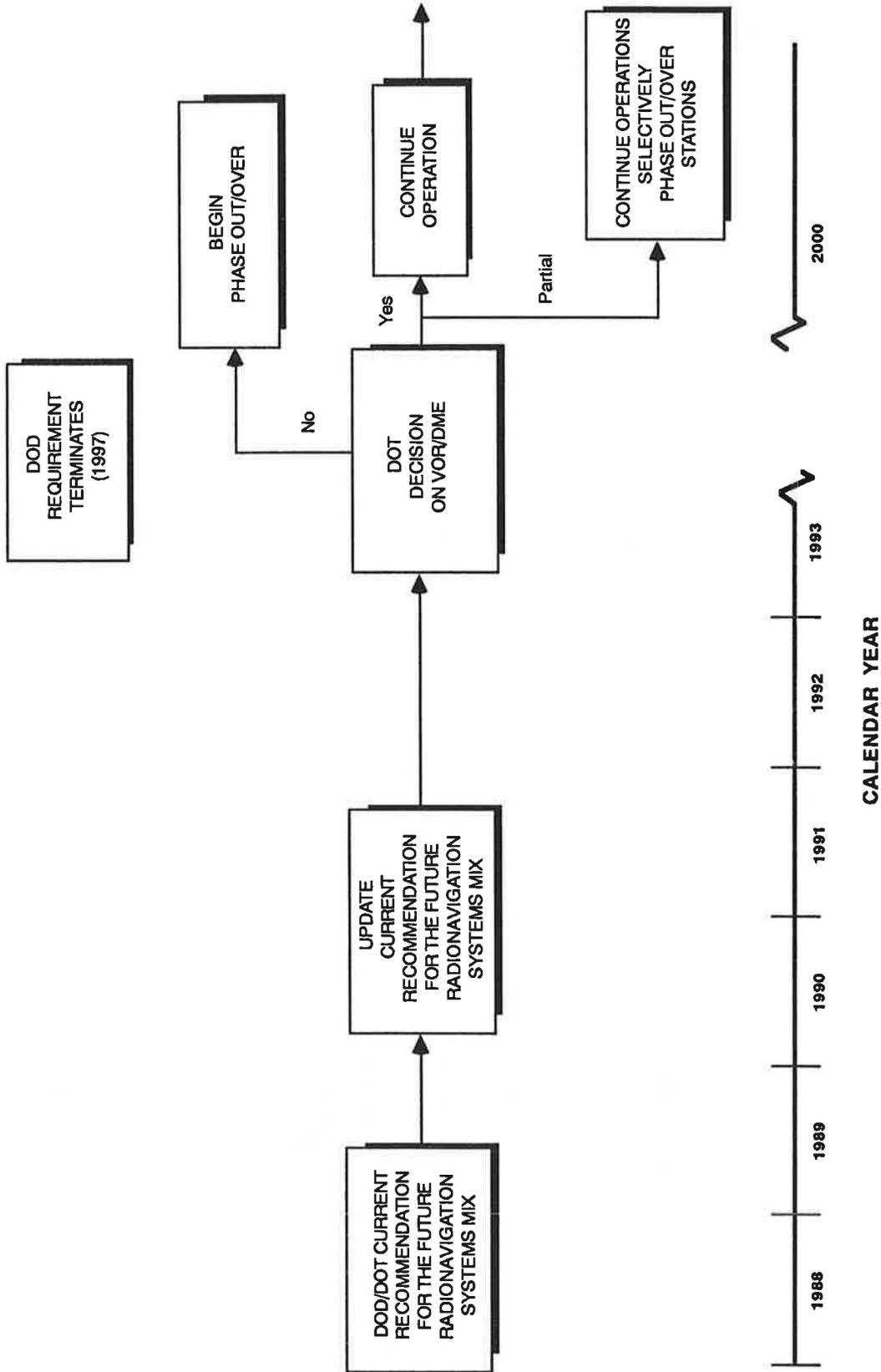


FIGURE 3-3. OPERATING PLAN FOR VOR, VOR/DME

TABLE 3-6. VOR, VOR/DME, VORTAC PROJECTIONS

FACILITIES/USERS	CALENDAR YEARS													
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
FAA FACILITIES	955	950	950	950	950	950	943	943	943	943	943	943	943	943
DOD FACILITIES	85	85	85	85	85	85	8	8	8	0	0	0	0	0
CIVIL USERS (VOR, VOR/DME)	226,000	233,000	239,000	246,000	253,000	261,000	269,000	277,000	285,000	294,000	302,000	310,000	305,000	300,000
CIVIL USERS (VOR/DME)	105,000	108,000	112,000	117,000	121,000	126,000	130,000	135,000	140,000	145,000	150,000	155,000	150,000	145,000
DOD USERS*	12,500	12,500	11,500	10,000	6,500	4,000	3,500	2,000	1,500**					

\* Includes Integrated VOR/LS Users.

\*\* DOD requirement for VOR/DME terminated. Data beyond this year are not available.

#### D. Outlook

Only a small increase in the number of transmitting stations is projected over the next decade in the U.S. These will meet requirements for new airports and new airways, as well as special Alaskan requirements.

A substantial increase in the general aviation user category is anticipated with the continuing growth of the number of aircraft being operated in U.S. airspace and the accompanying decreasing equipment cost. Since line-of-sight signal propagation seriously limits coverage at ground level, little or no use of the system by non-aviation vehicles is expected.

VOR/DME supports the current airways structure which is the basis for air traffic control procedures and operations. At present, no system has been identified by the FAA as a replacement. However, OMEGA and LORAN-C have been certified as supplements to VOR/DME in specific areas.

The VOR/DME system is protected by international agreement until 1995. It is expected to remain in service into the next century. If an alternate system such as LORAN-C or GPS should prove acceptable to the international aviation community as a replacement for VOR/DME, full implementation would not start until the late 1990s. It would require a substantial period beyond that before phaseout of VOR/DME could be accomplished.

The DOD VOR/DME operational concept is to maintain present system coverage until a suitable replacement is available. Present plans for expansion of the VOR/DME system are limited to site modernization or facility relocation. GPS is the planned replacement for DOD VOR/DME and VORTAC facilities. This transition will start in 1988. Planned phase-out of VOR/DME will be completed by DOD in 1997. In the case of a military VORTAC site that has developed an appreciable civilian-use community and is due for phase-out, transfer of operational responsibility to the DOT will be discussed between DOD and DOT.

#### 3.2.4 TACAN

TACAN is a UHF radionavigation system which provides a pilot with relative bearing and distance to a beacon on the ground, ship, or to specially equipped aircraft. TACAN is the primary tactical air navigation system for the military services ashore and afloat. TACAN is often collocated with the civil VOR stations (VORTAC facilities) to permit military aircraft to operate in civil airspace.

##### A. Operating Plan

DOD presently operates 172 and the FAA operates 680 TACAN beacons for DOD. Present TACAN coverage ashore will be maintained until phased out in favor of GPS. However, GPS in its present state cannot replace the TACAN function afloat (moving platforms).

Civil DME and the distance-measuring functions of TACAN will continue to be the same. The operating plan for TACAN is shown in Figure 3-4.

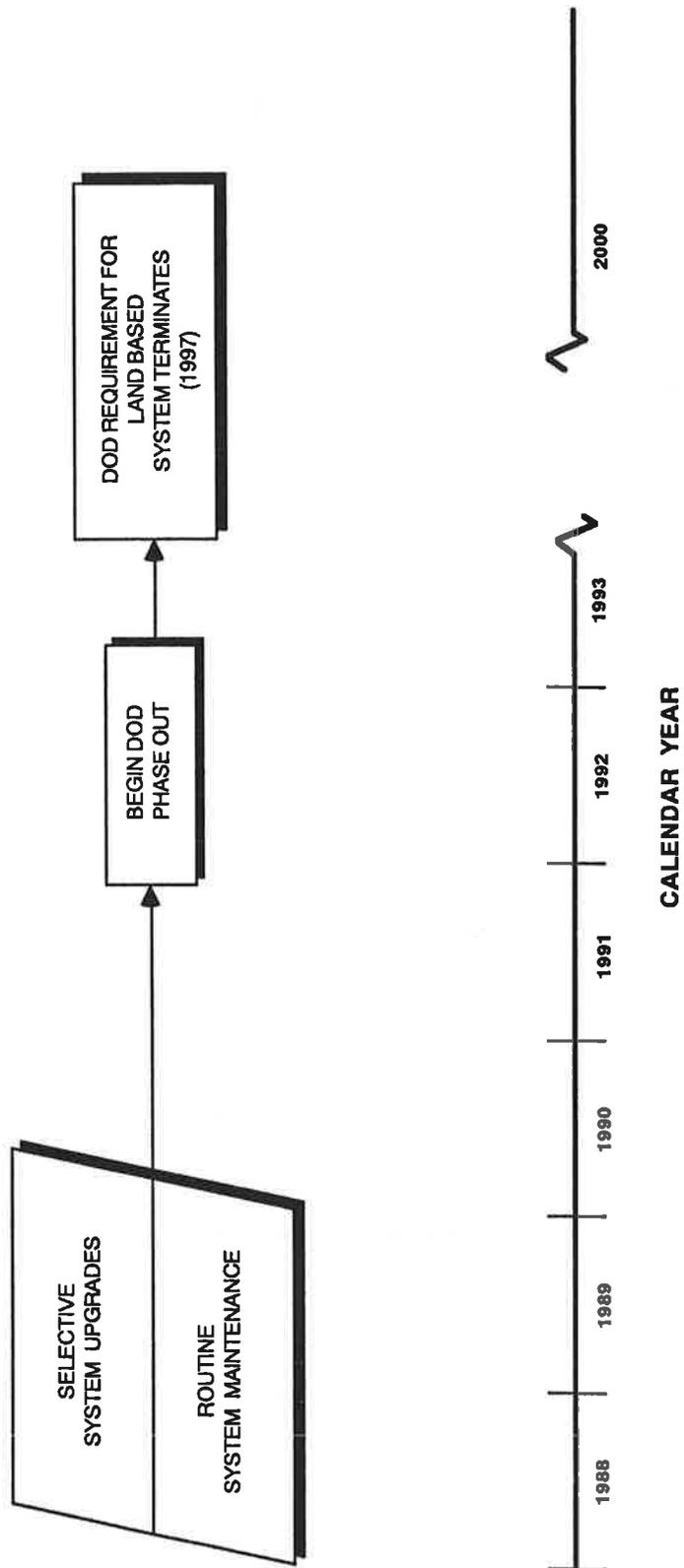


FIGURE 3-4. OPERATING PLAN FOR TACAN

## B. User Community

There are presently approximately 14,000 aircraft which are equipped to determine bearing and distance to TACAN beacons. These consist primarily of Navy, Air Force, and to a lesser extent, Army aircraft. The projected military user populations are shown in Table 3-7. Additionally, allied and third world military aircraft use TACAN extensively. NATO has standardized on TACAN until 1995.

## C. Acceptance and Utilization

TACAN is used by DOD and NATO aircraft operating under IFR ashore and IFR and VFR for tactical and en route navigation afloat. TACAN provides good accuracy in range and azimuth and is easy to use.

Because of propagation characteristics, TACAN is limited to line of sight which approximates 180 miles at higher altitudes. To receive range information an aircraft must radiate, thereby increasing the probability of detection. As with VOR/DME, special consideration must be given to location of ground-based TACAN facilities, especially in areas where mountainous terrain is involved due to its line-of-sight coverage.

## D. Outlook

DOD will phase out land-based TACAN by December 1997 if GPS, integrated with other onboard aircraft systems, proves acceptable as a sole means radionavigation system for military use in controlled airspace. Shipboard TACAN systems will continue in operation after that period.

### 3.2.5 ILS

ILS provides aircraft with precision vertical and horizontal navigation (guidance) information during approach and landing. Associated marker beacons or DME equipment identify the final approach fix, the point where the final descent to the runway is initiated.

#### A. Operating Plan

In 1989 there will be 758 ILS sites. Eventually, about 765 ILS sites will exist. In addition, there are approximately 165 ILS facilities operated by DOD in the U.S. The operating plan is shown in Figure 3-5.

#### B. User Community

Federal regulations require U.S. air carrier aircraft to be equipped with ILS avionics. It is also extensively used by general aviation aircraft. Since ILS is the ICAO standard landing system, it is extensively used by air carrier and general aviation aircraft of other countries. The projected civil and military user population is shown in Table 3-8.

TABLE 3-7. TACAN PROJECTIONS

FACILITIES/USERS	CALENDAR YEARS													
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
FAA FACILITIES OPERATED FOR DOD	663	655	648	640	633	633	633	633	633*	32**	32	32	32	32
DOD FACILITIES (Land-Based)	173	173	173	173	173	173	173	173	173**	11	11	11	11	11
CIVIL USERS	***													
DOD USERS	14,500	14,500	14,000	13,000	11,000	9,000	8,000	6,000	4,500*					

\* DOD requirement for land-based TACAN terminated.

\*\* Facilities that support shipboard operations.

\*\*\* Less than 100, no increase expected.

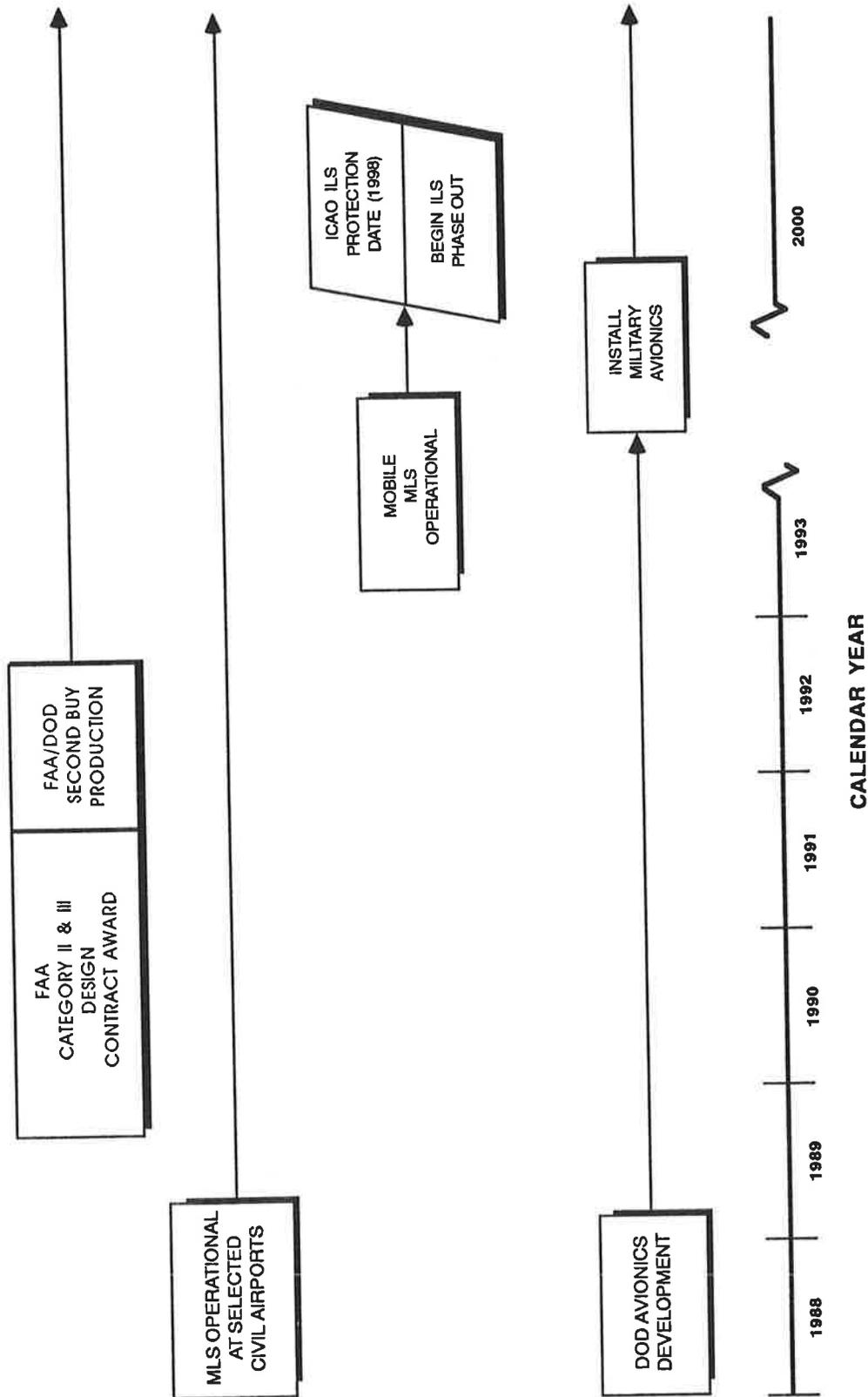


FIGURE 3-5. OPERATING PLAN FOR MLS/ILS

TABLE 3-8. ILS PROJECTIONS

FACILITIES/USERS	CALENDAR YEARS													
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
FAA FACILITIES	925	944	944	944	944	944	944	944	944	944	875	850	825	775
DOD FACILITIES	165	165	165	165	165	165	165	165	165	165	165	165	100	50
CIVIL USERS	168,000	175,000	185,000	195,000	195,000*									
DOD USERS	9,046	10,500	10,000	9,000	9,000*									

\* Data beyond this year are not available.

### C. Acceptance and Utilization

ILS is the standard civil landing system in the U.S. and the international standard for aircraft operating under IFR conditions. Since its introduction in the 1940s, it has been installed in steadily growing numbers throughout the world. Part of its attractiveness to aircraft owners lies in the economy of avionics costs. Since the ILS localizers and VOR stations operate in the same frequency band, common receivers are used.

Military services use ILS at fixed bases in the U.S. and overseas. Special systems are used to meet unique military requirements, including shipboard operations. Precision Approach Radar (PAR) is the NATO interoperable landing aid.

### D. Outlook

#### User Base Expansion

Based on a 1986 User Base Expansion survey, the number of civil aircraft equipped with ILS is estimated to be 149,000. This number is expected to increase until MLS is fully deployed.

#### Expected System Life

ILS is currently protected by ICAO agreement through at least 1998. ILS is being replaced by MLS.

#### System Limitations

ILS limitations manifest themselves in three major areas:

- (1) Performance of individual systems can be affected by terrain, man-made obstacles; e.g., buildings and surface objects such as taxiing aircraft and snow banks. These items may impose permanent use constraints on individual systems or limit their use at certain times.
- (2) The straight-line approach path inherent in ILS constrains airport operations to a single approach ground track for each runway. In contrast, MLS, will allow multiple ground track paths for approaches to the active runway as well as provide a steeper glide slope capability for STOL aircraft.
- (3) Even though the new 50 kHz frequency spacing will eventually double the ILS channel availability, frequency saturation limits the number of systems that can be installed. Frequency saturation occurs when ILS facilities in close proximity, with inadequate frequency separation, produce mutual interference.

### 3.2.6 TRANSIT

The Navy Navigation Satellite System (NNSS), also referred to as TRANSIT, is a satellite-based positioning system which provides submarines, surface ships, and a few specially-equipped aircraft with an accurate two-dimensional positioning

capability. The TRANSIT system consists of a minimum of four low-altitude satellites in near polar orbits, ground-based monitor stations to track the satellites, and injection facilities to update satellite orbital parameters. Developed mainly to support the Navy Fleet Ballistic Missile Submarines, TRANSIT is now installed on many domestic and foreign commercial vessels in addition to many military surface vessels.

#### A. Operating Plan

DOD plans to continue as the operator of TRANSIT until December 1996. Specifically, ground-based monitor and injection facilities and replenishment satellites will be funded and operated/supported by the Navy. Phase-out by military TRANSIT users in favor of GPS is planned to begin in 1990 and end in 1996.

