1996 FEDERAL RADIONAVIGATION PLAN

Published by
Department of Defense
and
Department of Transportation

This document is available to the public through the National
Technical Information Service, Springfield, Virginia 22161
DOT-VNTSC-RSPA-97-2/DOD-4650.5

Letter of Promulgation

This letter promulgates the ninth edition of the Federal Radionavigation Plan, which was prepared jointly by the Departments of Defense and Transportation. It supersedes the 1994 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.

William S. Cohen
Secretary of Defense

Rodney E. Slater
Secretary of Transportation

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
July 1997

3. REPORT TYPE AND DATES COVERED
Final Report
January 1994 - December 1996

4. TITLE AND SUBTITLE
1996 Federal Radionavigation Plan

5. FUNDING NUMBERS
OP70J/T7037

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Department of Transportation (OST/P)
Washington, DC 20590

U.S. Department of Defense (USD/A&T)
Washington, DC 20301

8. PERFORMING ORGANIZATION REPORT NUMBER
DOD-4650.5/DOT-VNTSC-RSPA-97-2

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation (OST/P)
Washington,DC 20590

U.S. Department of Defense (USD/A&T)
Washington,DC 20301

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DOT-VNTSC-RSPA-97-2
DOD-4650.5

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

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

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The Federal Radionavigation Plan (FRP) delineates policies and plans for radionavigation 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 ninth 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, 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.

14. SUBJECT TERMS

Navigation Planning, Radionavigation System, Navigation Requirements, Position Location, Global Positioning System

15. NUMBER OF PAGES
212

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

Preface

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

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

The plan is updated biennially. The established DOD/DOT interagency management approach allows continuing control and review of U.S. radionavigation systems. Your inputs for the next edition of 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 Positioning and Navigation (POS/NAV) Working Group (Attn: OST/P-7), Department of Transportation, Office of the Assistant Secretary for Transportation Policy, Washington, D.C. 20590.

Meetings and discussions with radionavigation user groups, to give them the opportunity to exchange ideas and comments on this document, are planned to be held before the preparation of the next FRP.

Table of Contents

List of Figures

List of Tables

Executive Summary

The Federal Radionavigation Plan (FRP) delineates policies and plans for Federally provided radionavigation systems. It also recognizes that the existence of privately operated radiodetermination systems may impact future government radionavigation planning. 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 1994 FRP and incorporates common-use radionavigation systems (i.e., systems used by both civil and military sectors) covered in the Department of Defense (DOD) Chairman, Joint Chiefs of Staff (CJCS) Master Navigation Plan (MNP). The MNP covers many radionavigation systems used exclusively by the military, and has not been superseded by the FRP.

This document describes the various phases of navigation and other applications of 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. Where there is a potential for radio spectrum currently supporting these radionavigation systems to be used for implementation of new aeronautical systems, these have been identified within the text of the FRP.

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:

- GPS
- Augmentations to GPS
- Loran-C
- Omega
- VOR and VOR/DME
- TACAN
- ILS
- MLS
- Transit
- Radiobeacons

A major goal of DOD and the Department of Transportation (DOT) is to select a mix of these common-use (civil and military) systems which meets diverse user requirements for accuracy, reliability, availability, integrity, coverage, operational utility, and cost; provides adequate capability for future growth; and eliminates unnecessary duplication of services. Selecting a future 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, large vessel operators, or spacecraft, to whom accuracy, flexibility, and availability may be more important than initial cost. The emerging applications of land navigation will most likely cover the entire range of requirements. 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 tradeoffs. This plan establishes a means to address user inputs and questions, and arrive at an optimum mix determination. This edition of the FRP builds on the foundation laid by previous editions and further develops national plans toward providing an optimum mix of radionavigation systems.

The constantly changing radionavigation user profile and rapid advancements in systems technology 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 describes the DOD and DOT policies and plans for the radionavigation system mix.

Section 2 - Radionavigation System User Requirements: Provides civil and military requirements for air, space, land, and marine navigation, and non-navigation applications of radionavigation systems.

Section 3 - Radionavigation System Use: Describes how the various radionavigation systems are used in meeting civil requirements, and the status and plans for each system.

Section 4 - Radionavigation System Research and Development Summary: Presents the research and development efforts planned and conducted by DOT, DOD, and other Federal organizations.

Appendix A - System Descriptions: Describes present and planned navigation systems in terms of ten major parameters: signal characteristics, accuracy, availability, coverage, reliability, fix rate, fix dimensions, system capacity, ambiguity, and integrity.

Appendix B - Reference Systems: Discusses geodetic datums and the reference systems based upon them.

Appendix C - Definitions

Appendix D - Glossary

References

Index

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, the national objectives for coordinating the planning of radionavigation services, national policy on radionavigation systems, and radionavigation authority and responsibility.

1.1 Background

The first edition of the FRP was released in 1980 as part of a Presidential Report to Congress, prepared in response to the International Maritime Satellite (INMARSAT) Act of 1978. It marked the first time that a joint Department of Transportation (DOT) and Department of Defense (DOD) plan for common-use (both civil and military) systems had been developed. Now, this biennially-updated plan serves as the planning and policy document for all present and future Federally provided common-use radionavigation systems.

The 1979 DOD/DOT Interagency Agreement for joint radionavigation planning, as well as for the development and publication of the FRP, was renewed in 1990. This agreement recognizes the need to coordinate all Federal radionavigation system planning and to attempt, wherever consistent with operational requirements, to utilize common systems. A memorandum of agreement between the DOD and DOT on the civil use of the Global Positioning System (GPS) signed in January 1993 established policies and procedures to ensure an effective working relationship between the two Departments regarding the civil use of GPS. The March 28, 1996 Presidential Decision Directive (PDD) on GPS provides a comprehensive national policy and guidelines on the future management and use of GPS. An Interagency

GPS Executive Board (IGEB), jointly chaired by the Departments of Defense and Transportation, will manage the dual civil/military use GPS and U.S. Government augmentations and support the implementation of GPS national policy in accordance with the provisions of the PDD. The IGEB will ensure that GPS and U.S. augmentations are operated in a manner that is consistent with national policy and that best serves the military and civil user communities. As directed by the PDD, the IGEB will consult with U.S. Government agencies, U.S. industries, and foreign governments involved in navigation and positioning system research, development, operation, and use. In addition to DOD and DOT, IGEB membership is currently expected to include the Department of State (DOS), Chairman, Joint Chiefs of Staff (CJCS), Department of Commerce (DOC), Department of Interior (DOI), Department of Agriculture (DOA), and the National Aeronautics and Space Administration (NASA). The IGEB management structure is shown in Figure 1-1.

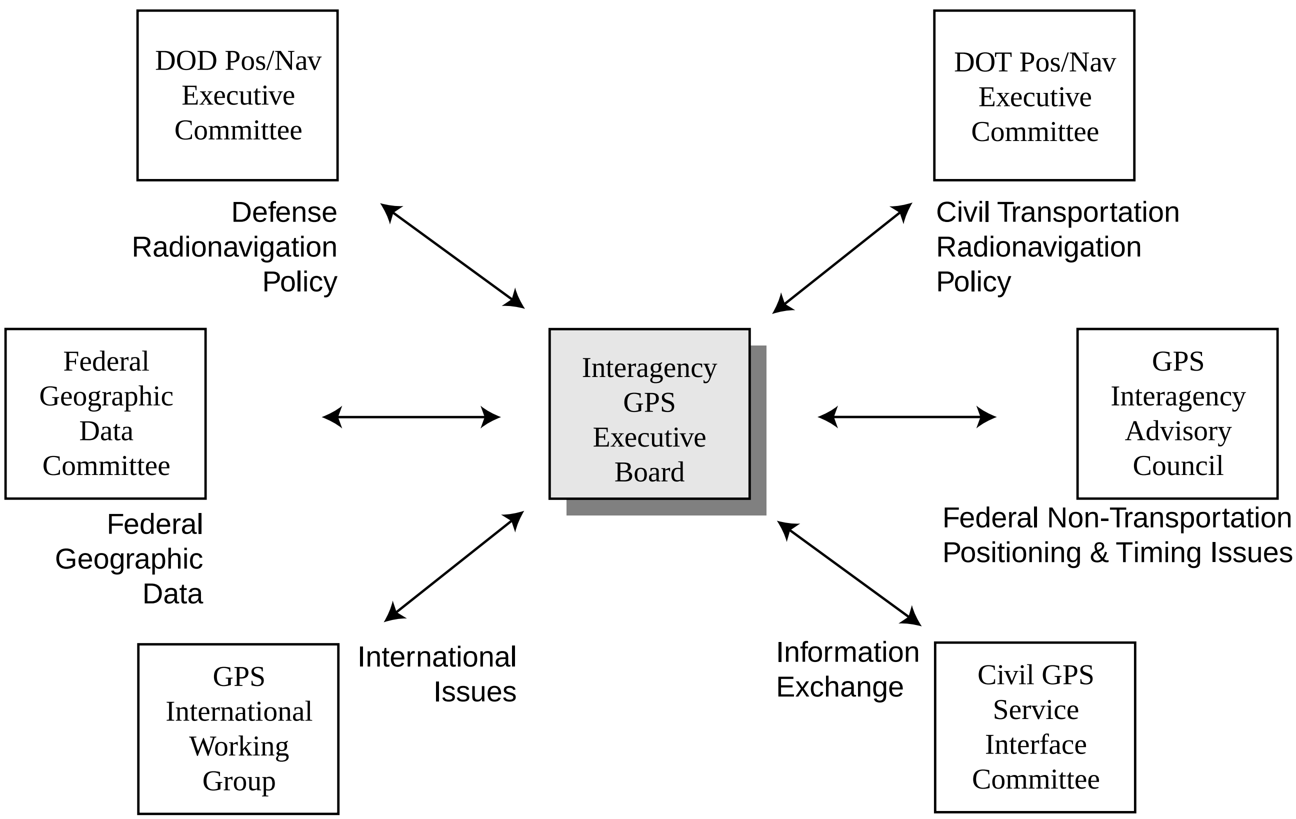


Figure 1-1. Interagency GPS Executive Board Management Structure

In 1990, the FRP began expanded discussions of land uses of radionavigation systems. This was driven primarily by a recognition of the use of systems such as GPS and Loran-C in land transportation applications. The 1996 FRP continues to expand discussions on new and developing applications, including the extensive use of radionavigation systems in positioning, surveying, timing, weather research, and many other areas.