The current TRANSIT constellation contains seven OSCAR satellites (five in the operational mode and two in orbit). The constellation also contains two NOVA satellites. These NOVA satellites:

- a. Have a 3 db gain in signal strength over the OSCAR satellite;
- b. Maintain a more precise orbit;
- c. Provide almost zero precession;
- d. Are capable of operating 8 days without a new data upload.
- e. Provide more precise time through a computer controlled clock system;

OSCAR and NOVA satellites appear identical to users. NOVA II will be reworked and maintained in storage for launch at a later date.

Production of four kits to allow launch of two OSCAR satellites (SOOS) with one booster is complete. This concept allows storing OSCAR satellites in orbit after termination of launch capability. These satellites are equipped with both a maintenance and operational mode to minimize on-orbit self-jamming and coplanar interference conditions. Launches of the SOOS configuration occurred in 1985, 1987 and 1988.

Current intentions are to maintain a mixed constellation of OSCAR and NOVA satellites to meet all military requirements. The operating plan is shown in Figure 3-6.

#### B. User Community

There are currently about 600 military TRANSIT users. Foreign and domestic commercial vessel use of the TRANSIT system has far outpaced the DOD use. It is estimated that 80,000 sets were in commercial use at the end of 1987. Approximately 90 percent of all commercial TRANSIT receiver sales are for the single channel receivers. Determination of precise position (surveying) has become an important use of TRANSIT. The projected user population is shown in Table 3-9.

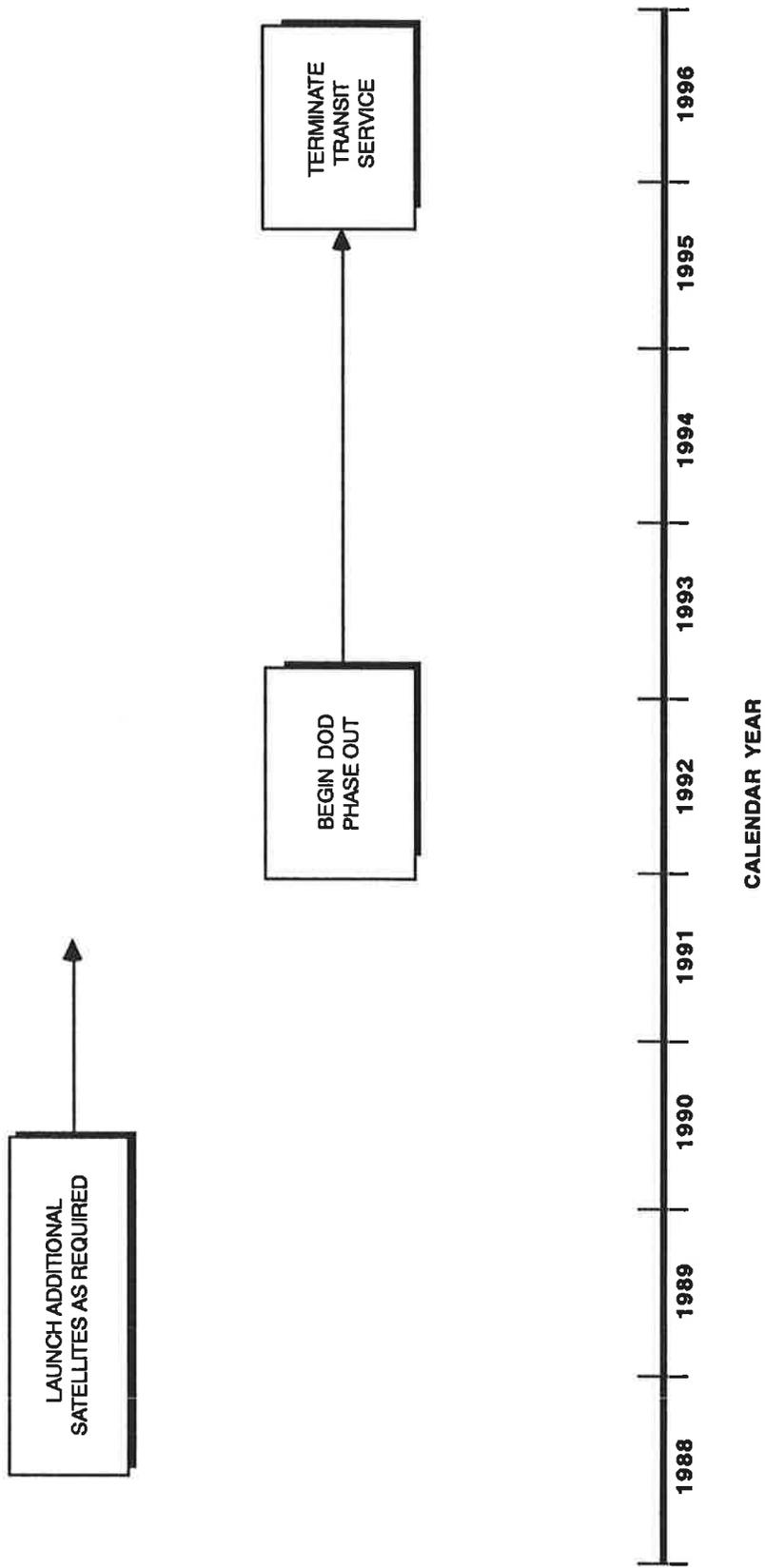


FIGURE 3-6. OPERATING PLAN FOR TRANSIT

TABLE 3-9. TRANSIT PROJECTIONS

FACILITIES/USERS	CALENDAR YEARS													
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
NOVA SATELLITES	3	2	2	2	1	1	1	1	0*					
OSCAR SATELLITES	4	5	5	5	6	6	6	6	0*					
CIVIL USERS (Worldwide)	90,000	95,000	95,000	90,000	85,000	80,000	75,000	70,000	0*					
DOD USERS	650	650	500	250	100	70	60	50	0*					

\* System terminated. Data beyond this year are not available.

### C. Acceptance and Utilization

TRANSIT provides periodic, worldwide, position-fixing information for Navy ships and submarines and commercial ships, as well as land users. Its acceptance is indicated by the large increase in commercial sales in recent years. The increased commercial demand for user equipment, and a continuing increase in the number of equipment manufacturers have reduced the user equipment costs.

From a military viewpoint, TRANSIT provides precise positioning for fixed and low dynamic vehicles (ships, submarines, surveying). In a high dynamic, tactical environment (aircraft, missiles), TRANSIT has little use since it is a Doppler system and small errors in user estimates of platform speed can cause large errors in user position. (One knot of unknown speed can cause a position error of 0.2nm).

### D. Outlook

The existing inventory of satellites and Scout launch vehicles are expected to support the Naval Fleet and TRANSIT program through 1996. No new procurements are planned. Ground-stored satellites will be launched for storage in orbit to support the program thru 1996. TRANSIT will be replaced with GPS by 1996. TRANSIT will not be operated by or transferred to a civilian agency of the U.S. Government.

### 3.2.7 Aeronautical and Maritime Radiobeacons

Aeronautical Non-Directional Beacons (NDB) are used for transition from en route to precision terminal approach facilities and as non-precision approach aids at many airports. In addition, many of the non-directional beacons are used to provide weather information to pilots. In Alaska, NDBs are also used as en route facilities.

Marine radiobeacons provide a backup to more sophisticated radionavigation systems and are the primary low-cost, medium accuracy system for vessels equipped with only minimal radionavigation equipment.

#### A. Operating Plan

The FAA operates over 700 NDBs. In addition, there are about 200 military aeronautical beacons and 800 non-Federally-operated aeronautical beacons. During the next 10 years, FAA expenditures for beacons are planned to be limited to the replacement of deteriorated components, modernization of selected facilities, and an occasional establishment or relocation of an NDB used for ILS transition. Approximately 200 marine radiobeacons are operated by the USCG. The operating plan is shown in Figure 3-7.

#### B. User Community

**Aeronautical NDBs:** All air carrier, most military, and many general aviation aircraft carry automatic direction finders (ADF).

**Marine Radiobeacons:** Beacons are utilized by all classes of users within the civil maritime community. They act as a backup for those users having more sophisticated radionavigational capability, and as a primary safety of operation

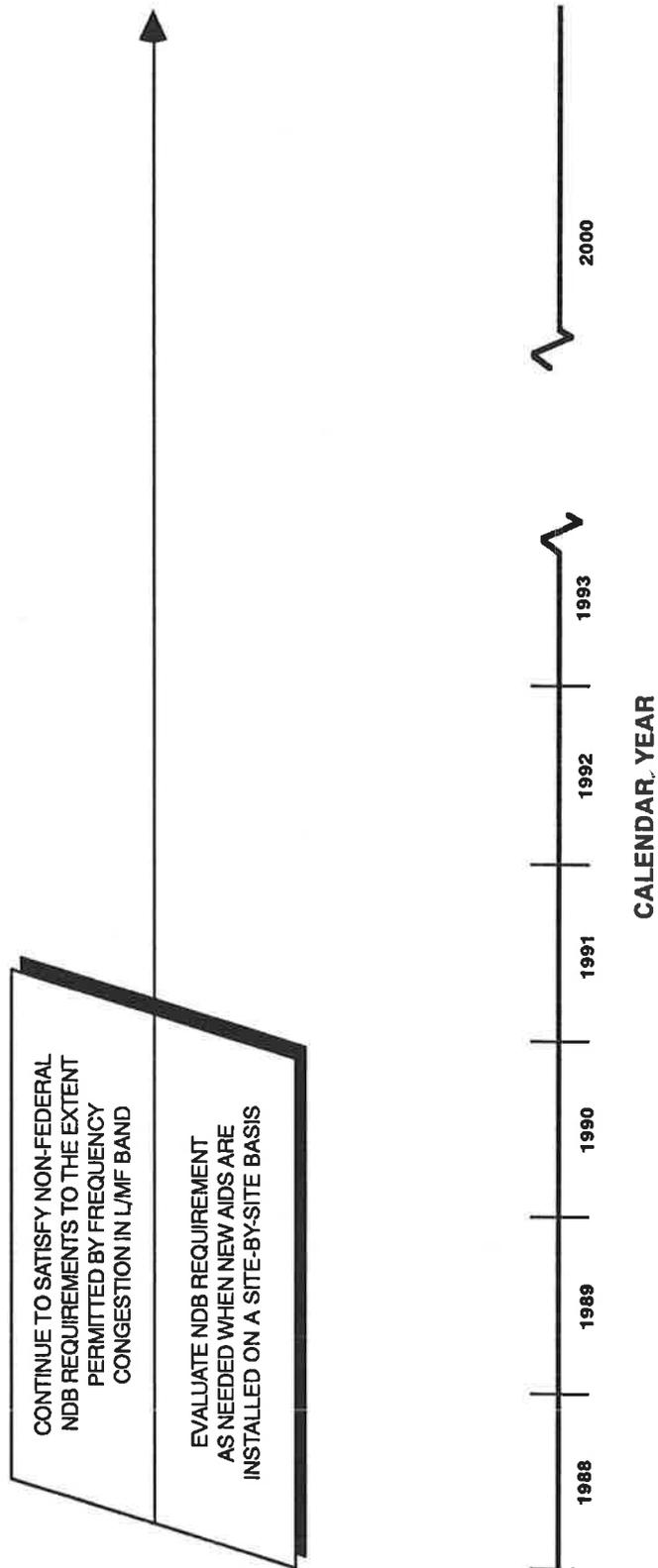


FIGURE 3-7. OPERATING PLAN FOR RADIOBEACONS (AERONAUTICAL AND MARITIME)

service to the small recreational craft operating in open water. The projected civil and military radiobeacon population is shown in Table 3-10.

### C. Acceptance and Utilization

The large number of general aviation aircraft and pleasure boats which are equipped with radio direction finders attest to the wide acceptance of radiobeacons by the user community. The primary reason for this acceptance is that adequate accuracy can be achieved with low-cost user equipment.

Aircraft use radiobeacons as compass locators to aid in finding the initial approach point of an instrument landing system as well as for non-precision approaches at low traffic airports without convenient VOR approaches.

Marine radiobeacons provide a bearing accuracy relative to vehicle heading on the order of  $\pm 3$  to  $\pm 10$  degrees. This might be considered a systemic limitation but, in actual use, it is satisfactory for many navigational purposes. Radiobeacons are not satisfactory for marine navigation within restricted channels or harbors. They do not provide sufficient accuracy or coverage to be used as a primary aid to navigation for large vessels in U.S. coastal areas.

### D. Outlook

Growth in aeronautical beacon requirements is primarily non-Federal and is unpredictable. Federal expenditures for aeronautical beacons are planned to be limited to the occasional establishment or relocation of NDB for ILS transition, replacement of deteriorated components, and modernization of selected facilities. Growth in the number of FAA beacons will be a function of these factors. It will also be influenced by the assumption of non-Federal facilities.

Frequency congestion is one of the principal constraints which limits the expansion of NDB service. At FAA request, this problem has been addressed by the RTCA, Special Committee 146 (SC-146). This committee developed a MOPS for ADF receivers (RTCA DO-179). As existing ADF equipment are amortized, the tighter selectivity of new equipment will permit a greater number of NDB frequency assignments and will result in more efficient use of the radio spectrum.

Recent information shows that marine radiobeacons are used primarily by pleasure boaters in the homing mode. A reconfiguration of the marine radiobeacon facilities is planned to eliminate sequenced radiobeacons and to relocate some radiobeacons for the best application of the homing mode.

At present, there is no known alternative system which would be as cost-effective for the user and the Government. Maritime and aeronautical radiobeacons serve the civilian user community with low cost navigation and will remain part of the radionavigation systems mix into the next century.

Radar beacons (RACONS) are short-range radio devices used to provide radar reference points in areas where it is important to identify a special location or aid to navigation. Examples of the use of RACONS are: landfall identification; improvement of ranging to and identification of an inconspicuous coastline; improvement of identification of coastlines permitting good ranging but which are otherwise featureless; improvement of the identification of a particular aid to

TABLE 3-10. RADIOBEACON PROJECTIONS

FACILITIES/USERS	CALENDAR YEARS													
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
AVIATION FACILITIES (FEDERAL)	728	728	728	728	728	728	728	728	728	728	728	728	700	650
AVIATION FACILITIES (NON-FEDERAL)	847	855	855	855	855	855	855	855	855	855	855	855	800	750
DOD FACILITIES (AVIATION)	190	190	180	170	160	150	120	120	100	100	50	50	50	40
MARITIME FACILITIES (FEDERAL)	200	200	200	200	200	200	200	200	200	200	200	200	150	150
CIVIL USERS (AVIATION)	157,000	163,000	170,000	177,000	184,000	191,000	199,000	206,000	214,000	222,000	230,000	238,000	235,000	230,000
DOD USERS (AVIATION)	12,525	12,100	11,800	10,900	10,000	9,000	8,000	7,000	6,000	5,000	4,000	3,000	2,000	1,000
CIVIL USERS (MARITIME)	500,000	500,000	500,000	500,000	500,000	490,000	450,000	430,000	410,000	380,000	350,000	320,000	315,000	310,000
DOD USERS (MARITIME)	410	405	390	385	380	375	370	350	300	250	200	150	100	50

navigation in an area where many radar returns appear on the radar display; provision of a lead to a specific point such as into a channel or under a bridge; warning to temporarily mark a new obstruction or other uncharted or especially dangerous fixed hazard to navigation.

Though RACONS offer a unique possibility of positive aid identification, uncontrolled proliferation could lead to an unacceptable increase in responses presented on a ship's radar display. This could degrade the usefulness of the display and cause confusion.

The USCG presently has approximately 75 RACONS in operation at various locations and has 100 more on order. The USCG currently operates various types of RACONS, but in the future will standardize on the frequency-agile types. (The RACONS presently on order are of the frequency-agile type.) In 1986, the Code of Federal Regulations was changed to allow private operation of RACONS with USCG approval.

### 3.3 DEVELOPING SYSTEMS - STATUS AND PLANS

#### 3.3.1 MLS

MLS is a joint development of the DOT, the DOD, and NASA under FAA management. Its purpose is to provide a civil/military, Federal/non-Federal standardized approach and landing system with improved performance compared with the existing landing systems.

##### A. Operating Plan

The U.S. Time Reference Scanning Beam (TRSB) MLS technique was selected by ICAO as the international standard in 1978. MLS is expected to replace ILS, and an MLS transition plan was approved in July 1981. The current operating plan is shown in Figure 3-5. Precision DME (DME/P) will be included with this system. The first production buy of airport MLS equipment was made in 1984 by the FAA.

##### B. User Community

MLS applications are limited to aviation. Widespread use by the U.S. civil and military aviation community is anticipated. Potential users include all segments of international civil and military aviation including NATO. Projected civil and military user population is shown in Table 3-11.

##### C. Acceptance and Utilization

Within the U.S. there has been widespread support for a common civil/military MLS. MLS does not have the siting problems of ILS, offers higher accuracy and greater flexibility, permitting precision approach service to be provided at more airports. MLS provides DOD tactical flexibility due to its ease in siting and adaptability to mobile operations.

TABLE 3-11. MLS PROJECTIONS

FACILITIES/USERS	CALENDAR YEARS													
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
FAA FACILITIES	33	76	126	176	176	196	300	420	540	660	780	900	1,020	1,140
DOD FACILITIES *	1	1	1	1	50	200	250	300	350	450	500	515	515	515
CIVIL USERS	50	100	500	1,000	3,000	4,500	8,000	15,000	24,500	37,000	50,000	80,000	85,000	90,000
DOD USERS	0	0	150	500	1,000	2,000	3,000	6,000	8,000	12,000	14,000	16,000	18,000	18,500

\* Both mobile and fixed base.

#### D. Outlook

MLS will gradually replace ILS in national and international civil aviation. MLS will replace or limit the deployment of non-standard or interim systems now in use.

MLS is expected to operate beyond the Year 2025. DOD phase-in of MLS will begin in the early 1990s and will be completed in 2003. Inclusion of the L-band DME with MLS would require extension of the DME segment of VOR/DME through the same period.

#### 3.3.2 GPS

GPS is a space-based positioning, navigation, and time distribution system designed for worldwide military use. Special capabilities of particular interest to DOD include precise, continuous, all-weather, common-grid positioning, velocity and timing. Additionally, the weapon system enhancement features of the GPS can be denied to enemy forces, and the system has features to prevent spoofing and to reduce susceptibility to jamming. Although designed for military use, the GPS/SPS will be available for civil use at the highest accuracy consistent with U.S. national security interests.

##### A. Operating Plan

**Space Segment:** DOD is procuring 28 satellites that will be used to establish a 24 satellite constellation (21 plus 3 operating spares). Launching of operational satellites is scheduled to begin in early 1989. The GPS constellation will be declared fully operational when 21 satellites are functioning in their assigned orbits. This is planned to occur in 1992. If current R&D satellites remain functional beyond their design life, this could occur before 1992.

**Control Segment:** The GPS Master Control station in Colorado Springs, Colorado, and its remote monitor stations and antennas are all operational. The Master Control station controls the GPS satellite constellation.

**User Equipment Segment:** Limited production of military user equipment, consisting of one-, two-, and five-channel receivers, started in 1986. Two thousand receiver sets are planned to be produced between 1986 and 1989. These sets will be integrated into various military platforms to include aircraft, ships, submarines, tanks, and other vehicles. They will be subjected to extensive operational tests and, after the results of these tests are reviewed, DOD will purchase over 25,000 units between 1990 and 2000. Although DOD does not currently authorize the use of GPS signals in space for any purpose except DOD tests, several commercial corporations both in the U.S. and abroad are developing, manufacturing, and selling (non-military) GPS receivers to civil customers for use with the GPS test constellation. Until DOD declares GPS operational, use of the system will be at the user's risk. The DOD operating plan for GPS is shown in Figure 3-8.