The Federal Government holds open meetings every two years to provide the user community with the opportunity to comment on Federal radionavigation system policies and plans as published in the FRP. In 1996, user meetings were held in Cambridge, MA and Boulder, CO. The meetings were very well attended, with a broad spectrum of users representing the private sector; Federal, state, and local government agencies; and academic institutions. Aviation, land, marine, and space navigation interests were represented, as well as other applications for radionavigation systems, such as precise timing, positioning, geodesy and surveying, and weather research. Major comments from the audience included widespread support for use of GPS; concerns with relying on a single radionavigation system (i.e., GPS) without backup or complementary systems; support from the general aviation community for continuing Loran-C beyond the current phaseout date; and support from the international meteorological community for continuing Omega beyond the current phaseout date. DOT plans to continue to hold discussions with user groups to address these concerns.

The need to consolidate and reduce the number of navigation systems as GPS is phased in is a major objective of DOD and DOT. The constantly changing radionavigation user profile and rapid advancements in systems technology require that the FRP remain as dynamic as the issues it addresses. The current DOD/DOT policy on the radionavigation systems mix is presented in Section 1.6.

1.2 Purpose

The purpose of the FRP is to:

- Present an integrated Federal policy and plan for all common-use civil and military radionavigation systems.
- Provide a document for specifying radionavigation requirements and addressing common-use systems and applications.
- Outline an approach for consolidating radionavigation systems.
- Provide government radionavigation system planning information and schedules.
- Define and clarify new or unresolved common-use radionavigation system issues.
- Provide a focal point for 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 Radar Transponder Beacons (RACONs), and others that interface with or impact Federally provided systems. The plan does not include systems which mainly perform surveillance and communication functions.

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

- GPS
- Augmentations to GPS
- Loran-C
- Omega
- VOR and VOR/DME
- TACAN
- ILS
- MLS
- Radiobeacons

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 U.S. Government radionavigation system policy are to:

- Strengthen and maintain national security.
- Provide safety of travel.
- Promote efficient transportation.
- Ensure environmental protection.
- Support peaceful civil, commercial, and scientific applications of radionavigation systems.

1.5 Policies and Practices

The following U.S. Government policies and practices support the above objectives:

a. Implementation and operation of radio aids to navigation. Services which contribute to safe, expeditious, and economic air, land 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. Avoidance of unnecessary duplication of radionavigation systems and services. The highest degree of commonality and system utility between military and civil users is sought through early consideration of mutual requirements.

d. Recognition of electromagnetic spectrum requirements in the planning and management of radionavigation systems.

e. Promotion of transportation safety and environmental protection by requiring certain vessels and aircraft to be fitted with radionavigation equipment as a condition for operating in the controlled airspace or navigable waters of the United States.

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; those offering major economic advantages over existing systems; and those providing significant benefits in the national interest.

g. Establishment of suitable system transition periods based on user equipage and acceptance, budgetary considerations, and the public interest.

h. Promotion of international exchange of scientific and technical information concerning radionavigation aids.

i. Guidance and assistance in siting, testing, evaluating, and operating non-Federal and private radio aids to meet unique aviation and land transportation requirements.

j. Promotion of national and international standardization of civil and military radionavigation aids.

k. Establishment, maintenance, and dissemination of system and signal standards and specifications.

l. Development, implementation, and operation of the minimum special radionavigation aids and services for military operations.

m. Availability of radionavigation systems operated by the U.S. Government subject to direction by the National Command Authorities (NCA) in the event of a real or potential threat of war or impairment to national security.

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.

o. Enhancement of GPS for civil applications.

p. Encouraging acceptance and integration of GPS into peaceful civil, commercial, and scientific applications worldwide.

q. Equipping of military vehicles, as appropriate, to satisfy civil aviation and maritime navigation safety requirements. However, the primary concern will be that U.S. military vehicles and users are equipped with navigation systems which best satisfy mission requirements. Standardization, although important, may be disregarded when unique military systems provide the capability to operate safely without reference to civil radionavigation systems.

r. Establishment of mechanisms, where practical, for users of Federally provided radionavigation systems to bear their fair share of the costs (except for direct charges for basic GPS signals) for development, procurement, operation, and maintenance of these systems.

s. Provision, through DOD/DOT interagency agreements, of comprehensive management for all Federally provided common-use radionavigation systems.

t. Ensuring, in accordance with the national policy found in OMB Circular A-76 (Ref. 1), that the private sector is considered in 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 Policy on the Radionavigation System Mix

The Department of Transportation is responsible under 49 United States Code (U.S.C.) Section 301 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 Assistant Secretary for Transportation Policy (OST/P) is responsible for coordinating radionavigation planning within DOT and with other civil Federal elements.

The USCG provides U.S. aids to navigation 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 for 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.