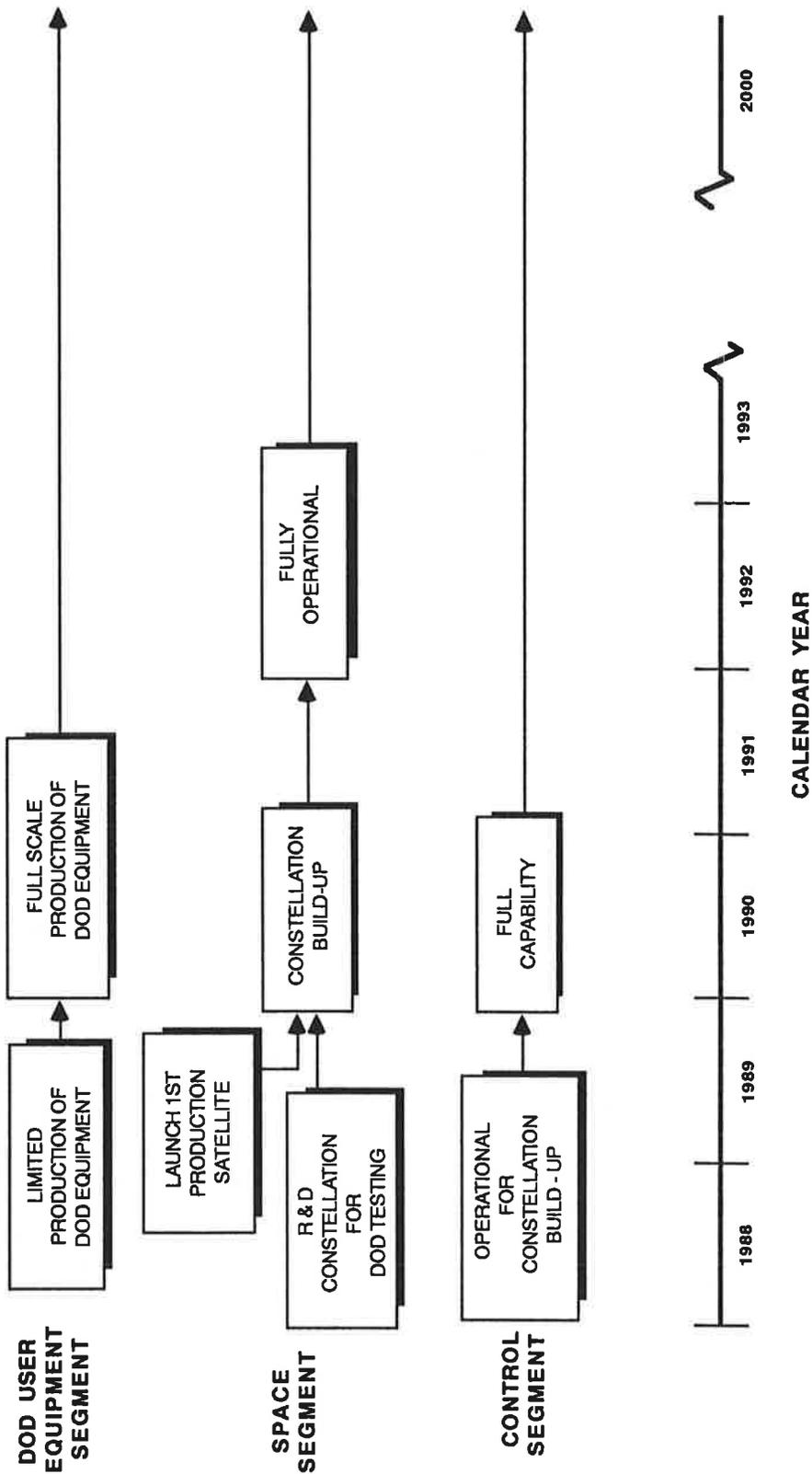


FIGURE 3-8. DOD OPERATING PLAN FOR GPS

## B. User Community

The DOD expects extensive use of GPS in almost every military mission area. The projected U.S. military user population is shown in Table 3-12. DOT and others are evaluating use and potential applications of GPS to meet civil navigation requirements.

The U.S. encouraged NATO participation in the development and deployment of GPS military user equipment. In response, ten NATO nations signed a Memorandum of Understanding in June 1978 (updated in 1984) for participation in the development of GPS. These nations include Belgium, Canada, Denmark, France, Germany, Italy, the Netherlands, Norway, the United Kingdom and the U.S. Spain joined the group in 1987.

The objective of this agreement is to establish a flow of information among the participating nations regarding all GPS program activities to facilitate national decisions supporting the application and use of GPS. To this end, personnel of participating nations are fully integrated within the GPS Joint Program Office to contribute to the U.S. development program and to advise on the coordinate NATO applications, development and testing.

In addition to formal NATO involvement in the development of military GPS user equipment, DOD has working relationships with other allied nations and is sharing information that is designed to create interest in the military use of GPS.

Widespread national and international civil use of the GPS Standard Positioning Service (SPS) is anticipated. Because of national security considerations the GPS Precise Positioning Service (PPS) will be restricted to U.S. Armed Forces, U.S. Federal agencies, and selected allied Armed Forces and governments. While GPS/PPS has been designed primarily for military radionavigation needs, it will nevertheless be made available on a very selective basis to U.S. and foreign private sector (nongovernmental) civil organizations. Access determinations will be made by the Government on a case by case evaluation that:

- (1) Access is in the U.S. national interest.
- (2) There are no other means reasonably available to the civil user to obtain a capability equivalent to that provided by GPS/PPS.
- (3) Security requirements can be met.

The Government is currently developing policy for submitting applications, granting approval for user access, and establishing operational procedures and compliance requirements for accessing the data from GPS/PPS. This guidance will be published in detail prior to GPS/PPS being made available to the private sector civil community.

The DOD has requested that DOT establish an interface office for civil GPS users. The DOT has proposed the establishment of the Civil GPS Service (CGS) in response. The CGS would consist of the Civil GPS Information Center (CGIC) and the Civil PPS Office (CPO).

TABLE 3-12. GPS PROJECTIONS

FACILITIES/USERS	CALENDAR YEARS													
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
USEABLE DEVELOPMENTAL SATELLITES	4	3	2	1	0	0	0	0	0	0	0	0	0	0
OPERATIONAL SATELLITES	9	18	21	24	24	24	24	24	24	24	24	24	24	24
DOD USERS	450	1,000	2,500	5,000	9,000	14,000	20,000	25,000	27,000	29,000	30,000	30,000	31,000	32,000
CIVIL USERS* (AIR)	200	250	400	600	900	1,200	2,000	3,000	5,000	10,000	20,000	40,000	50,000	75,000
CIVIL USERS (SURFACE)	1,000	1,600	2,000	2,300**										

\* Civil use of GPS/SPS is not authorized for IFR until DOD declares the GPS fully operational and until approved by FAA.

\*\* Data necessary for projections beyond 1992 are not available.

The CGIC would provide information to, and be the point of contact for, civil users of the GPS system. The CPO would disseminate GPS/PPS service to qualified civil users.

Establishment of the CGS depends on execution of necessary agreements between DOD and DOT, and agreements between DOT and other interested civil government agencies.

#### C. Acceptance and Utilization

When GPS becomes operational, DOD plans to phase-out its requirements for and use of all other common-use radionavigation systems except ILS/MLS and shipboard TACAN. There are current positive indications that the military forces of the NATO nations, as well as other allied countries, will use GPS. Because of the accuracy, worldwide coverage and flexibility to be provided by GPS, it is expected that non-Government civil use will grow rapidly and exceed military use. User population estimates will be influenced by many factors, such as the resolution of civil aviation system coverage and integrity issues currently being addressed by the FAA and DOD.

#### D. Outlook

The GPS constellation and control segments are scheduled to be fully operational in 1992. Initially, GPS will be integrated into military aircraft which are instrumented for instrument flight and contain inertial navigation systems or other forms of suitable attitude heading reference systems. These aircraft will be flight tested to ensure that they meet established standards for operation in the national airspace. Prior to 1992, there is expected to be significant civil use of the system (at the users' risk) to obtain accurate three-dimensional positioning, velocity and time, for geodetic surveying, land and sea navigation, and many other applications. Initial civil aircraft use will probably be as a supplementary system for en route domestic and foreign operations.

For GPS to become a sole means civil aviation radionavigation system (for oceanic en route, domestic en route, terminal, and non-precision approaches) it must provide at least five satellites in view above a mask angle of ten degrees in which all combinations of four out of five satellites have 100 meters 2 drms accuracy or better. At least five satellites are required so that if one satellite fails, unaided GPS navigation may continue. The current civil aviation integrity requirement for non-precision approaches is that the navigation system provide a warning to the pilot or removal of the signal from service within ten seconds after the signal has gone out-of-tolerance.



## 4. RADIONAVIGATION RESEARCH, ENGINEERING AND DEVELOPMENT SUMMARY

### 4.1 OVERVIEW

This part describes Government Research Engineering and Development (R,E&D) activities relating to the Federally-provided radionavigation systems and their worldwide use by the U.S. Armed Forces and the civilian community. This part is organized in two segments: (1) civil R,E&D efforts to be conducted mainly by DOT and to a lesser extent by NASA and (2) DOD R&E for military uses.

The DOT R,E&D activities consist of parallel efforts to develop current and future navigation systems to improve existing operations or to identify systems which can replace or supplement those now being used in civil air, marine, or land applications. The parallel efforts are described in two major sections, one covering GPS and the other covering all existing systems (such as VOR, OMEGA, and LORAN-C) now in use or being considered by DOT to meet new or emerging navigation requirements.

Although the DOT R,E&D activities for GPS will proceed in much the same manner as those for other systems, GPS has been identified separately because of its potentially broad multimodal civil and military application and the consequent need for close cooperation between Federal agencies in its evaluation. Such a cooperative effort will minimize duplication of effort and promote maximum productivity from the limited resources available for civil research. The cooperation should also ensure DOT participation in the early stages of DOD evaluation and development of GPS so that benefits can be derived from a continued assessment of DOD's advances in receiver technology and an improved Government planning process.

From the point of view of DOT, the analysis of performance requirements of civil navigation systems involves a variety of complex factors before it can be concluded that a specific system satisfies the principal objective to ensure safety and economy of transportation. These factors involve an evaluation of the overall economics of the system in relation to technical and operational considerations, including vehicle size and maneuverability, vehicle traffic patterns, user skills and workload, the processing and display of navigation information, and environmental restrictions (e.g., terrain hazards and other obstructions). For this reason, a DOT comparison of one navigation system to another requires more than just a simple evaluation of accuracy and equipment performance characteristics. As a first step in the comparison of system capabilities, ten performance parameters, discussed in Appendix A, can be identified and are listed below:

- o Signal Characteristics
- o Accuracy
- o Availability
- o Coverage
- o Reliability
- o Fix Rate
- o Fix Dimension
- o System Capacity
- o Ambiguity
- o Integrity

As implied above, for DOT, user equipment costs are a major consideration if universal civil participation is to be achieved. DOT R,E&D activities may involve evaluations and simulations of low-cost receiver designs, evaluation of future technologies and determination of future requirements for the certification of equipment.

In contrast to DOT, the DOD R&E activities mainly address GPS and MLS evaluations by Armed Forces user groups which are identified by military mission requirements and national security considerations. For this reason, DOD R&E is defined to include all activities before the final acquisition of a navigation system in accordance with detailed system specifications. The DOD view of TRANSIT, LORAN, TACAN, VOR, ILS and OMEGA is that these systems are already developed and, therefore, do not require R&E.

Although there are some similarities between the DOD and DOT analyses of the ten system performance parameters, DOD military missions place much greater emphasis on security and anti-jam capabilities. Such factors as anti-jam capabilities, updating of inertial navigation systems, input sensors for weapon delivery, portability, and reliable operation under extreme environmental or combat conditions become very important in establishing the costs of the navigation equipment.

Concurrent with the Federal R,E&D programs, the major cost issues will be evaluated. These evaluations and R,E&D programs will be used to support joint positions related to system mix, phase in/phase out, and transition strategies for common-use systems.

The relationship between DOT and DOD R,E&D programs is based on a continuing interchange of operational and technical information on radionavigation systems. DOD R&E will be coordinated with DOT R,E&D under the following guidelines:

- A. DOT will evaluate the costs of all radionavigation systems, including GPS and MLS, which meet identified civil user requirements.
- B. DOT will provide DOD with the most current information on civil user requirements which may have a significant impact on DOD-operated radionavigation systems.
- C. Consistent with existing DOD policy, DOD will provide information to DOT on GPS receiver designs that may be applicable to low-cost civil receiver development.
- D. DOT will conduct studies of GPS performance capabilities of low-cost receivers in order to provide an assessment of their applicability to the civil sector.

The specific civil R,E&D activities and their relationships to the FRP and the major Federal decisions on system implementations are outlined below in two segments: 1) GPS R,E&D, and 2) R,E&D for all existing civil navigation systems which include VOR, TACAN, DME, OMEGA, LORAN-C, ILS and MLS. These two segments have been coordinated to achieve efficient use of the limited funds available for R,E&D and to avoid duplication of effort. R,E&D tasks for the individual DOT agencies (FAA, USCG, MARAD, etc.) and related tasks by the NASA are addressed and schedules have been specified so that the results of the efforts will be of maximum usefulness to all participants in the program. R,E&D schedules and activities for the FAA, the USCG, and RSPA have been identified respectively under civil aviation, marine, and land activities in this document.

#### 4.2 DOT GPS R,E&D

DOT R,E&D activities for GPS have been conducted primarily by the USCG, the FAA and RSPA. Efforts initially were directed primarily toward determining the capability of GPS to meet civil user needs in the marine, air and land transportation communities. Subsequently, as it became apparent that the GPS capability to be provided to the civil community would not meet all user requirements, efforts have focused on ways of enhancing the system to meet these civil needs. The major DOT marine, air and land R,E&D activities for the GPS/SPS are described as follows:

- A. USCG activities focus on verifying and improving the performance of GPS/SPS for maritime navigation. There is particular emphasis upon the harbor and harbor approach phase of marine navigation, where augmentation of visual piloting using radio aids to navigation is needed. Major efforts are:
  - 1. Verify the differential GPS/SPS concept and techniques developed by the Radio Technical Commission Maritime Special Committee 104 (RTCM/SC-104) on differential GPS.
  - 2. Initiate action to publish a standard for a marine differential GPS system after the RTCM/SC-104 concepts and techniques have been verified.
- B. The FAA's basic R,E&D activities for GPS/SPS have been generally completed with coverage reliability and integrity being the only remaining major issues to be resolved. These activities have included substantial efforts to evaluate technical, operational, and economic characteristics of future aeronautical navigation systems including GPS. The GPS work has included simulations, engineering models, GPS user equipment design, technical analysis, and flight tests.
- C. RSPA has completed evaluations of several GPS receivers in the urban environment. RSPA land R,E&D activities in connection with GPS will focus on working with the USCG to verify the RTCM/SC-104 differential GPS concepts. RSPA will continue to review the results of work in the design of low-cost GPS receivers and field tests of GPS performance conducted by other organizations.

#### 4.2.1 Civil Aviation

The FAA, through its R,E&D GPS program, is developing the requirements for use of GPS/SPS in the national airspace, both as a supplemental and as a sole means navigation system. This includes determining the appropriate standards for GPS/SPS airborne receivers and developing the air traffic control methodology for handling GPS/SPS RNAV aircraft operation in an environment with non-GPS equipped aircraft. The FAA expects to certify GPS/SPS as a supplemental means of navigation by the time DOD declares it operational. There is close cooperation between the FAA, DOD and industry in these efforts.

##### A. Results of FAA R,E&D GPS efforts to date:

1. **ACCURACY:** GPS/SPS accuracy of 100 meters 2 drms (where there is adequate coverage) is suitable for all current civil aviation accuracy requirements except precision approach and landing.
2. **COVERAGE:** The coverage provided by the DOD-proposed GPS (21 plus 3 on-orbit spares) satellite configuration is suitable for sole means aviation use.
3. **INTEGRITY:** The current GPS satellite and control segment failure warning system does not provide warnings soon enough after an out-of-tolerance condition occurs to be suitable for civil non-precision approach integrity.
4. **TECHNICAL FACTORS:** GPS operation is basically the same as other RNAV systems and presents the same problems and benefits.
5. **ECONOMIC FACTORS:** GPS user equipment will probably cost more than VOR receivers for general aviation.
6. **USER NEED:** No compelling near-term requirement for GPS has been expressed by the civil aviation user community. The general sentiment appears to be that the marketplace will bring about civil use when GPS is implemented.

##### B. Planned FAA R,E&D GPS activities:

1. Additional studies will be conducted to determine methods to improve coverage. These studies will include satellite constellation changes and receiver design requirements.
2. Methods to detect and notify the pilot of GPS/SPS out-of-tolerance conditions within 10 to 15 seconds will be developed and analyzed.
3. A National Aviation Standard for GPS/SPS will be developed.
4. A MOPS for GPS/SPS avionics will be developed.
5. A fourth aviation users' conference on navigation and the role of GPS in aviation will be held.

6. Investigations of GPS/SPS user equipment cost will continue.
7. Investigations of GPS/GLONASS integrated operation.
8. Differential GPS application to aviation will be investigated.
9. Investigations of GPS/LORAN-C integrated operations and interoperability.

#### 4.2.2 Civil Marine

The major R,E&D activities of the USCG related to marine uses of GPS/SPS are low-cost receiver technology studies, user field tests for comparative assessment of GPS versus alternative aids to navigation, and assessment of SPS performance potential. The purpose of the marine program is to acquire a sufficient data base to determine those missions of the marine fleet for which the GPS/SPS system can satisfy the navigation performance requirements. Issues important to the use of GPS for marine navigation include:

1. **ACCURACY:** Can GPS/SPS provide the accuracies needed by marine users, including commercial fishing, coastal shipping and offshore industry? Can differential GPS/SPS give the accuracy required for Harbor and Harbor Approach and Inland Waterway Navigation?
2. **TECHNICAL AND ECONOMIC FACTORS:** What are the technical and economic issues that dominate a GPS receiver designed for civil marine use? What is a realistic estimate of receiver cost, and what technological factors might significantly alter this estimate? What receiver performance and cost trade-offs are feasible to develop GPS equipment acceptable for: (1) commercial ships over 1600 gross tons, and (2) smaller ships or tugs with barges?
3. **COMPARISON WITH MARINE RADIONAVIGATION SYSTEMS:** Comparison of GPS with current marine radionavigation systems is required. This comparison must be made with regard to navigation accuracy and repeatability, operational features and human factors considerations. Various missions must be considered, as well as a range of vessels from supertankers to Coast Guard cutters. This work must also consider the effect on electronics design and installation of the peculiarities of operations in protected waters and on the open ocean.
4. **OPERATIONAL TEST RESULTS:** What are the practical results of testing GPS receivers in the marine environment, such as: installation criticalities, marine and harbor environment peculiarities (RFI/multipath), and the suitability of performance and display for typical operations (e.g., fishing)?

The USCG completed its initial studies and tests for the Harbor and Harbor Approach phases of navigation. GPS/SPS was found to have potential use in these phases. Additional USCG R,E&D will be directed toward:

1. Promotion of the development of low-cost GPS/SPS receivers by industry for marine use.

2. Evaluation of the potential of GPS/SPS for navigation on inland waterways.
3. Definition of the role of harbor surveillance systems and alternative navigation systems as a backup for GPS/SPS where requirements exist for additional reliability, special vessel activities, or during emergencies.

Since GPS/SPS does not totally satisfy the performance and cost-effectiveness requirements for the Harbor and Harbor Approach phases, studies are being initiated to evaluate the increased use of alternative systems in these phases. Among these are harbor surveillance systems, improved short range aids to navigation, differential LORAN-C with retransmissions from shore-based monitor stations, and differential GPS.

The near-term USCG R,E&D program has the following goals:

1. Demonstrate a GPS/SPS-based navigation system capable of meeting the Harbor and Harbor Approach accuracy requirements.
2. Promote the development of a standard for the generation, interchange and application of differential GPS data for Harbor and Harbor Approach applications.
3. Demonstrate the feasibility of using USCG radiobeacons for transmitting differential GPS correction data.
4. Promote the development of a set of standards for differential GPS service.