Other elements within DOT participate in radionavigation planning. These elements include the St. Lawrence Seaway Development Corporation (SLSDC), the Maritime Administration (MARAD), the Federal Highway Administration (FHWA), the Intelligent Transportation Systems Joint Program Office (ITS-JPO), the Federal Railroad Administration (FRA), the National Highway Traffic Safety Administration (NHTSA), the Federal Transit Administration (FTA), the Research and Special Programs Administration (RSPA), and the Bureau of Transportation Statistics (BTS).

The Department of Defense 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-use systems operating or planned were considered in developing the policy on the mix of Federally provided radionavigation systems. The statement that follows is the U.S. Federal radionavigation policy and plans.

Federal Radionavigation System Policy and Plans (1996 Federal Radionavigation Plan)

Purpose: This statement sets forth the policy and plans for Federally provided radionavigation systems.

Objectives: The Federal Government operates radionavigation systems as one of the necessary elements to enable safe transportation and encourage commerce within the United States. 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 established a series of radionavigation systems over a period of years. Each system utilizes the latest technology available at the time of introduction to meet existing or unfulfilled needs. This statement addresses the conditions under which each system may be part of Federal radionavigation system policy and plans.

The Department of Defense (DOD) has deployed a new dual-use (civil and military) radionavigation system, the Global Positioning System (GPS). This system meets or exceeds the accuracy and coverage of many other radionavigation systems. Consequently, as the full civil potential of GPS is realized, the Federal Government expects to phase out radionavigation systems that are no longer required.

Decisions to discontinue Federal operation of existing systems will depend upon many factors including: (a) resolution of GPS accuracy, availability, coverage, integrity, financial, and institutional issues; (b) determination that the resulting systems mix meets civil and military needs currently met by existing systems; (c) availability of civil user equipment at economically acceptable prices; (d) establishment of a suitable transition period based on user equipment and acceptance, budgetary considerations, and the public interest, and (e) resolution of international commitments.

Although radionavigation systems are established primarily for safety of transportation, they also provide significant benefits to other civil, commercial, and scientific users. In recognition of this, any changes to Federal operation of radionavigation systems will consider these needs.

Radionavigation systems operated by the U.S. Government are available subject to direction by the National Command Authorities (NCA) in the event of a real or potential threat of war or impairment to national security. Operating agencies may cease operations or change characteristics and signal formats of radionavigation systems during a dire national emergency. All communication links, including those used to transmit differential GPS corrections and other GPS augmentations, are also subject to the direction of the NCA.

Individual System Plans:

GPS:

GPS, a 24-satellite-based radionavigation system operated by the DOD and managed by the Interagency GPS Executive Board, provides two levels of service - a Standard Positioning Service (SPS), which uses the C/A code on the L1 frequency, and a Precise Positioning Service (PPS) which uses the P(Y) code on both L1 and L2 frequencies. SPS is available to all users on a continuous, worldwide basis, for the foreseeable future, free of any direct user charge. The specific capabilities provided by SPS are established by DOD and DOT and are published in the *Global Positioning System Standard Positioning Service Signal Specification**, available through the USCG Navigation Information Service.

Access to the PPS component of the GPS service is made available to U.S. Federal and Allied Government (civil and military) users on a case-by-case basis through special Memoranda of Agreement with the DOD.

Although the L2 is not part of the Standard Positioning Service, many civil users currently employ dual frequency receiver technologies to support their requirements. DOT and DOD have determined that availability of a second coded signal is essential for these critical uses of GPS. Until such time as a second coded civil GPS signal is operational, the DOD will not intentionally reduce the current received minimum radio frequency signal strength of the P(Y)-code signal on the L2 link, as specified in the Interface Control Document (ICD) GPS 200, nor will the DOD intentionally alter the modulation codes, as known today, to generate the current P(Y)-code signal on the L2 link. This does not preclude additions of other codes or modifications to the L2 signal which do not change or make unusable the current L2 P(Y)-coded signal and its modulation codes.

Regarding pursuit of a second coded civil signal and its frequency, DOD and DOT will jointly complete by March 1998 identification of a second coded civil frequency and a detailed plan for providing the second coded civil signal.

* U.S. Department of Defense, 2nd Edition, June 2, 1995.

Augmentations to GPS:

When augmented to satisfy civil requirements for accuracy, coverage, availability and integrity, GPS will be the primary Federally provided radionavigation system for the foresable future.

Augmentations to GPS are enhancements to the basic GPS system to meet unique requirements. Augmentations to GPS fall into two categories: 1) differential GPS (DGPS), and 2) additional inputs from non-GPS navigation systems, equipment, or techniques.

The U.S. Government will not constrain the peaceful use of SPS-based DGPS services as long as applicable U.S. statutes and international agreements are adhered to.

Maritime DGPS: The USCG declared Initial Operational Capability (IOC) for maritime DGPS service on January 30, 1996. The USCG system provides service for coastal coverage of the continental U.S., the Great Lakes, Puerto Rico, portions of Alaska and Hawaii, and portions of the Mississippi River Basin. Maritime DGPS uses fixed GPS reference stations which broadcast pseudo-range corrections using radionavigation radiobeacons. The USCG DGPS system provides radionavigation accuracy better than 10 meters (2 drms) for U.S. harbor entrance and approach areas. The USCG is continuing to validate the current system's ability to meet the needs of the harbor entrance and approach and inland phases of navigation.