#### 4.2.3 Civil Land

Land radionavigation users, unlike air and marine users, do not come under the legislative jurisdiction of any agency. For this reason, RSPA has attempted to monitor their activities and identify R,E&D activities applicable to their needs. Limited RSPA R,E&D performed through the Transportation Systems Center indicates some limitations to the serviceability of GPS to land users in certain urban areas. Fiscal limitations prevent further specific RSPA R,E&D activities at this time. RSPA will, however, monitor technology developments in the private sector and the results of other Government-sponsored R,E&D in the following areas:

1. Land user equipment availability and cost
2. GPS/SPS land performance
3. Differential GPS technology development and system performance
4. Land navigation and radiolocation applications
5. Commercial RDSS system development status, performance and applications

RSPA, FHWA and NHTSA will also participate in industry/user/government groups developing standards for utilizing radionavigation equipment displays and data bases in land vehicles.

#### 4.3 DOT R,E&D FOR EXISTING CIVIL NAVIGATION SYSTEMS

##### 4.3.1 General

The main purposes of DOT R,E&D on existing civil navigation systems are to improve reliability and service, decrease costs, and satisfy new requirements. The major DOT R,E&D for existing systems is outlined in the context of air, marine, and land areas of operation, as follows:

##### A. Air

The FAA will continue its ongoing modernization and maintenance/sustaining engineering of VOR/DME and TACAN in order to reduce operation and maintenance costs and to improve the performance of ground-based air navigation aids in the U.S. and U.S. territories.

The FAA will continue to monitor the performance of OMEGA on oceanic air routes and the use of OMEGA and LORAN-C as supplements to VOR/DME.

The FAA will continue evaluation of LORAN-C as a non-precision approach aid. Also, the FAA will evaluate GPS/SPS as both a supplement to VOR/DME and as a sole means air radionavigation system. These evaluations involve field tests, low-cost user set design studies and analyses of coverage, reliability, integrity, and operational suitability (which includes the assessment of impacts on pilot workload and blunder potential). In addition, MOPS and certification criteria, including Flight Inspection Requirements, have been established for LORAN-C. RTCA SC-159 will provide a Minimum Aviation System Performance Standard for the GPS/SPS. Institutional issues such as international acceptance, signal availability, signal degradation, and economic issues are also being assessed. The developmental activities for MLS will continue.

##### B. Marine

The DOT marine R,E&D for existing systems is composed of several USCG programs. These R,E&D projects focus on system enhancements and techniques for improving navigational safety in the Harbor and Harbor Approach phase of marine navigation. They include LORAN-C projects on signal analysis and chain enhancements, differential LORAN-C, and shipboard display projects. A project is also underway to evaluate the requirements for Harbor and Harbor Approach navigation system performance.

##### C. Land

As navigation benefits to land users become apparent, and as receiver equipment costs decrease due to technology improvements and expanding user markets, adaptation of the existing navigation systems to serve a variety of land users will prove cost-effective. Therefore, RSPA, FHWA and NHTSA R,E&D activities are planned to enhance the potential benefits of radionavigation applied to public and private land uses.

Typical applications include site registration for remote site location, highway records, land management and resource exploration; AVM/AVL for truck fleets, rail vehicles, buses, as well as police and emergency vehicles; driver information systems for highway vehicles; and also for land navigation on highways and in remote areas.

#### 4.3.2 Specific Civil R,E&D Activities

##### A. Civil Aviation

The R,E&D activities of the FAA are broadly directed toward improving navigation systems serving civil and military air users. The activities cover five phases of flight: (1) Oceanic and Domestic En Route, (2) Non-precision Approach, (3) Remote Areas, (4) Helicopter IFR Operations, and (5) Precision Approach and Landing. The FAA navigation program has three specific goals: (1) to provide information that will support the FAA recommendation on the future mix of navigation aids; (2) to assist in the near-term integration of existing navigation aids into the NAS as supplements to VOR/DME; and (3) to provide information that will support the definition of long-term navigation opportunities.

In the long term, communication, navigation, and surveillance (CNS) may be combined into an integrated system providing a single satellite-based system for civil users; i.e., integrated CNS (ICNS). Low-altitude users, including VFR as well as IFR traffic, could be accommodated more easily in the NAS since one ICNS system would respond to the needs of all users.

ICNS services would extend ATC service to more airspace in support of flexible routes. This airspace includes extreme (low and high) altitudes, oceanic, offshore, remote, and urban environments.

Time-based navigation and ATC practices in the en route and terminal environment would involve issuing time-based clearances to certain aircraft which can navigate with sufficient precision to fly space-time profiles and arrive at points in space at specified times. Aircraft equipped with advanced flight navigation and management systems may be able to receive clearances directly from ground automation equipment, and follow such clearances automatically along trajectories of their choice, either to maximize fuel efficiency or to minimize time.

Automatic dependent surveillance is defined as a function in which aircraft automatically transmit navigation data derived from onboard navigation systems via a data-link for use by air traffic control. Automatic direct surveillance R,E&D will develop functions to permit tactical and strategic control of aircraft. Automated position report processing and analysis will result in nearly real-time monitoring of aircraft movement. Automatic flight plan deviation alerts and conflict probes will support reductions in separation minima and increased accommodation of user-preferred routes and trajectories. Graphic display of aircraft movement and automated processing of data messages, flight plans, and weather data will significantly improve the ability of the controller to interpret and respond to all situations without an increase in workload.

Opportunities exist to develop receiver avionics which combine two radionavigation signals such as GPS and LORAN-C, and GPS and VOR/DME, and thereby significantly improve user navigation performance.

#### 1. Oceanic and Domestic En Route

The FAA has approved the use of OMEGA on oceanic routes as a sole means of navigation. Limited supplemental approval has also been granted for use of OMEGA/VLF avionics in the NAS with the provision that VOR/DME be available on the aircraft. U.S. National Aviation Standards will be prepared for NDBs, LORAN-C, OMEGA and GPS. LORAN-C has also been approved as a supplemental system where there is coverage.

#### 2. Non-Precision Approach

The differential GPS concept will be evaluated for potential operational benefits for non-precision approaches.

#### 3. Remote Areas (Including Offshore)

While the present VOR/DME coverage meets most civilian user requirements, there are areas, such as some mountainous regions and low altitude airspace areas, where there is a requirement for air navigation service that VOR/DME does not presently provide. Alternatives being investigated to provide the required coverage include additional VOR/DME facilities, and supplementing the existing VOR/DME system with GPS or LORAN-C. Currently, OMEGA/VLF and LORAN-C (in specific areas) are approved as a supplement to VOR/DME.

#### 4. Helicopter IFR Operations

The FAA is addressing special helicopter navigation requirements attributable to operations at low altitudes and in remote areas which are frequently below and beyond service volumes associated with conventional VHF NAVAID systems. The examination of LORAN-C and GPS for use in en route, terminal, and approach phases of operation are being emphasized. The feasibility of enhancing ADF/NDB systems and the suitability of military Doppler navigators for civil helicopter use are also being explored. Approach capabilities using airborne radar approach have been established for offshore platforms. Further target and target processing enhancement work, to improve operational capabilities at poorly equipped landing sites, will be conducted with NASA using the airborne radar approach, a technique which uses airborne weather radar in the ground mapping mode. Also in support of helicopter approach operations, data for revised helicopter Terminal Instrument Procedures (TERPS) criteria are being collected with various helicopters and NAVAIDs, including VOR/DME, LORAN-C, NDB, ILS, and MLS. A navigation-based system of automatic aircraft position reporting and display for ATC is being evaluated for application in areas lacking radar surveillance. The system, LORAN-C Flight Following, has been installed in the Houston Air Route Traffic Control Center (ARTCC) and will be used to enhance ATC operations in the offshore helicopter sector of the Gulf of Mexico.

The FAA is also addressing the proper integration of the helicopter, with its unique set of characteristics and attributes, into the air traffic control system. Activities establishing the foundation for direct random routing are being planned for helicopters. Fixed, indirect routes have a most adverse effect on helicopters which predominantly operate on relatively short flights. Separate, reduced-width routes are also being used in high traffic-density areas where it is desirable to segregate helicopters and other low-speed aircraft. Simultaneous airport landings and departures of helicopters and fixed-wing aircraft are being used today and will increase with the introduction of MLS with its flexible approach path capability. The special nature of navigation requirements for these helicopter operations, as well as for others, such as holding airspace and curvilinear/decelerating approaches, are aimed at the integration of helicopters into the NAS.

#### 5. Precision Approach and Landing

The objective of the FAA is to support the integration of MLS, in an evolutionary manner, into the NAS. The first contract for procurement of production MLS ground equipment was awarded in 1984.

#### B. Civil Marine

The USCG plans for improving marine navigation systems, which serve the civil maritime user, are described below. They cover the following phases of marine navigation: Oceanic, Coastal, Harbor, Harbor Approach, and Inland Waterways.

##### 1. Oceanic

The primary terrestrial-based system in use for oceanic navigation is OMEGA. No R,E&D activities are ongoing or planned.

##### 2. Coastal

The primary system in use for U.S. coastal marine radionavigation is LORAN-C. No R,E&D activities are ongoing or planned.

##### 3. Harbor and Harbor Approach and Inland Waterways

There currently is no Federally-provided radionavigation system capable of meeting the 8 to 20 meter accuracy required for marine navigation in Harbor and Harbor Approach areas. LORAN-C can meet these requirements in a few selected areas. The USCG has developed and demonstrated a differential LORAN-C system which readily meets Harbor and Harbor Approach accuracy requirements in many, but not all, major harbor areas.

GPS/SPS, with the current planned level of selective availability degradation, will not meet the Harbor and Harbor Approach requirements. The USCG is working with other DOT modes and members of the civil community to develop a differential GPS system which will meet or exceed the Harbor and Harbor Approach accuracy requirements. The system will use fixed GPS reference stations which will broadcast differential corrections over USCG radiobeacons. The system has potential application in marine and terrestrial navigation and survey operations. The system is based on differential message and data standards developed by a multi-disciplinary committee under the sponsorship of the RTCM.

A proof of concept differential system, including the radiobeacon data link and user equipment, is under development. Operational tests of the system will result in recommended differential GPS/SPS marine performance specifications for future development.

A series of ship simulator studies are planned to evaluate the minimum radionavigation sensor accuracy and display requirements for piloting in restricted waterways. These studies will be used to provide a basis for establishing requirements for Harbor and Harbor Approach navigation system performance.

No efforts are being expended by the USCG to develop any radionavigation systems for inland waterways.

### C. Civil Land

DOT does not have any specific R,E&D activities planned for existing radionavigation systems that will directly affect the land user community. Use of the existing radionavigation systems for land applications will be monitored to determine if there is a need for future DOT R,E&D on existing systems. RSPA will also monitor private sector R,E&D for use of existing radionavigation systems for land applications.

In recent years, several departments and agencies of the U.S. Government sponsored R,E&D activities utilizing existing radionavigation systems for various land uses. Examples of such applications include locating and monitoring the position of vehicles including automobiles, trucks, buses, rapid transit vehicles and trains; from remote sites; monitoring the position of hazardous materials shipments; and registering the location of and boundaries for natural and agricultural resources.

There is also a cooperative research study among State and Federal governments and private industry to assess the feasibility of using in-vehicle highway navigation and motorist information systems as a means of improving safety and reducing traffic congestion in urban areas. The study, "Pathfinder", is a relatively small scale field experiment on a section of urban freeway and adjacent arterials in the Santa Monica Freeway in Los Angeles. The study involves instrumenting 25 vehicles with dead-reckoning map-matching navigators. Real-time traffic information will be conveyed to motorists equipped with the in-vehicle guidance equipment by enhancing the map to display congestion information, time-of-day restrictions, and information on both recurring and non-recurring incidents. Also, information on travel time throughout the test network, resulting from feedback from the 25 test vehicles, will be transmitted to the Traffic Operations Center (TOC). A radio communication system, will be used to communicate this information between the TOC and the vehicles, and also update the in-vehicle map display.

#### 4.4 GPS R,E&D PLANNED BY NASA

While NASA has no requirements per se, survey of potential space users indicates that most scientific missions require position accuracy no greater than 50 meters. However, to perform onboard image registration, position accuracies of 5 to 10 meters will be required.

NASA Ames is investigating the potential use of differential GPS to support approaches for aircraft. Flight tests are being conducted at Crow's Landing near Mountain View, California. Initial results have proved very promising.

#### 4.5 DOD MLS R&D

DOD is committed to a transition to MLS in conjunction with FAA and NATO. The USAF as lead service has initiated a 15-year program to phase out ILS airborne and ground equipment. The program is timed to coincide with FAA, ICAO and NATO transition plans. Maximum use will be made of avionics and ground equipment developed for civil applications. USAF R&E will be limited to developing ground equipment for use in mobile or high-threat applications and to acquiring military avionics for those platforms for which commercial civil avionics are not suitable.

**Fixed Based Systems:** MLS ground systems identical to those purchased by the FAA for civil airports will be purchased by the USAF (256), the Navy (112), and the Army (37). DOD systems will be purchased at the same time as the FAA's second and third contracts are prepared.

**Mobile MLS:** The USAF as lead service will develop a mobile MLS ground system compatible with fixed-base systems for DOD, and will provide precision approach capability at tactical, expeditionary, or austere locations. The MLS equipment must be small, easily-sited, relocatable, reliable, and sufficiently rugged for wartime operations.

**Avionics:** Military cargo, tanker, transport, and support aircraft will be equipped with commercial MLS avionics that will meet FAA requirements. Special military avionics will be developed by the USAF and the Navy for combat aircraft.

#### 4.6 DOD DIFFERENTIAL GPS R&D

The DOD, in coordination with the FAA and NASA, is investigating the feasibility of developing a differential GPS for use at improvised aircraft landing sites (jungle clearings, interstate highways, etc/). The concept is to assemble light, person-transportable components that are currently available and that may be able to provide a differential data link. Every attempt will be made to avoid the requirement for additional aircraft avionics. The objective of this R&D effort is to enhance the benefits of GPS rather than the development of a new precision landing aid. The DOD remains committed to MLS and will continue with mobile MLS developments.

**APPENDIX A**  
**RADIONAVIGATION SYSTEM DESCRIPTIONS**



## APPENDIX A. RADIONAVIGATION SYSTEM DESCRIPTIONS

This appendix addresses the characteristics, capabilities, and limitations of existing and proposed common-use radionavigation systems. The systems covered are:

- o LORAN-C
- o VOR, VOR/DME, VORTAC
- o OMEGA
- o TACAN
- o Radiobeacons (including RACONS)
- o ILS
- o MLS
- o GPS
- o TRANSIT

### A.1 HYBRID SYSTEMS

The above systems are sometimes used in combination with each other or with other systems. These combined systems are often implemented so that a major attribute of one system will supplement a weakness of another. For example, a system having high accuracy and a low fix rate might be combined with a system with a lower accuracy and higher fix rate. The combined system would demonstrate characteristics of a system with both high accuracy and a high fix rate.

### A.2 DIFFERENTIAL APPLICATIONS

Large area coverage systems such as OMEGA, GPS or LORAN-C may exhibit variances from a predicted grid established for navigation, charting or derivation of guidance information. This variance may be caused by propagation anomalies, errors in geodesy, accidental perturbations of signal timing or other factors. Intentional security protocols may also induce variances which will degrade the accuracy of the systems.

Adverse effects of these variances may be substantially reduced, if not practically eliminated, by differential use of signals available. In such differential operation, a facility may be located at a fixed point (or points) within an area of interest. Signals from the system to be used (for example GPS) are observed in real time and compared with signals expected to be observed at the fixed point. Differences between observed signals and predicted signals are transmitted to users as a differential correction to upgrade the precision and performance of the user's receiver processor.

The area over which corrections can be made from a single differential facility depends on a number of factors, including timeliness of correction dissemination, range of the correction transmission, area and uniformity of the system's grid, and user equipment implementations. A differential facility might serve an area with a radius of several hundred miles, depending on the system used and the method of implementation.

The FRP does not specifically address the kinds or numbers of differential facilities that may be implemented in the future. Research and development to assess the potential for differential operation are a part of current as well as future plans for specific applications.

It should be noted that, with the exception of OMEGA, no standards have been developed for the transmission of differential corrections. Guidelines for the transmission of differential OMEGA corrections were established by the Inter-governmental Maritime Consultative Organization (now known as the International Maritime Organization) in Resolution A.425 (XI), "Differential OMEGA Correction Transmitting Stations," dated November 15, 1979.

### A.3 RADIONAVIGATION SYSTEM PARAMETERS

All of the systems considered are defined in terms of system performance parameters which determine the utilization and limitations of the individual navigation systems. These parameters are:

- o Signal characteristics
- o Accuracy
- o Availability
- o Coverage
- o Reliability
- o Fix rate
- o Fix dimension
- o Capacity
- o Ambiguity
- o Integrity

These parameters characterize the signal in space and are principally signal power levels, frequencies, signal formats, data rates, and any other data sufficient to completely define the means by which a user derives navigational information.

#### A.3.1 Accuracy

In navigation, the accuracy of an estimated or measured position of a craft (vehicle, aircraft, or vessel) at a given time is the degree of conformance of that position with the true position of the craft at that time. Since accuracy is a statistical measure of performance, a statement of the accuracy of a navigation system is meaningless unless it includes a statement of the uncertainty in position which applies.

#### Statistical Measure of Accuracy

Navigation system errors generally follow a known error distribution. Therefore, the uncertainty in position can be expressed as the probability that the error will not exceed a certain amount. A thorough treatment of errors is complicated by the fact that the total error is comprised of errors caused by instability of the transmitted signal, effects of weather and other physical changes in the propagation medium, errors in the receiving equipment, and errors introduced by the human navigator. In specifying or describing the accuracy of a system, the human errors usually are excluded. Further complications arise because some navigation systems are linear (one-dimensional) while others provide two or three dimensions of position.

When specifying linear accuracy, or when it is necessary to specify requirements in terms of orthogonal axes (e.g., along-track or cross-track), the 95 percent confidence level will be used. Vertical or bearing accuracies will be specified in one-dimensional terms (2 sigma), 95 percent confidence level.

When two-dimensional accuracies are used, the 2 drms (distance root mean square) uncertainty estimate will be used. Two drms is twice the radial error,  $d_{rms}$ . The radial error is defined as the root-mean-square value of the distances from the true location point of the position fixes in a collection of measurements. It is often

found by first defining an arbitrarily-oriented set of perpendicular axes, with the origin at the true location point. The variances around each axis are then found, summed, and the square root computed. When the distribution of errors is elliptical, as it often is for stationary, ground-based systems, these axes can be taken for convenience as the major and minor axes of the error ellipse. Then the confidence level depends on the elongation of the error ellipse. As the error ellipse collapses to a line, the confidence level of the 2 drms measurement approaches 95 percent; as the error ellipse becomes circular, the confidence level approaches 98 percent. The GPS 2 drms accuracy will be at 95 percent probability.

DOD specifies horizontal accuracy in terms of Circular Error Probable (CEP--the radius of a circle containing 50 percent of all possible fixes). For the FRP, it is agreed that the conversion of CEP to 2 drms would be accomplished by using 2.5 as the multiplier.

### Types of Accuracy

Specifications of radionavigation system accuracy generally refer to one or more of the following definitions:

- A. Predictable accuracy: The accuracy of a position with respect to the geographic, or geodetic, coordinates of the earth.
- B. Repeatable accuracy: The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system.
- C. Relative accuracy: The accuracy with which a user can measure position relative to that of another user of the same navigation system at the same time. This may be expressed also as a function of the distance between the two users. Relative accuracy may also refer to the accuracy with which a user can measure position relative to his own position in the recent past. For example, the present position of a craft whose desired track forms a specific geometric pattern in search operations or hydrographic survey, will be measured generally with respect to a previously determined datum.

### A.3.2 Availability

The availability of a navigation system is the percentage of time that the services of the system are usable by the navigator. Availability is an indication of the ability of the system to provide usable service within the specified coverage area. Signal availability is the percentage of time that navigational signals transmitted from external sources are available for use. It is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities.

### A.3.3 Coverage

The coverage provided by a radionavigation system is that surface area or space volume in which the signals are adequate to permit the navigator to determine

position to a specified level of accuracy. Coverage is influenced by system geometry, signal power levels, receiver sensitivity, atmospheric noise conditions, and other factors which affect signal availability.

#### A.3.4 Reliability

The reliability of a navigation system is a function of the frequency with which failures occur within the system. It is the probability that a system will perform its function within defined performance limits for a specified period of time under given operating conditions. Formally, reliability is one minus the probability of system failure.

#### A.3.5 Fix Rate

The fix rate is defined as the number of independent position fixes or data points available from the system per unit time.

#### A.3.6 Fix Dimensions

This characteristic defines whether the navigation system provides a linear, one-dimensional line-of-position, or a two- or three-dimensional position fix. The ability of the system to derive a fourth dimension (i.e., time) from the navigational signals is also included.

#### A.3.7 System Capacity

System capacity is the number of users that a system can accommodate simultaneously.

#### A.3.8 Ambiguity

System ambiguity exists when the navigation system identifies two or more possible positions of the vehicle, with the same set of measurements, with no indication of which is the most nearly correct position. The potential for system ambiguities should be identified along with provision for users to identify and/or resolve them.

#### A.3.9 Integrity

Integrity is the ability of a system to provide timely warnings to users when the system should not be used for navigation.

### A.4 RADIONAVIGATION SYSTEM DESCRIPTIONS

This section describes the characteristics of those individual radionavigation systems currently in use or under development. These systems are described in terms of the parameters previously defined in Section A.3. All of the systems used for civil navigation are discussed. The systems which are used exclusively to meet the special applications of DOD are discussed in the JCS MNP.

#### A.4.1 LORAN-C

LORAN-C was developed to provide DOD with a radionavigation capability having longer range and much greater accuracy than its predecessor, LORAN-A. It was subsequently selected as the Federally-provided radionavigation system for civil marine use in the U.S. coastal areas. For further LORAN-C coverage information, consult the LORAN-C Users Handbook (available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402).

##### A. Signal Characteristics

LORAN-C is a pulsed, hyperbolic system, operating in the 90 to 110 kHz frequency band. The system is based upon measurement of the difference in time of arrival of pulses of RF energy radiated by a chain of synchronized transmitters which are separated by hundreds of miles. The measurements of time difference (TD) are made by a receiver which achieves high accuracy by comparing a zero crossing of a specified RF cycle within the pulses transmitted by master and secondary stations within a chain. Making this comparison early in the pulse assures that the measurement is made before the arrival of the corresponding skywaves. Precise control over the pulse shape ensures that the proper comparison point can be identified by the receiver. To aid in preventing skywaves from affecting TD measurements, the phase of the 100 kHz carrier of some of the pulses is changed in a predetermined pattern. Envelope matching of the signals is also possible but cannot provide the advantage of cycle comparison in obtaining the full system accuracy. The characteristics of LORAN-C are summarized in Table A-1.

##### B. Accuracy

Within the ground wave range, LORAN-C will provide the user who employs an adequate receiver with predictable accuracy of 0.25 nm (2 drms) or better. The repeatable and relative accuracy of LORAN-C is usually between 18 to 90 meters. All accuracy is dependent upon the Geometric Dilution of Precision (GDO<sup>n</sup>) factors at the user's location within the coverage area.

For LORAN-C navigation, primarily the ground wave is used. Skywave navigation is feasible, but with considerable loss in accuracy. Ground waves and to some degree skywaves may be used for measuring time and time intervals. LORAN-C was originally designed to be a hyperbolic navigation system. However, with the advent of the highly stable frequency standards, LORAN-C can also be used in the range-range (rho-rho) mode of navigation. This is accomplished by a comparison of the received signal phase to a known time reference to determine propagation time and, therefore, range from the stations. It can be used in situations where the user is within reception range of individual stations, but beyond the hyperbolic coverage area. The rho-rho method, using LORAN-C requires that the user have a very precise and stable time reference. The high cost of equipment of this type limits the use of this mode.

The inherent accuracy of the LORAN-C system makes it a suitable candidate for many land radiolocation applications. The purely numeric TD readings (no names, words, or narratives) are easy and efficient to both store and retrieve in automated form. Since the data are purely numeric, there can be none of the ambiguity that results from attempting to retrieve narrative descriptors from traffic accident reports and highway inventory data. While the 100 kHz signal is affected to some

TABLE A-1. LORAN-C SYSTEM CHARACTERISTICS

PREDICTABLE	ACCURACY		AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	CAPACITY	AMBIGUITY POTENTIAL
	REPEATABLE	RELATIVE							
0.25nm (460m) 1:3 SNR	60-300 ft. (18-90m)	60-300 ft. (18-90m)	99+%	U.S. coastal areas, some continental U.S., selected overseas areas	99.7%*	10-20 fixes/mln.	2D	Unlimited	Yes, easily resolved

\* *Triad reliability.*

SYSTEM DESCRIPTION: LORAN-C is a Low Frequency (LF) 100kHz hyperbolic radionavigation system. The receiver computes lines of position (LOP) based on the time of arrival difference between two time synchronized transmitting stations of a chain. Three stations are required (master and two secondaries) to obtain a position fix in the normal mode of operation. LORAN-C can be used in the Rho-Rho mode and accurate position data can be obtained with only two stations. Rho-Rho requires that the user platform have a precise clock. The United States is the primary provider of LORAN-C coverage, although several nations in Europe and the Middle East have or are planning to initiate LORAN-C service.

extent by soil conductivity and terrain, it can be received in mountainous areas (where VHF and UHF systems can be terrain limited); however, some distortion of the hyperbolic grid has been noted. Propagation anomalies may be encountered in urban areas where the proximity of large manmade structures affects the signal. The existence of these anomalies is predictable and can be compensated for, usually by surveying the area. The long range of the LORAN-C system makes it particularly desirable for application to remote areas, or where the user population is too low to justify the cost of a large number of short range facilities.

By monitoring LORAN-C signals at a fixed site, the receiver TD can be compared with a computed TD for the known location of the site. A correction for the area can then be broadcast to users. This technique (called differential LORAN-C), whereby real-time corrections are applied to LORAN-C TD readings, provides improved accuracy. This method shows promise of providing the higher precision needed for marine navigation in harbor approaches and inland waterways. Another technique involves installing short-baseline, low power chains to serve specific restricted areas. In other locations, a low-power transmitter could serve as an additional secondary station to improve the grid geometry and signal strength in a local area.

LORAN-C receivers are available at a relatively low cost and achieve the 0.25 nm (2 drms) accuracy that LORAN-C provides at the limits of the coverage area. A modern LORAN-C receiver automatically acquires and tracks the LORAN-C signal and is useful to the limits of the specified LORAN-C coverage areas.

#### C. Availability

The LORAN-C transmitting equipment is very reliable. Redundant transmitting equipment is used to reduce system downtime. LORAN-C transmitting station signal availability is greater than 99.9 percent.

#### D. Coverage

The LORAN-C system has been expanded over the years to meet the requirements for coverage of the U.S. coastal waters of the conterminous 48 states, the Great Lakes, the Gulf of Alaska, the Aleutians and into the Bering Sea. This coastal LORAN-C system also provides coverage over approximately two-thirds of the conterminous 48 states. Joint USCG/FAA plans now being executed will complete coverage over the 48 conterminous states and improve land coverage in the southern Alaska area around Anchorage. An increase of coverage of the current system is shown in Figure A-1. With DOD funding, the USCG also operates LORAN-C stations in the Far East, Northern Europe and the Mediterranean Sea.

Expansion of the LORAN-C system into the Caribbean Sea, the North Slope of Alaska and Eastern Hawaii has been investigated. Studies have shown, however, that the benefit/cost ratio is currently insufficient to justify expansion of the LORAN-C into any of these areas.

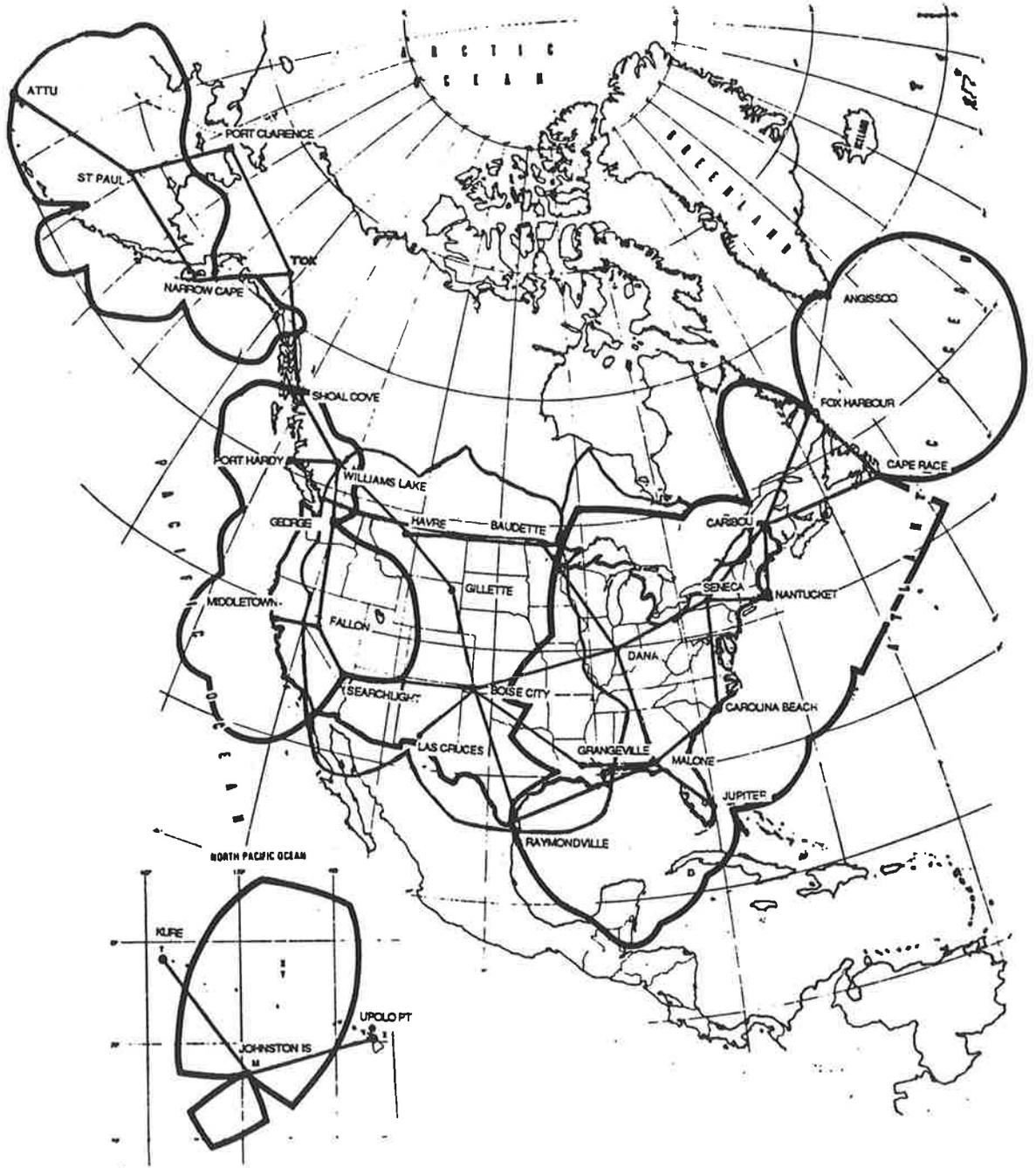


FIGURE A-1. LORAN-C COVERAGE

#### E. Reliability

LORAN-C stations are constantly monitored. The accuracy of system timing is maintained to half the system tolerance. Stations which exceed the system tolerance are "blinked". Blink is the on-off pattern of the first two pulses of the secondary signal indicating that a baseline is unusable. For stations serving the Coastal Confluence Zone, system tolerance is  $\pm 100$  nanoseconds of the calibrated control value. Individual station reliability normally exceeds 99.9 percent, resulting in triad availability exceeding 99.7 percent.

#### F. Fix Rate

The fix rate available from LORAN-C ranges from 10 to 20 fixes per minute.

#### G. Fix Dimension

LORAN-C will furnish two or more LOPs to provide a two-dimensional fix.

#### H. Capacity

An unlimited number of receivers may use LORAN-C simultaneously.

#### I. Ambiguity

As with all hyperbolic systems, theoretically, the LOPs may cross at more than one position on the earth. However, because of the design of the coverage area, the ambiguous fix is at a great distance from the desired fix and is easily resolved.

#### J. Integrity

LORAN-C stations are constantly monitored to detect signal abnormalities which would render the system unuseable for navigation purposes. The secondary stations "blink" to notify the user that a master-secondary pair is unuseable. Blink begins within sixty seconds of the occurrence of an abnormality. For those aviation applications in which notification is required in less than sixty seconds, the USCG and the FAA are considering an "aviation blink" based on tolerances consistent with aviation use.

#### A.4.2 VOR, VOR/DME, TACAN

The three systems that provide the basic guidance for en route air navigation in the U.S. are VOR, DME, and TACAN. Information provided to the aircraft pilot by VOR is the azimuth relative to the VOR ground station. DME provides a measurement of distance from the aircraft to the DME ground station. In most cases, VOR and DME are collocated as a VOR/DME facility. TACAN provides both azimuth and distance information and is used primarily by military aircraft. When TACAN is collocated with VOR, it is a VORTAC facility. DME and the distance measuring function of TACAN are the same.

## I. VOR

### A. Signal Characteristics

VORs are assigned frequencies in the 108 to 118 MHz frequency band, separated by 100 kHz. A VOR transmits two 30 Hz modulations resulting in a relative electrical phase angle equal to the azimuth angle of the receiving aircraft. A cardioid field pattern is produced in the horizontal plane and rotates at 30 Hz. A non-directional (circular) 30 Hz pattern is also transmitted during the same time in all directions and is called the reference phase signal. The variable phase pattern changes phase in direct relationship to azimuth. The reference phase is frequency modulated while the variable phase is amplitude modulated. The receiver detects these two signals and computes the azimuth from the relative phase difference. For difficult siting situations, a system using the Doppler effect was developed and uses 50 instead of four antennas for the variable phase. The same avionics works with either type ground station. The signal characteristics of VOR are summarized in Table A-2.

### B. Accuracy (2 sigma)

1. Predictable - The ground station errors are approximately  $\pm 1.4$  degrees. The addition of course selection, receiver and flight technical errors, when combined using root-sum-squared (RSS) techniques, is calculated to be  $\pm 4.5$  degrees.

2. Relative - Although some course bending could influence position readings between aircraft, the major relative error consists of the course selection, receiver and flight technical components. When combined using RSS techniques, the value is approximately  $\pm 4.3$  degrees. The VOR ground station relative error is  $\pm 0.35$  degrees.

3. Repeatable - The major error components of the ground system and receiver will not vary appreciably in the short term. Therefore, the repeatable error will consist mainly of the flight technical error (the pilots' ability to fly the system) which is  $\pm 2.3$  degrees.

### C. Availability

Because VOR equipments are redundant and the facilities are overlapped by adjacent stations, the availability is considered to approach 100 percent for new solid state equipment.

### D. Coverage

VOR has line-of-sight limitations which could limit ground coverage to 30 miles or less. At altitudes above 5000 feet, the range is approximately 100 nm, and above 20,000 feet, the range will approach 200 nm. These stations radiate approximately 200 watts. Terminal VOR stations are rated at approximately 50 watts and are only intended for use within the terminal areas. Actual VOR coverage information is contained in FAA Order 1010.55C.

TABLE A-2. VOR, VOR/DME SYSTEM CHARACTERISTICS

PREDICTABLE	ACCURACY (2 Sigma)		AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	CAPACITY	AMBIGUITY POTENTIAL
	REPEATABLE	RELATIVE							
VOR: 90m (± 1.4°)*	23m (± 0.35°)**	23m (± 0.35°)**	Approaches 100%	Line of sight	Approaches 100%	Continuous	Heading in degrees or angle off course  Slant range (nm)	Unlimited  100 users per site, full service	None
DME: 185m (± 0.1nm)	185m (± 0.1nm)	185m (± 0.1nm)							

\* The flight check of published procedures for the VOR signal is ± 1.4°. The ground monitor turns the system off if the signal exceeds ± 1.0°. The cross track error used in the chart is for ± 1.4° at 2nm from the VOR site. However, some uses of VOR are overhead and or 1/2nm from the VOR.  
 \*\* Test data shows that 99.94% of the time the error is less than ± .35°. These values are for ± .35° at 2nm from the VOR.

**SYSTEM DESCRIPTION:** VOR provides aircraft with bearing information relative to the VOR signal and magnetic north. The system is used for landing, terminal and en route guidance. VOR transmitters operate in the VHF frequency range. DME provides a measurement of distance from the aircraft to the DME ground station. DME operates in the UHF frequency range.

### E. Reliability

Due to advanced solid state construction and the use of remote maintenance monitoring techniques, the reliability of solid state VOR approaches 100 percent.

### F. Fix Rate

This system allows a continuous update of deviation from a selected course. Initialization is less than one minute after turn-on and will vary as to receiver design.

### G. Fix Dimension

The system shows magnetic bearing to a VOR station and deviation from a selected course, in degrees.

### H. Capacity

The capacity of a VOR station is unlimited.

### I. Ambiguity

There is no ambiguity possible for a VOR station.

### J. Integrity

VOR provides system integrity by removing a signal from use within ten seconds of an out-of-tolerance condition detected by an independent monitor.

## II. DME

### A. Signal Characteristics

The interrogator in the aircraft generates a pulsed signal (interrogation) which, when of the correct frequency and pulse spacings, is accepted by the transponder. In turn, the transponder generates pulsed signals (replies) which are sent back and accepted by the interrogator's tracking circuitry. Distance is then computed by measuring the total round trip time of the interrogation and its reply. The operation of DME is thus accomplished by paired pulse signals and the recognition of desired pulse spacings accomplished by the use of a decoder. The transponder must reply to all interrogators. The interrogator must measure elapsed time between interrogation and reply pulse pairs and translate this to distance. All signals are vertically polarized. These systems are assigned in the 960 to 1213 MHz frequency band with a separation of 1 MHz.

The capability to use Y-channel service has been developed and implemented to a very limited extent (approximately 15 DMEs paired with localizers use the Y-channel frequencies). The term "Y-channel" refers to VOR frequency spacing. Normally, X-channel frequency spacing of 100 kHz is used. Y-channel frequencies are offset from the X-channel frequencies by 50 kHz. In addition, Y-channel DMEs are identified by a wider interrogation pulse-pair time spacing of 0.036 msec versus X-channel DMEs at 0.012 msec spacing. X- and Y-channel applications are presently limited to minimize user equipment changeovers. The signal characteristics of DME are summarized in Table A-2.

B. Accuracy (2 sigma)

1. Predictable - The ground station errors are less than  $\pm 0.1$  nm. The overall system error (airborne and ground RSS) is not greater than  $\pm 0.5$  nm or 3 percent of the distance, whichever is greater.

2. Relative - Although some errors could be introduced by reflections, the major relative error emanates from the receiver and flight technical error.

3. Repeatable - Major error components of the ground system and receiver will not vary appreciably in the short term.

C. Availability

The availability of DME is considered to approach 100 percent, with positive indication when the system is out-of-tolerance.

D. Coverage

DME has a line-of-sight limitation, which limits ground coverage to 30 nm or less. At altitudes above 5,000 feet, the range will approach 100 nm. En route stations radiate at 1000 watts. Terminal DMEs radiate 100 watts and are only intended for use in terminal areas.