Aeronautical Augmentations to GPS/SPS (WAAS/LAAS): The Federal Aviation Administration (FAA), in cooperation with other DOT organizations and DOD, is augmenting the GPS/SPS with both a wide area and a local area system. The Wide Area Augmentation System (WAAS) can provide the required accuracy, integrity, and availability to be the primary means of navigation for all phases of flight from en route to Category I approaches. The FAA plans to commission an initial WAAS capability in 1999, at which time it is expected to be certified as a primary means of navigation for en route and terminal operations and limited precision approach service. WAAS is envisioned to reach its full operational capability in 2001 with multiple redundancy to support all phases of flight from en route to Category I precision approach. The Local Area Augmentation System (LAAS) is expected to provide the required accuracy, integrity, and availability for Category II and Category III precision approaches, as well as to increase the availability of CAT I systems.

The FAA will continue to evaluate progress in transitioning to satellite-based navigation and landing technology. By 2003, the FAA expects to determine whether to alter its schedule for terminating remaining ground-based systems. This determination will consider the performance of GPS and its augmentations, user acceptance of satellite technology, and user equipage with satellite-based avionics. Based on the results of its evaluation and on anticipated budgetary constraints, the FAA may need to accelerate the decommissioning of the remaining ground-based systems.

Loran-C: Loran-C provides coverage for maritime navigation in U.S. coastal areas. It provides navigation, location, and timing services for both civil and military air, land and marine users. Loran-C is approved as a supplemental air navigation system and also serves a large number of users that operate under Visual Flight Rules (VFR). The Loran-C system serves the 48 conterminous states, their coastal areas, and parts of Alaska. The U.S. plans to terminate Loran-C operations on December 31, 2000. The Coast Guard Authorization Act of 1996 requires, however, that the DOT prepare a report on the future use and funding of Loran-C. The report will be developed in consultation with the users of the Loran-C system and in cooperation with the Secretary of Commerce.

Omega: Omega provides global radionavigation coverage and primarily serves maritime, aviation, and weather users. The U.S. operates Omega under bilateral agreements with six partner nations (Norway, Liberia, France, Argentina, Australia, and Japan). The U.S. plans to terminate Omega operations on September 30, 1997. On October 11, 1996, a Federal Register (Volume 61, Number 199) notification was made providing notice of intent to terminate the world wide Omega Radionavigation System on 30 September 1997. A formal letter was also delivered to ICAO for distribution to the 184 member States.

VOR/DME: VOR/DME provides users with the primary means of air navigation in the National Airspace System (NAS). VOR/DME will remain the primary means of navigation for the en route through nonprecision approach phases of flight until GPS/WAAS is approved as a primary means of navigation. The current International Civil Aviation Organization (ICAO) protection date for VOR/DME is January 1, 1998. The phaseout of VOR/DME from the NAS is expected to begin in 2005 and to be complete by 2010.

TACAN: TACAN is the military counterpart of VOR/DME. The DOD requirement for land-based TACAN will terminate when aircraft are properly integrated with GPS and when GPS is certified by the DOD for operation in national and international controlled airspace. The target date to begin phaseout is 2005.

Precision Landing Systems: The Instrument Landing System (ILS) serves as the standard for civil precision approach systems in the U.S. and abroad. It will remain the standard for Category I precision approaches until replaced by the GPS-based service. Limited WAAS Category I precision approach service is expected to be available beginning in 1999, and the system is anticipated to be fully operational in 2001. Dual ILS and WAAS service will be provided for a transition period to allow users to equip with WAAS receivers and to be comfortable with its service. The phaseout of Category I ILS is then expected to begin in 2005 and to be complete by 2010.

Although the exact date is uncertain, the FAA expects LAAS Category II/III precision approaches to be available for public use by 2005. Until LAAS systems are available, the FAA plans to meet Category II/III requirements with ILS, and does not anticipate phasing out any Category II/III ILS systems prior to 2005. The phaseout is expected to be complete by 2010.

In April 1995, ICAO endorsed the Global Navigation Satellite System (GNSS) as the core system for international use and canceled the requirement for international runways to be equipped with the Microwave Landing System (MLS) by January 1, 1998. ICAO also extended the ILS protection date to January 1, 2010. The U.S. will continue to promote the international acceptance and implementation of GPS for navigation in all phases of flight.

The FAA has terminated the development of MLS based on favorable GPS test results and budgetary constraints. The U.S. does not anticipate installing additional MLS equipment in the NAS, but could purchase systems on the open market for Category II/III operations if the need should arise in the future. The phaseout of Category I MLS is expected to begin in 2005 and to be complete in 2010.

Transit: Transit ceased operation as a positioning and timing system on December 31, 1996.