E. Reliability

With the use of solid state components and remote maintenance monitoring techniques, the reliability of the DME approaches 100 percent.

F. Fix Rate

The system essentially gives a continuous update of distance to the facility. Actual update rate varies with the design of airborne equipment and system loading.

G. Fix Dimension

The system shows slant range to the DME station in nm.

H. Capacity

For present traffic capacity 110 interrogators are considered reasonable. Future traffic capacity could be increased when necessary through reduced individual aircraft interrogation rates and removal of beacon capacity reply restrictions.

I. Ambiguity

There is no ambiguity in the DME system.

## J. Integrity

DME provides system integrity by removing a signal from use within ten seconds of an out-of-tolerance condition detected by an independent monitor.

## III. TACAN

### A. Signal Characteristics

TACAN is a short-range UHF (960 to 1215 MHz) radionavigation system designed primarily for aircraft use. TACAN transmitters and responders provide the data necessary to determine magnetic bearing and distance from an aircraft to a selected station. TACAN stations in the U.S. are frequently collocated with VOR stations. These facilities are known as VORTACs. The signal characteristics of TACAN are summarized in Table A-3.

### B. Accuracy (2 sigma)

1. Predictable - The ground station errors are less than  $\pm 1.0$  degree for azimuth for the 135 Hz element and  $\pm 4.5$  degrees for the 15 Hz element. Distance errors are the same as DME errors.

2. Relative - The major relative errors emanate from course selection, receiver and flight technical error.

3. Repeatable - Major error components of the ground station and receiver will not vary greatly in the short term. The repeatable error will consist mainly of the flight technical error.

### C. Availability

The availability of TACAN service is considered to approach 100 percent.

### D. Coverage

TACAN has a line-of-sight limitation which limits ground coverage to 30 nm or less. At altitudes of 5,000 feet the range will approach 100 nm; above 18,000 feet, the range approaches 130 nm. The station output power is 5 KW.

### E. Reliability

With the use of solid state electronics and remote maintenance monitoring techniques, the reliability of the TACAN system approaches 100 percent.

### F. Fix Rate

TACAN provides a continuous update of the deviation from a selected course. Initialization is less than one minute after turn on. Actual update rate varies with the design of airborne equipment and system loading.

**TABLE A-3. TACAN SYSTEM CHARACTERISTICS**

ACCURACY			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE							
Azimuth $\pm 1^\circ$ ( $\pm$ 63m at 3.75km)	Azimuth $\pm 1^\circ$ ( $\pm$ 63m at 3.75km)	Azimuth $\pm 1^\circ$ ( $\pm$ 63m at 3.75km)	98.7%	Line of sight	99%	Continuous	Distance and bearing from station	110 for distance. Unlimited in azimuth	No ambiguity in range. Slight potential for ambiguity at multiples of $40^\circ$
DME: 185m ( $\pm$ 0.1nm)	DME: 185m ( $\pm$ 0.1nm)	DME: 185m ( $\pm$ 0.1nm)							

**SYSTEM DESCRIPTION:** TACAN is a short range navigation system primarily used by the military. The system provides range, bearing and station identification. TACAN operates in the UHF band. When TACAN is collocated with a VOR it is called a VORTAC facility.

### G. Fix Dimension

The system shows magnetic bearing, deviation in degrees, and distance to the TACAN station in nm.

### H. Capacity

For distance information, 110 interrogators are considered reasonable for present traffic handling. Future traffic handling could be increased when necessary through reduced airborne interrogation rates and increased reply rates. Capacity for the azimuth function is unlimited.

### I. Ambiguity

There is no ambiguity in the TACAN range information. There is a slight probability of azimuth ambiguity at multiples of forty degrees.

### J. Integrity

TACAN provides system integrity by removing a signal from use within ten seconds of an out-of-tolerance condition detected by an independent monitor.

## A.4.3 OMEGA

The OMEGA system was proposed initially to meet a DOD need for worldwide general en route navigation but has now evolved into a system used primarily by the civil community. The system is comprised of eight continuous wave (CW) transmitting stations situated throughout the world. Worldwide position coverage was attained when the station in Australia became operational in 1982.

### A. Signal Characteristics

OMEGA utilizes CW phase comparison of signal transmission from pairs of stations. The stations transmit time-shared signals on four frequencies, in the following order: 10.2 kHz, 11.33 kHz, 13.6 kHz, and 11.05 kHz. In addition to these common frequencies, each station transmits a unique frequency to aid station identification and to enhance receiver performance. The signal characteristics of OMEGA are summarized on Table A-4.

### B. Accuracy

The inherent accuracy of the OMEGA system is limited by the accuracy of the propagation corrections that must be applied to the individual receiver readings. The corrections may be in the form of predictions from tables which can be applied to manual receivers or may be stored in memory and applied automatically in computerized receivers. The system was designed to provide a predictable accuracy of 2 to 4 nm (2 drms). That accuracy depends on location, station pairs used, time of day, and validity of the propagation corrections.

TABLE A-4. OMEGA SYSTEM CHARACTERISTICS

ACCURACY		AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	CAPACITY	AMBIGUITY POTENTIAL	
PREDICTABLE	REPEATABLE								RELATIVE
2-4nm (3.7-7.4km)	2-4nm (3.7-7.4km)	0.25-0.5nm (463-926m)	99+%	Worldwide continuous	97%*	1 fix every 10 seconds	2D	Unlimited	Requires knowledge to $\pm$ 36nm**

\* Three station joint signal availability.

\*\* Three frequency receiver (10.2, 11.33, 13.6kHz).

SYSTEM DESCRIPTION: OMEGA is a Very Low Frequency (VLF) 10.2 - 13.6kHz hyperbolic radionavigation system. There are eight transmitting stations now in full operation. Position information is obtained by measuring relative phase difference of received OMEGA signals. The system is multinational, being operated by seven nations with day-to-day operational control exercised by the U.S. Coast Guard.

Propagation correction tables are based on theory and modified to fit monitor data taken over long periods for localized areas. An extensive monitoring program is in use to verify the propagation model used to predict the corrections and the system accuracy in the area of the network stations. A number of permanent monitors will be maintained to update the model on a long-term basis. The system currently provides coverage over most of the earth. The specific accuracy attained depends on the type of equipment used as well as the time of day and the location of the user. In most cases, the accuracies attained are consistent with the 2 to 4 nm system design goal and some cases much better accuracy is reported. An area validation program is being conducted by the USCG to verify that the OMEGA system meets its design goal of 2 to 4 nm accuracy. Validations indicate that goal is being met.

A differential OMEGA system has been developed and there are approximately 15 stations in operation primarily along the coast of Europe and in the Mediterranean. Differential OMEGA stations operate on the principal of a local area monitor system comparing the received OMEGA signal with the predicted signal for the location and then transmitting a correction factor based on the observed difference. The correction factor is usually transmitted over an existing radiobeacon system and can provide an accuracy ranging from 0.3 nm at 50 miles to 1 nm at 500 miles. The range of transmission of the correction factor varies with the range of the beacon, but is roughly three times the advertised range of the beacon. Reception of the differential OMEGA signal requires the use of a differential OMEGA receiver.

#### C. Availability

Exclusive of infrequent periods of scheduled off-air time for maintenance, OMEGA availability is greater than 99 percent per year for each station and 95 percent for three stations. Annual system availability has been greater than 97 percent with scheduled off-air time included.

#### D. Coverage

OMEGA provides essentially worldwide coverage.

#### E. Reliability

OMEGA system design requirements for reliability called for 99 percent single station availability and 95 percent three-station joint signal availability. Three station joint signal availability exceeds 97 percent, including both emergency shutdowns and scheduled off-air periods.

#### F. Fix Rate

OMEGA provides independent positional fixes once every ten seconds.

#### G. Fix Dimension

OMEGA will furnish two or more lines of position (LOPs) to provide a two-dimensional fix.

## H. Capacity

An unlimited number of receivers may be used simultaneously.

### I. Ambiguity

In this CW system, ambiguous LOPs occur since there is no means to identify particular points of constant phase difference which recur throughout the coverage area. The area between lines of zero phase difference are termed "lanes." Single-frequency receivers use the 10.2 kHz signals whose lane width is about eight nautical miles on the baseline between stations. Multiple-frequency receivers extend the lane width, for the purpose of resolving lane ambiguity. Lane widths of approximately 288 nm along the base line can be generated with a four-frequency receiver. Because of the lane ambiguity, a receiver must be preset to a known location at the start of a voyage. The accuracy of that position must be known with sufficient accuracy to be within the lane that the receiver is capable of generating (i.e., 4 nm for a single-frequency receiver or approximately 144 nm for a four-frequency receiver). Once set to a known location, the OMEGA receiver counts the number of lanes it crosses in the course of a voyage. This lane count is subject to errors which may be introduced by an interruption of power to the receiver, changes in propagation conditions near local sunset and sunrise and other factors. To use the single frequency OMEGA receiver effectively for navigation, it is essential that a DR plot or similar means be carefully maintained and the OMEGA positions compared to it periodically so that any lane ambiguities can be detected and corrected.

The accuracy of an OMEGA phase-difference measurement is independent of the elapsed time or distance since the last update. Unless the OMEGA position is verified occasionally by comparison to a fix obtained with another navigation system or by periodic comparison to a carefully maintained plot, the chance of an error in the OMEGA lane count increases with time and distance. These errors are reduced in multiple frequency receivers since they are capable of developing larger lane widths to resolve ambiguity problems.

### J. Integrity

OMEGA transmissions are monitored constantly to detect signal abnormalities that affect the useable coverage area. Emergency advisories for unplanned status changes (reduced power, off-air, Polar Cap Anomaly, etc.) are provided by the OMEGA Navigation System Center within 24 hours. This notification is distributed by the National Bureau of Standards (WWV/WWVH announcements), Broadcast Notice to Mariners, Notice to Airmen, HYDROLANT/HYDROPAC messages and recorded telephone messages. Scheduled off-air periods are announced in weekly OMEGA Status Advisory Messages and Notice to Mariners.

#### A.4.4 Radiobeacons

Radiobeacons are nondirectional radio transmitting stations which operate in the low- and medium-frequency bands to provide ground wave signals to a receiver. A radio direction finder (RDF) is used to measure the bearing of the transmitter with respect to an aircraft or vessel.

Presently, there are 1488 low- and medium-frequency aeronautical NDBs. These are distributed as follows: FAA-operated Federal facilities: 728; non-Federally-owned facilities: 760. No change in the navigational status of the civil facilities is expected before 1990 and probably not before 2000. At this time, the probability of change beyond the year 2000 cannot be accurately predicted.

There are approximately 200 USCG-operated marine radiobeacons. Operation of this system will be continued indefinitely. The system is being modernized and expanded slightly with some reconfiguring to better serve the recreational boater who is the main user of the system. This effort includes establishing some new beacons and the relocation of others. Some long range sequenced beacons are being changed to short range continuous beacons to provide more effective homing characteristics for the recreational user. Elimination of some long range beacons and some changes in frequency assignments will result in more efficient use of the allotted RF spectrum and allow for additional beacons in some areas if needed.

#### A. Signal Characteristics

NDBs operate in the 190 to 415 kHz and the 510 to 535 kHz bands. Their transmissions include a coded continuous-wave (CCW) or modulated continuous-wave (MCW) signal to identify the station. The CCW signal is generated by modulating a single carrier with either a 400 Hz or a 1020 Hz tone for morse code identification. The MCW signal is generated by spacing two carriers either 400 Hz or 1020 Hz apart and keying the upper carrier to give the Morse Code identification.

Marine radiobeacons operate in the 275 to 335 kHz band. Some of the longer-range marine radiobeacons operate in groups on the same frequency and are time sequenced to prevent mutual interference. The signal characteristics for the aeronautical and marine beacons are summarized in Table A-5.

#### B. Accuracy

Positional accuracy derived from the bearing information is a function of geometry of the LOPs, the accuracy of compass heading, measurement accuracy, distance from the transmitter, stability of the signal, time of day, nature of the terrain between beacon and craft, and noise. In practice, bearing accuracy is on the order of  $\pm 3$  to  $\pm 10$  degrees. Achievement of  $\pm 3$  degree accuracy requires that the RDF be calibrated before it is used for navigation by comparing radio bearings to accurate bearings obtained visually on the transmitting antenna. Since most direction finder receivers will tune to a number of radio frequency bands, transmissions from sources of known location, such as AM broadcast stations, are also used to obtain bearings, generally with less accuracy than obtained from radiobeacon stations because these signals are not calibrated. For FAA flight inspection, NDB system accuracy is stated in terms of permissible needle swings:  $\pm 5$  degrees on approaches and  $\pm 10$  degrees in the en route area.

#### C. Availability

Availability of marine radiobeacons and aeronautical NDBs is in excess of 99 percent.

TABLE A-5. RADIOBEACON SYSTEM CHARACTERISTICS

PREDICTABLE	ACCURACY (2 Sigma)		REPEATABLE	RELATIVE	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	CAPACITY	AMBIGUITY POTENTIAL
	REPEATABLE	RELATIVE									
Aeronautical ± 3.10°	N/A	N/A	N/A	99%	Approximately 560km for high power stations	99%	Function of the type of beacon continuous or sequenced	One LOP per beacon	Unlimited	Potential is high for reciprocal bearing without sense antenna	
Marine ± 3°	N/A	N/A	N/A	99%	Out to 50nm or 100 fathom curve	99%					

SYSTEM DESCRIPTION: Aircraft non-directional beacons are used to supplement VOR-DME for transition from en route to airport precision approach facilities and as a non-precision approach aid at many airports. Only low frequency beacons are considered in the FRP since there is little common use of the VHF/UHF beacons. Marine radiobeacons are used to identify the entrance to harbors and also provide a means for low cost navigation in the coastal areas.

D. Coverage

The coverage of marine radiobeacons is shown in Figures A-2 and A-3. Extensive NDB coverage is provided by 1488 ground stations, of which the FAA operates 728.

E. Reliability

Reliability is in excess of 99 percent.

F. Fix Rate

The fix rate is a function of whether the beacon is continuous or sequenced. In general, at least one line of position, or relative bearing, is provided continuously. If sequenced, fixing a position may require up to six minutes, depending on the LOPs selected.

G. Fix Dimension

In general, one LOP is available from a single radiobeacon. If within range of two or more beacons, a fix may be obtained.

H. Capacity

An unlimited number of receivers may be used simultaneously.

I. Ambiguity

The only ambiguity which exists in the radiobeacon system is one of reciprocal bearing provided by some receiving equipment which does not employ a sense antenna to resolve direction.

J. Integrity

A radiobeacon is an omnidirectional NAVAID. For aviation radiobeacons (NDBs), out-of-tolerance conditions are limited to output power reduction below operating minimums and loss of the transmitted station identifying tone. The radiobeacons used for non-precision approaches are monitored and will shut down within 15 seconds of an out-of-tolerance condition. Marine radiobeacons are monitored either continuously or periodically, depending on equipment configuration. Notification of outages is provided by a broadcast Notice to Mariners. Outages of long duration are announced in both the Local Notice to Mariners and the Notice to Mariners.

A.4.5 ILS

ILS is a precision approach system normally consisting of a localizer facility, a glide slope facility, and two or three VHF marker beacons. It provides vertical and horizontal navigational (guidance) information during the approach to landing at an airport runway.



FIGURE A-2. CONTERMINOUS U.S. MARINE RADIOBEACON COVERAGE

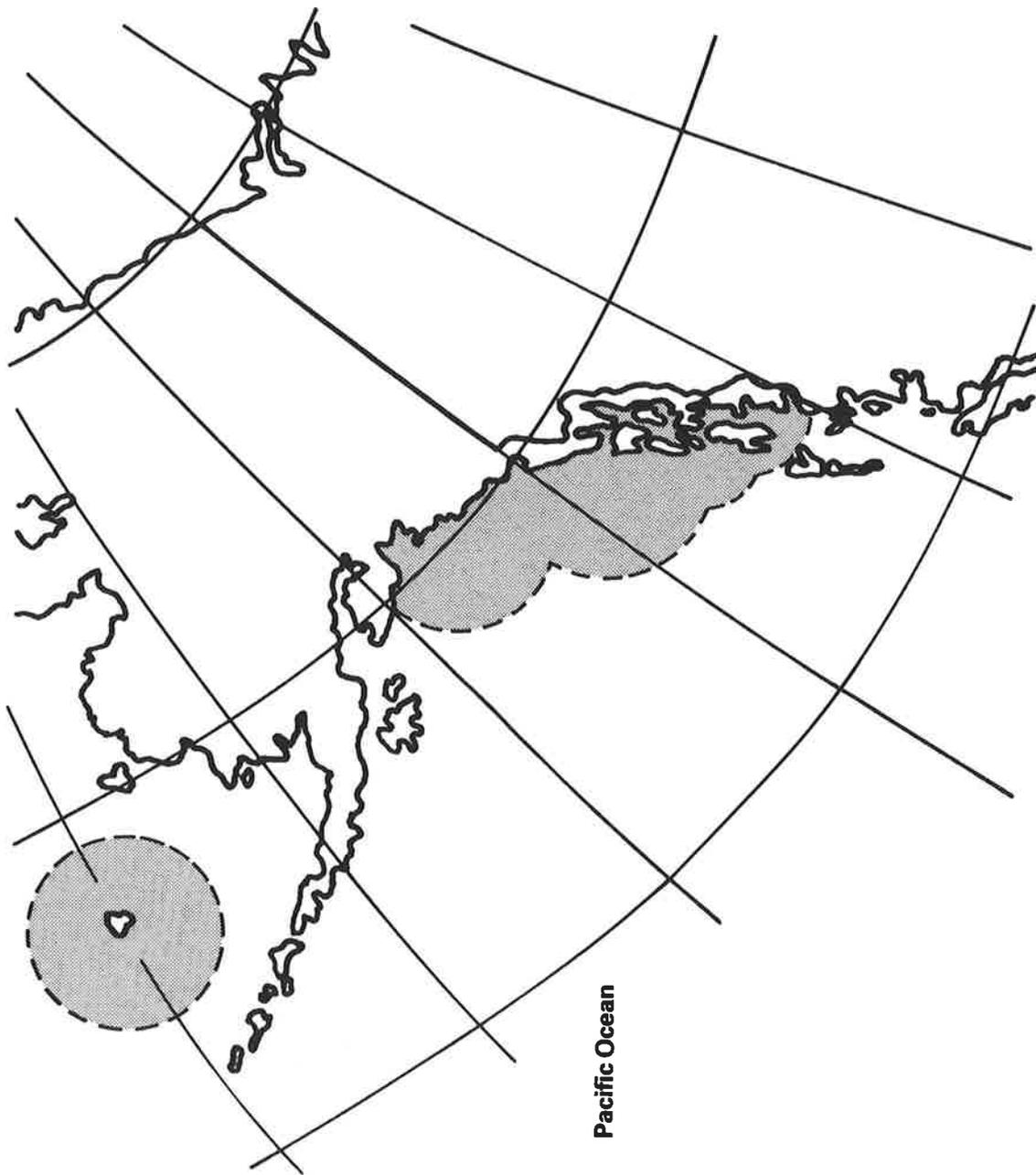


FIGURE A-3. ALASKAN MARINE RADIOBEACON COVERAGE

At present, ILS is the primary worldwide, ICAO-approved, precision landing system. This system is presently adequate, but has limitations in siting, frequency allocation, cost, and performance. Scanning beam MLS, an alternate system, has been developed and approved by the ICAO, and is expected to be implemented to eventually replace ILS.