Radiobeacons: Maritime and aeronautical radiobeacons serve the civilian user community with low-cost navigation. Selected maritime radiobeacons have been modified to carry differential GPS correction signals. This may cause these maritime radiobeacons to be unusable by certain aeronautical receivers. Maritime radiobeacons not used for DGPS are expected to be phased out by the year 2000. Many of the functions of the aeronautical nondirectional beacon (NDB) are now being provided by GPS. FAA-operated NDBs that provide redundant services, i.e., where essentially equivalent capability is provided by VOR, may be decommissioned beginning in 2000. The remaining stand-alone NDBs will be rapidly phased out after 2005. NDBs used as compass locators will be phased out when the underlying ILSs are withdrawn. A separate transition timeline will be developed for NDBs that define low frequency airways in Alaska.

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:

a. Define performance requirements applicable to military mission needs.

b. Design, develop, and evaluate systems and equipment to ensure cost-effective performance.

c. Maintain liaison with other government research and development activities affecting military radionavigation systems.

d. Develop forecasts and analyses as needed to support the requirements for future military missions.

e. Develop plans, activities, and goals related to military mission needs.

f. Define and acquire the necessary resources to accomplish mission requirements.

g. Identify special military route and airspace requirements.

h. Foster standardization and interoperability of systems with North Atlantic Treaty Organization (NATO) and other friendly countries.

i. Operate and maintain radionavigation aids as part of the NAS when such activity is economically beneficial and specifically agreed to by the appropriate DOD and DOT agencies.

j. Provide liaison with DOT.

k. Derive and maintain astronomical and atomic standards of time and time interval, and to disseminate these data.

The PDD directs the DOD to:

- Continue to acquire, operate, and maintain the basic GPS; maintain a Standard Positioning Service that will be available on a continuous, worldwide basis; and maintain a Precise Positioning Service for use by the U.S. military and other authorized users.

- Cooperate with the Director of Central Intelligence, the Department of State and other appropriate departments and agencies to assess the national security implications of the use of GPS, its augmentations, and alternative satellite-based positioning and navigation systems.

- Develop measures to prevent the hostile use of GPS and its augmentations to ensure that the U.S. retains a military advantage without unduly disrupting or degrading civilian uses.

The National Imagery and Mapping Agency (NIMA) is responsible for military mapping, charting, and geodesy aspects of navigation, including geodetic surveys, accuracy determination, and positioning. Within DOD, NIMA 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 NIMA 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. The USNO role as the nation's time standard was stated most recently in the National Defense Authorization Act FY92 and 93 Report, page 50. "The Department of the Navy serves as the country's official time keeper, with the master clock facility at the Washington Naval Observatory."

DOD carries out its responsibilities for radionavigation coordination through the internal management structure shown in Figure 1-2. Figure 1-2 shows the administrative process used to consider and resolve positioning and navigation issues. The operational control of DOD positioning and navigation systems is not shown here, but is described in the Chairman, Joint Chiefs of Staff (CJCS) Master Navigation Plan (MNP) and other DOD documents.

1.7.1 Operational Management

The President or the Secretary of Defense, with the approval of the President, are the National Command Authorities. The Chairman, Joint Chiefs of Staff (CJCS), supported by the Joint Staff, is the primary military advisor to the National Command Authorities. The Service Chiefs provide guidance to their military departments in the preparation of their respective detailed navigation plans. The JCS are aware of operational navigation requirements and capabilities of the Unified Commands and the Services, and are responsible for the development, approval, and dissemination of the CJCS Master Navigation Plan (MNP).

The MNP is the official navigation policy and planning document of the CJCS. It is a coordinated navigation system plan which addresses operational defense requirements.

The following organizations also perform navigation management functions:

The Deputy Director for Defense-Wide Command, Control, Communications and Computer Systems Support, Joint Staff (J-62), is responsible for:

- Analysis, evaluation, and monitoring of navigation system planning and operations.
- General navigation matters and the CJCS MNP.