#### A. Signal Characteristics

The localizer facility and antenna are typically located 1000 feet beyond the stop end of the runway and provides a VHF (108 to 112 MHz) signal. The glide slope facility is located approximately 1000 feet from the approach end of the runway and provides a UHF (328.6 to 335.4 MHz) signal. Marker beacons are located along an extension of the runway centerline and identify particular locations on the approach. Ordinarily, two 75 MHz beacons are included as part of the instrument landing system: an outer marker at the initial approach fix (typically four to seven miles from the approach end of the runway) and a middle marker located 3500 feet plus or minus 250 feet from the runway threshold. The middle marker is located so as to note impending visual acquisition of the runway in conditions of minimum visibility for Category I ILS approaches. An inner marker, located approximately 1000 feet from the threshold, is normally associated with Category II and III ILS approaches. The signal characteristics of ILS are summarized in Table A-6.

#### B. Accuracy

For typical air carrier operations at a 10,000 foot runway, the course alignment (localizer) at threshold is maintained within  $\pm 25$  feet. Course bends during the final segment of the approach do not exceed  $\pm 0.06$  degrees (2 sigma). Glide slope course alignment is maintained within  $\pm 7.0$  feet at 100 feet (2 sigma) elevation and course bends during the final segment of the approach do not exceed  $\pm 0.07$  degrees (2 sigma).

#### C. Availability

While the availability of existing installations has been adequate, many are vacuum tube installations and are being replaced with solid state equipment to further improve availability. The Air Force experienced approximately 95.2 percent overall availability in 1980, (92 percent tube, 97 percent old solid state, 99+ percent new solid state).

#### D. Coverage

Coverage for individual systems is as follows:

Localizer:	$\pm 2^{\circ}$ centered about runway centerline
Glide Slope:	Nominally $3^{\circ}$ above the horizontal
Marker Beacons:	$\pm 40^{\circ}$ (approximately) on minor axis (along approach path) $\pm 85^{\circ}$ (approximately) on major axis.

TABLE A-6. ILS CHARACTERISTICS

ACCURACY AT DECISION HEIGHT (Meters - 2 Sigma)		AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	CAPACITY	AMBIGUITY POTENTIAL
CATEGORY	AZIMUTH							
1	± 9.1	± 3.0	Normal limits from center of localizer + 10° out to 18nm and + 35° out to 10nm	98.6% with positive indication when the system is out of tolerance	Continuous	Heading and deviation in degrees	Limited only by aircraft separation requirement	None
2	± 4.6	± 1.4						
3	± 4.1	± 0.4						

SYSTEM DESCRIPTION: The Instrument Landing System (ILS) is a precision approach system consisting of a localizer facility, a glide slope facility and two or three VHF marker beacons. The VHF (108-112MHz) localizer facility provides accurate, single path horizontal guidance information. The UHF (328.6-335.4MHz) glide slope provides precise, single path, vertical guidance information to a landing aircraft.

#### E. Reliability

ILS reliability approaches 100 percent. However, terrain and other factors may impose limitations upon the use of the ILS signal. Special account must be taken of terrain factors and dynamic factors such as taxiing aircraft which can cause multipath signal transmissions. In some cases, to resolve ILS siting problems, use has been made of localizers with wide aperture antennas and two-frequency systems. In the case of the glide slope, use has been made of wide aperture, two-frequency image arrays and single-frequency broadside arrays to provide service at difficult sites.

#### F. Fix Rate

The glide slope and localizer provide continuous fix information. Marker beacons which provide an audible and visual indication to the pilot are sited at specific points along the approach path as indicated in Table A-7.

**TABLE A-7. AIRCRAFT MARKER BEACONS**

<u>Marker Designation</u>	<u>Typical Distance to Threshold</u>	<u>Audible Signal</u>	<u>Light Color</u>
Outer	4-7nm	continuous dashes (2/sec)	Blue
Middle	3250-3750 ft	continuous alternating dot-dash	Amber
Inner	1000 ft	continuous dots (6/sec)	White

#### G. Fix Dimension

ILS provides both vertical and horizontal guidance with glideslope and localizer signals. At periodic intervals (passing over marker beacons) distance to threshold is obtained.

#### H. Capacity

ILS has no capacity limitations except those imposed by aircraft separation requirements since aircraft must be in trail to use the system.

#### I. Ambiguity

Any potential ambiguities are resolved by imposing system limitations as described in section A.4.5-E.

#### J. Integrity

ILS provides system integrity by removing a signal from use within one second of an out-of-tolerance condition detected by an integral monitor.

#### A.4.6 MLS

MLS is being developed by DOT, DOD, and NASA to provide a common civil/military landing system to meet the full range of user operational requirements to the year 2000 and beyond. It is intended as a replacement for ILS used by both civil and military aircraft and the Ground Controlled Approach system used primarily by military operators. The signal is transmitted throughout a large volume of airspace, thereby permitting service to multiple aircraft, along multiple approach paths, throughout the approach, flare, touchdown, and rollout maneuvers. The system permits greater flexibility in air traffic procedures, enhancing safety, and permits curved and segmented approach paths for purposes of noise abatement. It allows reduced intervals between aircraft to increase runway acceptance rates, and facilitates short field operations for short and/or vertical takeoff and landing (STOL and VTOL) aircraft.

##### A. Signal Characteristics

MLS transmits signals that enable airborne units to determine the precise azimuth angle, elevation angle, and range. The technique chosen for the angle function of the MLS is based upon Time-Referenced Scanning Beams (TRSB). All angle functions of MLS operate in the 5.00 to 5.25 GHz band. Ranging is provided by DME operating in the 0.96 to 1.215 GHz band. An option is included in the signal format to permit a special purpose system to operate in the 15.4 to 15.7 GHz band. The system characteristics of MLS are summarized in Table A-8.

##### B. Accuracy (2 sigma)

The azimuth accuracy is  $\pm 13.0$  feet ( $\pm 4.0$ m) at the runway threshold approach reference datum and the elevation accuracy is  $\pm 2.0$  feet ( $\pm 0.6$ m). The lower surface of the MLS beam crosses the threshold at 8 feet (2.4 meters) above the runway centerline. The flare guidance accuracy is  $\pm 1.2$  feet throughout the touchdown zone and the DME accuracy is  $\pm 100$  feet for the precision mode and  $\pm 1600$  feet for the non-precision mode.

##### C. Availability

Equipment redundancy, as well as remote maintenance monitoring techniques, should allow the availability of this system to approach 100 percent.

##### D. Coverage

Current plans call for the installation of systems with azimuthal coverage of  $\pm 40^\circ$  on either side of the runway centerline, elevation coverage from  $0^\circ$  to a minimum of  $15^\circ$  over the azimuthal coverage area, and out to 20 nm. A few systems will have  $\pm 60^\circ$  azimuthal coverage. MLS signal format has the capability of providing coverage to the entire  $360^\circ$  area but with less accuracy in the area outside the primary coverage area of  $\pm 60^\circ$  of runway centerline. There will be simultaneous operations of ILS and MLS during the transition period.

TABLE A-8. MLS CHARACTERISTICS

ACCURACY AT DECISION HEIGHT (Meters - 2 Sigma)		AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	CAPACITY	AMBIGUITY POTENTIAL
CATEGORY	AZIMUTH							
1	+ 9.1	+ 3.0	+ 40° from center line of runway out to 20nm in both directions*	Expected to approach 100%	6.5-39 fixes/sec depending on function	Heading and deviation in degrees. Range in nm	Limited only by aircraft separation requirements	None
2	+ 4.6	+ 1.4						
3	+ 4.1	+ 0.4						

\* There are provisions for 360° out to 20nm.

SYSTEM DESCRIPTION: The Microwave Landing System (MLS) is a common use precision landing system that will replace ILS and GCA/PAR. MLS operates in the 5-5.25 GHz band. Ranging is provided by precision DME operating in .96-1.22 GHz band.

#### E. Reliability

The MLS signals are generally less sensitive than ILS signals to the effects of snow, vegetation, terrain, structures, and taxiing aircraft. This allows the reliability of this system to approach 100 percent.

#### F. Fix Rate

Elevation angle is transmitted at 39 samples per second, azimuth angle at 13 samples per second, and back azimuth angle at 6.5 samples per second. Usually the airborne receiver averages several data samples to provide fixes of 3 to 6 samples per second. A high rate azimuth angle function of 39 samples per second is available and is normally used where there is no need for flare elevation data.

#### G. Fix Dimensions

This system provides signals in all three dimensions and can provide time if aircraft are suitably equipped.

#### H. Capacity

DME signals of this system are capacity limited; the system limits are approached when 110 aircraft are handled.

#### I. Ambiguity

No ambiguity is possible for the azimuth or elevation signals. Only a very small probability for ambiguity exists for the range signals and then only for multipath caused by moving reflectors.

#### J. Integrity

MLS integrity is provided by an integral monitor. The integral monitor will shut down the MLS within one second of an out-of-tolerance condition.

#### A.4.7 GPS

GPS is a space-based positioning, velocity and time system that has three major segments: space, control and user. The GPS space segment, when fully operational, will be composed of 21 satellites (plus three operational spares) in six orbital planes. The satellites will operate in circular 20,200 km (10,900 nm) orbits at an inclination angle of 55 degrees and with a 12-hour period. The precise spacing of satellites in orbit will be arranged so that a minimum of five satellites will be in view to users worldwide. Each satellite will transmit on two L band frequencies  $L_1$  and  $L_2$ .  $L_1$  will carry a precise (P) signal and a coarse/acquisition (C/A) signal.  $L_2$  will carry a P signal only. Superimposed on these signals will be navigation and system data including satellite ephemeris, atmospheric propagation correction data, and satellite clock bias information.

The control segment will include a number of monitor stations and ground antennas located throughout the world. The monitor stations will use a GPS receiver to passively track all satellites in view and thus accumulate ranging data from the satellite signals. The information from the monitor stations will be processed at the master control station (MCS) to determine satellite orbits and to update the navigation message of each satellite. This updated information will be transmitted to the satellites via the ground antennas, which will also be used for transmitting and receiving satellite control information.

The user segment will consist of antennas and receiver-processors that provide positioning, velocity and precise timing to the user.

#### A. Signal Characteristics

The GPS concept is predicated upon accurate and continuous knowledge of the spatial position of each satellite in the system with respect to time and distance from a transmitting satellite to the user. Each satellite transmits its unique ephemeris data. This data is periodically updated by the master control station based upon information obtained from five widely dispersed monitor stations.

The GPS receiver automatically selects appropriate signals from three or four of the satellites best in view based on optimum satellite-to-user geometry. It then solves time-of-arrival difference quantities to obtain distance between user and satellites. This information establishes the user position with respect to the satellite system. A time correction factor then relates the satellite system to earth coordinates. Each satellite continuously transmits a composite spread spectrum signal at 1227.6 and 1575.42 MHz. User equipment measures four independent pseudo-ranges and range rates and translates these to three-dimensional position, velocity and system time. The characteristics of GPS are summarized in Table A-9.

#### B. Accuracy\*

GPS provides two services for position determination, PPS and SPS. Accuracy of a GPS fix varies with the capability of the user equipment.

##### 1. Precise Positioning Service (PPS)

GPS/PPS is the most accurate positioning, velocity and timing information continuously available, worldwide, from the basic GPS. This service will be limited to authorized U.S. and allied Federal Government and military users and to those civil users who can satisfy U.S. national security requirements. Unauthorized users will be denied access to PPS through the use of cryptography. Precision signal capable military user equipment will provide a predictable positioning accuracy of at least 17.8 meters (2 drms), horizontally and 27.7 meters (2 sigma) vertically, in each of the three dimensions, and timing/timing interval accuracy within 90 nanoseconds.

---

\*Reference System: The geodetic reference system selected for use by the Global Positioning System (GPS) is the DOD World Geodetic System (WGS). The GPS currently uses the 1984 version which is designated as WGS 84. Datum transformation will permit coordinates to be transformed between WGS 84 and most of the major and local datums in the world.

TABLE A-9. GPS CHARACTERISTICS

ACCURACY		REPEATABLE	RELATIVE	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE										
PPS*		Horz - 17.8m Vert - 27.7m Time - 90ns	Horz - 7.6m Vert - 11.7m	Expected to approach 100%	Worldwide continuous	98% probability that a 21-satellite constellation will be operating	Essentially continuous	3D + Velocity + Time	Unlimited	None
SPS		Horz - 100m Vert - 156m Time - 175ns	Horz - 28.4m Vert - 44.5m							

\* For US and Allied military, US Government, and selected civil users specifically approved by the US Government.

**SYSTEM DESCRIPTION:** GPS is a space-based radio positioning navigation system that will provide three-dimensional position, velocity and time information to suitably equipped users anywhere on or near the surface of the earth. The space segment will consist of 21 satellites plus 3 operational spares in 12 hour orbits. Each satellite will transmit navigation data and time signals on 1575.4 and 1227.6 MHz.

2. Standard Positioning Service (SPS)

GPS/SPS is a standard specified level of positioning, velocity and timing accuracy that is available, without qualification and/or restrictions, to any user on a continuous worldwide basis. The accuracy of this service will be established by the U.S. Department of Defense based on U.S. security interests. Present DOD policy provides that a predictable accuracy of 100 meters (2 drms) or better horizontally and 156 meters (2 sigma) vertically will be made available from the beginning of full GPS operation. The GPS 2 drms accuracy will be at the 95 percent level. The best relative accuracy for SPS will be 28.4 meters (2 drms) horizontally and 44.5 meters (2 sigma) vertically.

C. Availability

GPS will provide availability approaching 100 percent to be refined based on orbital experience. This is based upon a 21 satellite constellation plus three orbital spares with at least four satellites in view above a 5° masking angle.

D. Coverage

A 24 satellite constellation (21 plus 3 spares) will provide worldwide three dimensional coverage.

E. Reliability

Operational reliability figures for the GPS satellites will be obtained when operational satellites are launched. However, a GPS satellite has a design life of 7.5 years. With the planned replenishment strategy, a constellation of 21 satellites plus 3 orbital spares will provide a 98 percent probability of having 21 or more satellites operational at any time.

F. Fix Rate

The fix rate is essentially continuous. Actual time to a first fix depends on user equipment capability and initialization with current satellite almanac data.

G. Fix Dimensions

GPS provides three-dimensional positioning and velocity fixes, as well as extremely-accurate time information.

H. Capacity

The capacity is unlimited.

I. Ambiguity

There is no ambiguity.

## J. Integrity

In accordance with the DOD GPS concept, GPS satellites are monitored more than 95 percent of the time by a network of five monitoring stations spread around the world. The information collected by the monitoring stations is processed by the Master Control Station at Colorado Springs, Colorado, and used to periodically update the navigation message (including a health message) transmitted by each satellite. The satellite health message, which is not changed between satellite navigation message updates, is transmitted as part of the GPS navigation message for reception by both PPS and SPS users. Additionally, satellite operating parameters such as navigation data errors, signal availability/anti-spoof failures, and certain types of satellite clock failures are monitored internally within the satellite. If such internal failures are detected, users are notified within six seconds. Other failures detectable only by the control segment may take from 15 minutes to several hours to rectify.

The DOD GPS user equipment utilizes the information contained in the navigation and health messages, as well as self-contained satellite geometry algorithms and internal navigation solution convergence monitors, to compute an estimated figure of merit. This number is continuously displayed to the operator, indicating the estimated overall confidence level of the position information.

### A.4.8 TRANSIT

TRANSIT is a space-based radionavigation system consisting of four or more satellites in approximately 600 nm polar orbits. The phasing of the satellites is deliberately staggered to minimize time between fixes for users. In addition, TRANSIT has four ground based monitors. The monitor stations track each satellite while in view and provide the tracking information necessary to update satellite orbital parameters every 12 hours.

#### A. Signal Characteristics

The satellites broadcast ephemeris information continuously on 150 and 400 MHz. One frequency is required to determine a position. However, by using the two frequencies, higher accuracy can be attained. A receiver measures successive Doppler, or apparent frequency shifts of the signal, as the satellite approaches or passes the user. The receiver then calculates the geographic position of the user based on knowledge of the satellite position that is transmitted from the satellite every two minutes, and knowledge of the Doppler shift of the satellite signal. The characteristics of TRANSIT are summarized in Table A-10.

#### B. Accuracy

Predictable positioning accuracy for a single frequency receiver is 500 meters, for a dual frequency receiver is 25 meters. Repeatable positioning accuracy is 50 meters for a single frequency and 15 meters for a dual frequency receiver. Relative positioning accuracy of less than 10 meters has been measured through translocation techniques. Navigational accuracy is heavily dependent upon the accuracy to which vessel course, speed, and time are known. A one knot velocity input error can cause up to 0.2 nm fix error.

TABLE A-10. TRANSIT CHARACTERISTICS

ACCURACY* (Meters - 2 Sigma)		RELIABILITY	FIX RATE**	FIX DIMENSION	CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE					
Dual Frequency 25m	15m	99%	Every 30 seconds	2D	Unlimited	None
Single Frequency 500m	50m					
AVAILABILITY		Worldwide non-continuous	99%	99% when satellite is in view		

\* Position accuracy is highly dependent on the user's knowledge of his velocity.

\*\* Maximum satellite waiting time varies with latitude. (30 minutes at 80°, 110 minutes at equator)

SYSTEM DESCRIPTION: TRANSIT nominally consists of four operational satellites in polar orbits. The satellites broadcast information on 150 and 400 MHz. A receiver measures the apparent frequency shift of the signals (doppler) as the satellite approaches and passes the user. The receiver then calculates the geographic position of the user, based on satellite position knowledge and corrections received from the transmitted signal.

C. Availability

Availability is better than 99 percent when a TRANSIT satellite is in view. It depends on user latitude, antenna mask angle, user maneuvers during a satellite pass, the number of operational satellites and satellite configuration.

D. Coverage

Coverage is worldwide but not continuous due to the relatively low altitude of the TRANSIT satellites and the precession of satellite orbits.

E. Reliability

The reliability of the TRANSIT satellites is greater than 99 percent.

F. Fix Rate

Fix rate varies with latitude, theoretically from an average of 110 minutes at the equator to an average of 30 minutes at 80 degrees. Presently, due to non-uniform orbital precession, the TRANSIT satellites are no longer in evenly spaced orbits. Consequently, a user can occasionally expect a period greater than 6 hours between fixes. This condition exists for less than 5 percent of system availability.

G. Fix Dimensions

TRANSIT satellites provide a two-dimensional fix.

H. Capacity

TRANSIT satellites have unlimited capacity.

I. Ambiguity

There is no ambiguity.

J. Integrity

TRANSIT satellite signals are monitored by the Naval Astronautics Group (NAG) at Point Mugu, CA, which serves as the satellite constellation ground control facility. Whenever a satellite-transmitted navigation signal is out-of-tolerance or otherwise unsuitable for navigation, NAG will issue a "SPATRAK" alerting message to all known U.S. Navy TRANSIT users, with an information copy to DMA. DMA then ensures that the alert is entered into the Notice to Mariners system for distribution to civil users. The same procedure is used for scheduled test or preventative maintenance periods on selected satellites. TRANSIT receivers do not possess inherent navigation signal integrity monitoring capabilities, other than the ability to recognize and reject the scrambled signal format broadcast by selected satellites during certain NAG-implemented system tests.

**APPENDIX B**  
**CHART REFERENCE SYSTEMS**



## **APPENDIX B CHART REFERENCE SYSTEMS**

### **B.1 CHART REFERENCE SYSTEMS**

Geodetic datums are basic control networks that are used to establish precise geographical positions for features on the surface of the earth. They are established by national governments and form the legal basis for all positioning within the respective nations. Within the last 20 years there have been great strides in the science of geodesy and improvement in our knowledge of the shape and size of the earth. The old datums are no longer scientifically valid. In recent years, international agreements have been made to establish a single earth model for a common World Geodetic System (WGS). This geodetic system has evolved into what is now termed WGS-84. The Global Positioning system (GPS) and inertial navigation systems require geocentric coordinates; i.e., coordinates established on perpendiculars that pass through the center of earth as opposed to coordinates developed on surface algorithms. Within the U.S., the National Geodetic Survey (NGS) is the legal authority for the establishment of the U.S. Datums. The current datum used throughout most of the United States is the North American Datum 1927 (NAD 27). Practically all nautical charts, aeronautical charts, Federal surveys and digital data provided by the National Ocean Service (NOS) are legally established to NAD 27. Subsequently, the NGS has developed a new datum known as North American Datum 1983 (NAD83), which for all practical purposes is identical to WGS-84. NAD 1983 is based upon an internationally accepted earth model, uses geocentrically derived coordinates and is compatible with satellite navigation systems.

### **B.2 NAUTICAL CHARTS**

Most nautical charts, as presently published by various authorities, including those produced by the Defense Mapping Agency (DMA) and the Office of Charting and Geodetic Services (C&GS) of the National Ocean Service, National Oceanic and Atmospheric Administration (NOS/NOAA), are based on regional horizontal datums which have been defined over the years independently of each other. In addition, in many parts of the world, the positional accuracy of chart features (such as hazards to navigation) sometimes varies from chart to chart and, in some cases, within a chart. Certain charts for waters in the Southern Hemisphere, for example, do not show islands in their correct geodetic positions, absolute or relative. Therefore, datums and limited chart accuracy must be considered when a navigational fix is plotted by a navigator on a nautical chart.

Modern sophisticated navigational positioning is based on satellite systems which are geocentric by definition, and these satellite coordinate systems differ significantly in many cases with the local or regional datums of nautical charts. In addition to this difference, the plotted detail such as soundings and navigational aids, contain a minimum plottable error that ranges between 0.5 mm to 1.0 mm on paper.

Virtually all radionavigation equipment incorporating coordinate converters (automated computation of geodetic latitude and longitude from data received from a radionavigation system) are programmed with the World Geodetic System 1972 (WGS-72) description of the earth. In January 1987, GPS began using WGS-84, an improvement over WGS-72. There are significant variations between WGS-72 and WGS-84 coordinates and coordinates referenced to local datum ellipsoids. These differences range from a few meters in the central U.S. to 300 meters in Alaska and the Caribbean.

The large majority (86 percent) of the nautical charts published by the NOS have been compiled on a regional horizontal datum, specifically, the North American Datum of 1927 (NAD 27). The remaining 14 percent of the charts in the NOS nautical chart suite have been published on eight other local or regional datums. NOS has recently adopted a geocentric datum, NAD 83, and is beginning to convert its suite of nautical charts to that datum. The charts of the Pacific islands (U.S. Trust Territories) published by NOS will be compiled on WGS 84. For charting purposes, however, NAD 83 is equivalent to WGS 84. As charts are converted, datum transformation notes will be added which report the extent of the shift from NAD 27 coordinates.

Improvements in worldwide navigational accuracy, which are anticipated with the implementation of the GPS in the early 1990s, will be significant. However, the ability to safely navigate along the coastlines of the world and on the high seas will remain limited where accurate, up-to-date hydrography and associated topographic features are not all positioned on the same satellite-based WGS reference system.

### B.3 AERONAUTICAL CHARTS

The ultimate responsibility for the accuracy of air cartographic positional data rests with National Ocean Service (NOS). Under section 307 (b) (3) of the FAA Act, FAA funds for and determines the requirements and standards for positioning and NOS performs the service. Within the National Airspace System (NAS), the National Geodetic Survey (NGS) establishes the basic U.S. Datum that legally controls all positioning with the U.S. The Nautical Charting Division (NCD) conducts the Airport Obstruction Clearance Surveys (OC Surveys) which establish the positioning for 750 U.S. major civil airports and all NAVAIDS to existing U.S. Datums. The NGS is currently conducting the Airport Datum Monument Program (ADAM) which is establishing datum monuments on 1,700 U.S. non-OC surveyed airports. The ADAM data, which includes end of runway coordinates are determined using GPS and are available in both NAD 27 and NAD 83 datums. In the interim, NAD 27 is used until conversion to NAD 83. The Aeronautical Charting Division verifies all other positions before they are charted.

The planned conversion from NAD 27 to NAD 83 will have a major impact upon FAA. FAA regions are currently evaluating all programs that will be affected by this planned conversion. All positional data currently used within the system will require conversion. The NGS has determined that the differences in horizontal datum within the U.S. (NAD 27 vs NAD 83) are as large as 450 meters in Hawaii, 160 meters in Alaska, 100 meters in the contiguous states, and the differences are not uniformly distributed. Vertical datum differences are relatively minor and transportation will be effected after horizontal datum conversion. The new NAD 83 system will be for all practical purposes identical to the World Geodetic System WGS-84 employed by the Department of Defense for GPS and inertial navigation.

**APPENDIX C**

**DEFINITIONS**



## DEFINITIONS

**ACCURACY** - The degree of conformance between the estimated or measured position and/or velocity of a platform at a given time and its true position or velocity. Radionavigation system accuracy is usually presented as a statistical measure of system error and is specified as:

- a. Predictable - The accuracy of a position with respect to the geographic or geodetic coordinates of the earth.
- b. Repeatable - The accuracy with which a user can return to a position having coordinates which have been measured previously with the same navigation system.
- c. Relative - The accuracy with which a user can measure position relative to that of another user of the same navigation system at the same time. This may be expressed also as a function of the distance between the two users. Relative accuracy may also refer to the accuracy with which a user can measure position relative to his own position in the recent past. For example, the present position of a craft whose desired track forms a specific geometric pattern in search operations or hydrographic survey, will be measured generally with respect to a previously-determined datum.

**AIR TRAFFIC CONTROL** - A service operated by appropriate authority to promote the safe, orderly and expeditious flow of air traffic.

**APPROACH REFERENCE DATUM (MLS)** - A point at a specified height above the runway centerline and the threshold. The height of the MLS approach reference datum is 15 meters (50ft.) A tolerance of plus 3 meters (10 ft.) is permitted.

**AREA NAVIGATION (RNAV)** - A method of navigation that permits aircraft operations on any desired course within the coverage of station-referenced navigation signals or within the limits of self-contained system capability.

**AVAILABILITY** - The availability of a navigation system is the percentage of time that the services of the system are usable. Availability is an indication of the ability of the system to provide usable service within the specified coverage area. Signal availability is the percentage of time that navigational signals transmitted from external sources are available for use. Availability is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities.

**CIRCULAR ERROR PROBABLE (CEP)** - In a circular normal distribution (the magnitudes of the two one-dimensional input errors are equal and the angle of cut is 90°), circular error probable is the radius of the circle containing fifty percent of the individual measurements being made, or the radius of the circle inside of which there is a fifty percent probability of being located.

**COASTAL CONFLUENCE ZONE** - Harbor entrance to 50 nautical miles offshore or the edge of the Continental Shelf (100 fathom curve), whichever is greater.

COMMON-USE SYSTEMS - Systems used by both civil and military sectors.

CONTERMINOUS U.S. - Forty-eight adjoining states and the District of Columbia.

COORDINATE CONVERSION - The act of changing the coordinate values from one system to another; e.g., from geodetic coordinates (latitude and longitude) to Universal Transverse Mercator grid coordinates.

COVERAGE - The coverage provided by a radionavigation system is that surface area or space volume in which the signals are adequate to permit the user to determine position to a specified level of accuracy. Coverage is influenced by system geometry, signal power levels, receiver sensitivity, atmospheric noise conditions, and other factors which affect signal availability.

DIFFERENTIAL - A technique used to improve radionavigation system accuracy by determining positioning error at a known location and subsequently transmitting the determined error, or corrective factors, to users of the same radionavigation system, operating in the same area.

DISTANCE ROOT MEAN SQUARE (drms) - The root-mean-square value of the distances from the true location point of the position fixes in a collection of measurements. As used in this document, 2 drms is the radius of a circle that contains at least 95 percent of all possible fixes that can be obtained with a system at any one place. Actually, the percentage of fixes contained within 2 drms varies between approximately 95.5 percent and 98.2 percent, depending on the degree of ellipticity of the error distribution.

EN ROUTE - A phase of navigation covering operations between a point of departure and termination of a mission. For airborne missions the en route phase of navigation has two subcategories, en route domestic and en route oceanic.

EN ROUTE DOMESTIC - The phase of flight between departure and arrival terminal phases, with departure and arrival points within the conterminous U.S.

EN ROUTE OCEANIC - The phase of flight between the departure and arrival terminal phases, with an extended flight path over an ocean.

FLIGHT TECHNICAL ERROR - The contribution of the pilot in using the presented information to control aircraft position.

GEOCENTRIC - Relative to the earth as a center, measured from the center of the earth.

GEODESY - The science related to the determination of the size and shape of the earth (geoid) by such direct measurements as triangulation, leveling, and gravimetric observations; which determines the external gravitational field of the earth and, to a limited degree, the internal structure.

GEOMETRIC DILUTION OF PRECISION (GDOP) - All geometric factors that degrade the accuracy of position fixes derived from externally-referenced navigation systems.

INCLINATION - One of the orbital elements (parameters) that specifies the orientation of an orbit. Inclination is the angle between the orbital plane and a reference plane, the plane of the celestial equator for geocentric orbits and the ecliptic for heliocentric orbits.

**INTEGRITY** - Integrity is the ability of a system to provide timely warnings to users when the system should not be used for navigation.

**NANOSECOND** - One billionth of a second.

**MEACONING** - A technique of manipulating radio frequency signals to provide false navigation information.

**NATIONAL AIRSPACE SYSTEM (NAS)** - The NAS includes U.S. airspace; air navigation facilities, equipment and services; airports or landing areas; aeronautical charts, information and service; rules, regulations and procedures; technical information; and labor and material used to control and/or manage flight activities in airspace under the jurisdiction of the U.S. System components shared jointly with the military are included.

**NAUTICAL MILE** - A unit of distance used principally in navigation. The International Nautical Mile is 1852 meters long.

**NAVIGATION** - The process of planning, recording, and controlling the movement of a craft or vehicle from one place to another.

**NON-PRECISION APPROACH** - A standard instrument approach procedure in which no electronic glide slope is provided (e.g., VOR, LORAN-C, TACAN, or NDB).

**PERIOD** - The time required by a satellite to complete one revolution.

**PRECISE TIME** - A time requirement accurate to within ten milliseconds.

**PRECISION APPROACH** - A standard instrument approach procedure in which an electronic glideslope is provided (e.g., ILS).

**RADIODETERMINATION** - The determination of position, or the obtaining of information relating to positions, by means of the propagation properties of radio waves.

**RADIOLOCATION** - Radiodetermination used for purposes other than those of radionavigation.

**RADIONAVIGATION** - The determination of position, or the obtaining of information relating to position, for the purposes of navigation by means of the propagation properties of radio waves.

**RELIABILITY** - The probability of performing a specified function without failure under given conditions for a specified period of time.

**RHO (RANGING MODE)** - A mode of operation of a radionavigation system in which the times for the radio signals to travel from each transmitting station to the receiver are measured rather than their differences (as in the hyperbolic mode).

**SOLE MEANS AIR NAVIGATION SYSTEM** - An approved navigation system that can be used for specific phases of air navigation in controlled airspace without the need for any other navigation system.

**SPHERICAL ERROR PROBABLE (SEP)** - The radius of a sphere within which there is a 50 percent probability of locating a point or being located. SEP is the three-dimensional analogue of CEP.

**STANDARD DEVIATION** - A measure of the dispersion of random errors about the mean value. If a large number of measurements or observations of the same quantity are made, the standard deviation is the square root of the sum of the squares of deviations from the mean value divided by the number of observations less one.

**SUPPLEMENTAL AIR NAVIGATION SYSTEM** - An approved navigation system that can be used in controlled airspace of the National Airspace System in conjunction with a sole means navigation systems.

**SURVEILLANCE** - The observation of an area or space for the purpose of determining the position and movements of craft or vehicles in that area or space.

**SURVEY** - The act of making measurements to determine the relative position of points on, above, or beneath the earth's surface.

**SURVEYING** - That branch of applied mathematics which teaches the art of determining accurately the area of any part of the earth's surface, the lengths and directions of the bounding lines, the contour of the surface, etc., and accurately delineating the whole on a map or chart for a specified datum.

**TERMINAL** - A phase of navigation covering operations required to initiate or terminate a planned mission or function. For airborne missions, the terminal phase is used to describe airspace in which approach control service or airport traffic control service is provided.

**TERMINAL AREA** - A general term used to describe airspace in which approach control service or airport traffic control service is provided.

**THETA** - Bearing or direction to a fixed point to define a line of position.

**TIME INTERVAL** - The duration of a segment of time without reference to where the time interval begins or ends.

**UNIVERSAL TRANSVERSE MERCATOR (UTM) GRID** - A military grid system based on the Transverse Mercator projection applied to maps of the earth's surface extending to 84°N and 80°S latitudes.

**VEHICLE LOCATION MONITORING (or Vessel Traffic Services)** - A service provided to maintain the orderly and safe movement of platforms or vehicles. It encompasses the systematic observation of airspace, surface and subsurface areas by electronic, visual or other means to locate, identify and control the movement of platforms or vehicles.

**WORLD GEODETIC SYSTEM (WGS)** - A consistent set of parameters describing the size and shape of the earth, the positions of a network of points with respect to the center of mass of the earth, transformations from major geodetic datums, and the potential of the earth (usually in terms of harmonic coefficients).

## **GLOSSARY**



## GLOSSARY

The following is a listing of abbreviations for organization names and technical terms used in this plan:

ADF	Automatic Direction Finder
AFSCF	Air Force Satellite Control Facility
AGL	Above Ground Level
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATMSMN	Air Traffic Management System Material Need
AVL	Automatic Vehicle Location
AVM	Automatic Vehicle Monitoring
C/A	Coarse/Acquisition
CCW	Coded Continuous Wave
CCZ	Coastal and Confluence Zone
CDI	Course Deviation Indicator
CEP	Circular Error Probable
CGS	Civil GPS Service
CIA	Central Intelligence Agency
CNI/NAV	Communications, Navigation & Identification/Navigation
CNS	Communication, Navigation and Surveillance
CONUS	Continental United States
CS	Control Segment
CSOC	Consolidated Space Operations Center
CSE	Course Selection Error
CW	Continuous Wave
DH	Decision Height
DIA	Defense Intelligence Agency
DMA	Defense Mapping Agency
DME	Distance Measuring Equipment
DME/P	Precision Distance Measuring Equipment
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOS	Department of State
DOT	Department of Transportation
DPM	Deputy Program Manager
DR	Dead Reckoning
drms	distance root mean squared
DSARC	Defense System Acquisition Review Council
DT&E	Development Test & Evaluation
ECCM	Electronic Counter-Countermeasures
ECD	Envelope-to-Cycle Difference
EHF	Extremely High Frequency
EMI	Electromagnetic Interference
EMS	Emergency Medical Service
ERDA	Energy Research & Development Administration (Now Department of Energy)
F <sup>3</sup>	Form, Fit, and Function
FAA	Federal Aviation Administration

FAATC	Federal Aviation Administration Technical Center
FAF	Final Approach Fix
FAR	Federal Aviation Regulation
FCC	Federal Communications Commission
FCZ	Fishery Conservation Zone
FHWA	Federal Highway Administration
FL	Flight Level
FM	Frequency Modulation
FRA	Federal Railroad Administration
FRP	Federal Radionavigation Plan
FSD	Full-Scale Development
FTE	Flight Technical Error
GA	General Aviation
GBF/DIME	Geographic Base File/Dual Independent Map Encoding
GCA	Ground Control Approach
GDOP	Geometric Dilution of Precision
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
GSTDN	Ground Satellite Tracking and Data Network
HF	High Frequency
HHE	Harbor and Harbor Entrance Area
Hz	Hertz
IALA	International Association of Lighthouse Authorities
IAP	Improved Accuracy Program
ICAO	International Civil Aviation Organization
ICNS	Integrated Communication, Navigation and Surveillance
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMO	International Maritime Organization
INS	Inertial Navigation System
IOT&E	Initial Operational Test & Evaluation
JCS	Joint Chiefs of Staff
JPO	Joint Program Office
JTIDS	Joint Tactical Information Distribution System
JTML	Joint Tactical Microwave Landing System
kHz	Kilohertz
LF	Low Frequency
LOFF	LORAN Flight Following
LOP	Line of Position
LORAN	Long-Range Navigation
MAP	Missed Approach Point
MEP	Midcontinent Expansion Plan
MARAD	Maritime Administration
MCS	Master Control Station
MCW	Modulated Carrier Wave
MDA	Minimum Descent Altitude
MF	Medium Frequency
MHz	Megahertz
MIJI	Meaconing, Interference, Jamming, and Intrusion
MLS	Microwave Landing System
MNP	Master Navigation Plan
MOPS	Minimum Operational Performance Standards
MPA/TAC	Maritime Patrol Aircraft/Tactical Support Center

MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
NAD	North American Datum
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NATO	North Atlantic Treaty Organization
NDB	Nondirectional Beacon
NEEDS	NASA End-to-End Data System
NHTSA	National Highway Traffic Safety Administration
nm	nautical miles
NNSS	Navy Navigation Satellite System (TRANSIT)
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
NPN	National Plan for Navigation
NSF	National Science Foundation
NSWC	Naval Surface Weapon Center
NTIA	National Telecommunications and Information Agency
NWG	Navigation Working Group
O&M	Operation & Maintenance
OAST	Office of Aeronautics and Space Technology (NASA)
OCS	Operational Control Segment
OCST	Office of Commercial Space Transportation
OJCS	Office of the Joint Chiefs of Staff
OMB	Office of Management and Budget
OMEGA	(Not an abbreviation)
OPS/QTV	Operations/Qualification Test Vehicle
OSD	Office of the Secretary of Defense
OTP	Office of Telecommunications Policy
PAR	Precision Approach Radar
PILOT	Precision Intracoastal LORAN Equipment
PLAD	Portable LORAN Assist Device
POS/NAV	Positioning and Navigation
PPS	Precise Positioning Service
PRN	Pseudo-Random Noise
PSE	Peculiar Support Equipment
PTTI	Precise Time Time Interval
R&D	Research & Development
RACON	Radar Transponder Beacon
RBN	Radiobeacon
RD&D	Research, Development, & Demonstration
RDF	Radio Direction Finder
RDSS	Radiodetermination Satellite Service
R,E&D	Research, Engineering & Development
RF	Radio Frequency
RFI	Radio Frequency Interference
RNAV	Area Navigation (Radio)
RSPA	Research and Special Programs Administration
RSS	Root Sum Square
RTCM	Radio Technical Commission Maritime
RTCA	Radio Technical Commission for Aeronautics
RVR	Runway Visual Range
SAFI	Semi-Automatic Flight Inspection

SAR	Search and Rescue
SARPS	Standard and Recommended Practices
SEP	Spherical Error Probable
SHF	Super High Frequency
SLSDC	Saint Lawrence Seaway Development Corporation
SPS	Standard Positioning Service
STOL	Short Take-Off and Landing
STS	Satellite Test System
SV	Space Vehicle
TACAN	Tactical Air Navigation
TCV	Terminal Configured Vehicle
TD	Time Difference
TDRSS	Tracking and Data Relay Satellite System
TDSS	Time Difference Survey System
TERPS	Terminal Instrument Procedures
TIP	Transit Improvement Program
TIWG	Test Integration Working Group
TOA	Time of Arrival
TRANSIT	(Not an abbreviation)
TRSB	Time Referenced Scanning Beam
TSC	Transportation Systems Center
TSO	Technical Standard Order
TT&C	Telemetry Tracking and Control
TVOR	Terminal VOR
UE	User Equipment
UHF	Ultra High Frequency
UMTA	Urban Mass Transportation Administration
USAF	United States Air Force
USCG	United States Coast Guard
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USNO	United States Naval Observatory
UTC	Universal Coordinated Time
VFR	Visual Flight Rules
VHF	Very High Frequency
VLF	Very Low Frequency
VNAV	Vertical Navigation
VOR	Very High Frequency Omnidirectional Range
VORTAC	Collocated VOR and TACAN
VTOL	Vertical Take-Off and Landing
VTS	Vessel Traffic Service
WGS	World Geodetic System