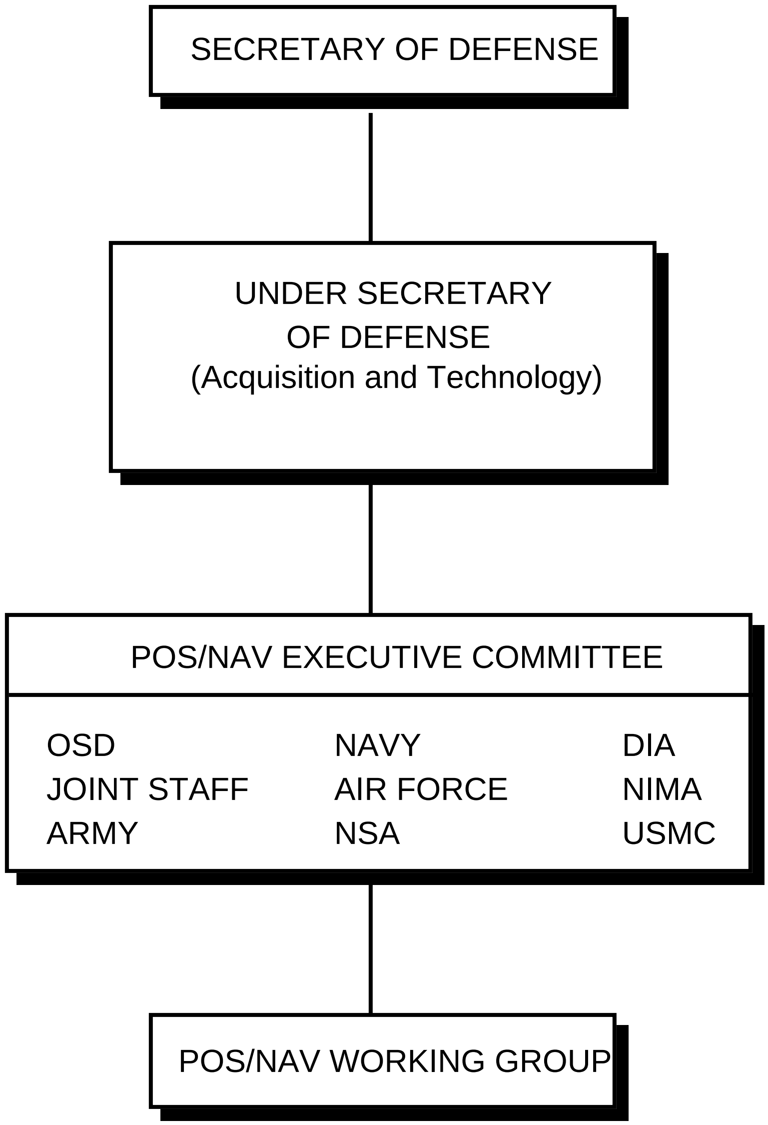


Figure 1-2. DOD Navigation Management Structure

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

1.7.2 Administrative Management

Three permanent organizations provide radionavigation planning and management support to the Under Secretary of Defense for Acquisition and Technology (USD/A&T). These organizations are the POS/NAV Executive Committee; the POS/NAV Working Group; and the Military Departments/Service Staffs. Brief descriptions are provided below.

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 (DIA) and the National Security Agency (NSA)). The Executive Committee contributes to the development of the FRP and coordinates with the DOT POS/NAV Executive Committee.

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 with the DOT POS/NAV Working Group 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 CJCS MNP and for managing the development, deployment, 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 effectively phase GPS into the military operational forces.

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. DOT carries out its responsibilities for civil radionavigation systems planning through the internal management structure shown in Figure 1-3. The structure was originally established by DOT Order 1120.32 (April 27, 1979) and revised by DOT Order 1120.32C (October 11, 1994) for the following purposes:

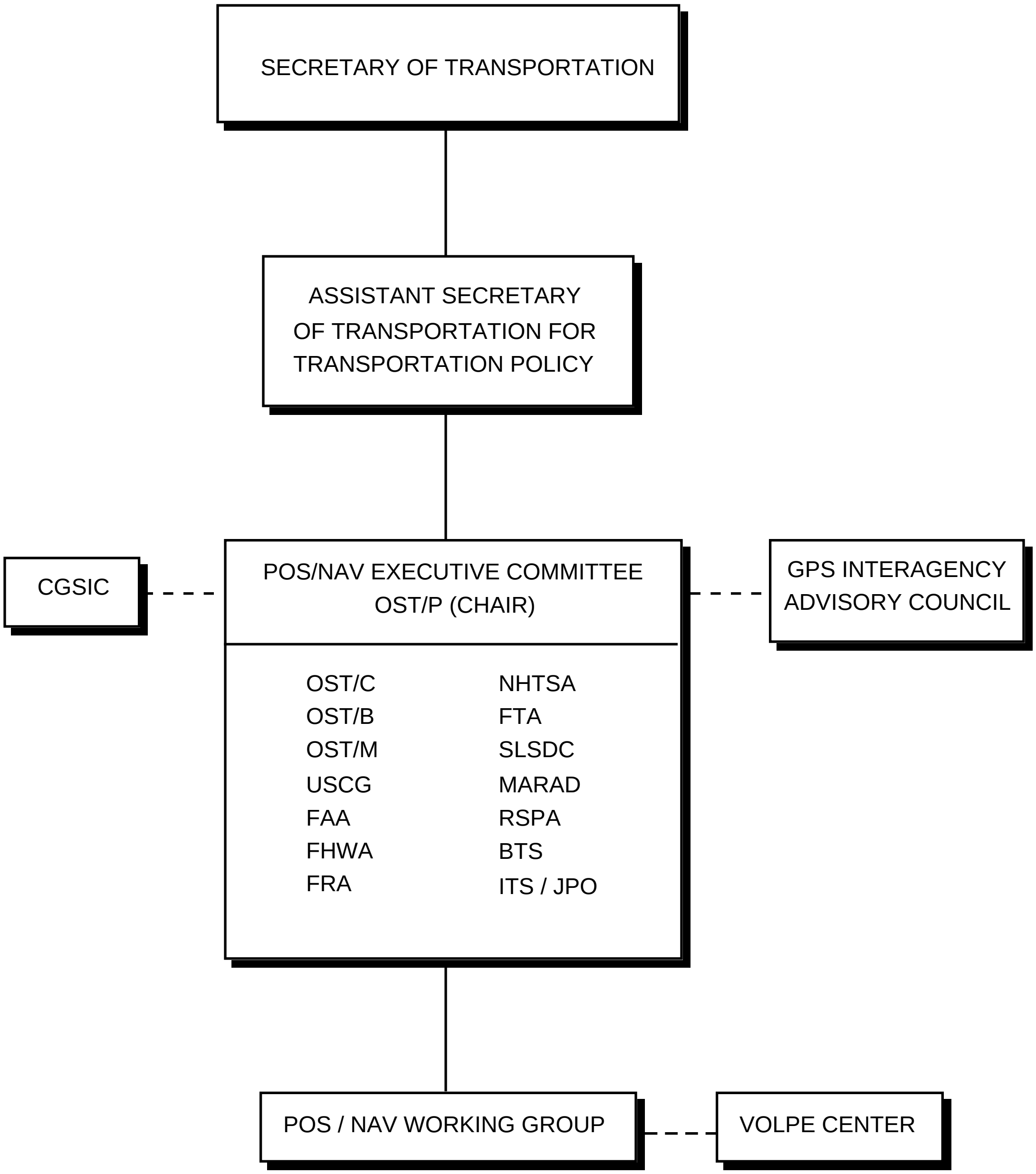


Figure 1-3. DOT Navigation Management Structure

a. To provide an organizational structure that will facilitate the coordination of policy recommendations and integrated planning regarding navigation and positioning among the operating elements of DOT, to help assure the most efficient implementation of these policies and plans, and to help ensure the most effective use of resources of the DOT operating elements (i.e., help avoid duplication of effort).

b. To provide a management level body which can, on a continuing basis, facilitate coordination of navigation and positioning planning on a multimodal basis within DOT, and to serve as a focal point for recommendations on which DOT navigation and positioning policies and plans can be formulated.

c. To assure that the Secretary of Transportation receives consolidated information; and to provide the means to obtain a coordinated high-level review of proposed navigation and positioning policies and plans.

d. To establish a planning framework wherein the DOT operating elements are allowed maximum latitude for navigation and positioning system research, development, and implementation, consistent with OST/P policy guidance and the need to avoid duplication of effort.

e. To provide the technical resources and appropriate management structure to supplement navigation and positioning planning, implementation, coordination, and decision making of the operating elements.

f. To provide a focal point for obtaining inputs from those elements of DOT which may not have a continuous interest in navigation and positioning issues.

g. To provide a DOT focal point for multimodal or inter-departmental navigation and positioning issues.

h. To provide liaison with DOD.

i. To coordinate DOT activities aimed at promoting international acceptance of U.S. radionavigation systems and supporting U.S. radionavigation and positioning manufacturing and service industries.

The DOT POS/NAV Executive Committee is the top-level management body of the organizational structure. It is chaired by the OST/P, and consists of policy level representatives from the General Counsel’s Office (OST/C), the Office of the Assistant Secretary for Budget and Programs (OST/B), the Assistant Secretary for Administration (OST/M), USCG, FAA, FHWA, ITS-JPO, FRA, NHTSA, FTA, SLSDC, MARAD, RSPA, and BTS. The DOT POS/NAV Executive Committee:

(1) serves as the focal point to formulate coordinated policy recommendations to the Secretary;

(2) provides policy and planning guidance to the Department’s operating administrations on navigation and positioning matters;

(3) attempts to resolve any multimodal navigation and positioning issues that cannot be resolved by the POS/NAV Working Group;

(4) is the focal point for coordination with similar committees in other government agencies;

(5) provides unified Departmental comments on the proposed rulemakings of other governmental agencies in regard to radionavigation and positioning and related matters; and

(6) provides guidance to the POS/NAV Working Group.

The POS/NAV Working Group is the staff working core of the organizational structure. It is chaired by the OST/P Program Manager and consists of one representative each from OST/C, OST/B, OST/M, USCG, FAA, FHWA, ITS-JPO, FRA, NHTSA, FTA, SLSDC, MARAD, RSPA, BTS, the Volpe National Transportation Systems Center (Volpe Center), and other DOT element representatives as necessary. Each representative may be assisted by advisors. The Center for Navigation, Volpe Center, also provides technical assistance to the POS/NAV Working Group. The Working Group shall facilitate the coordination of:

(1) navigation and positioning requirements developed by the DOT operating elements;

(2) navigation and positioning plans;

(3) navigation and positioning R&D (research and development) and implementation programs;

(4) DOT navigation and positioning planning with the Department of Defense, the Department of Commerce, the National Aeronautics and Space Administration, the Federal Geographic Data Committee (FGDC), and other Federal agencies, as required;

(5) multimodal navigation and positioning issues with other governmental agencies, industry, and user groups, as directed by the POS/NAV Executive Committee; and

(6) Department comments on the proposed rulemakings of other governmental agencies in regard to radionavigation and positioning and related matters.

The operating elements within DOT, as appropriate with their mission, shall:

(1) assess, analyze, and document navigation and positioning requirements;

(2) conduct the necessary research and development on navigation and positioning systems having potential application to their operation;

(3) implement navigation and positioning systems needed to carry out their responsibilities to the public in a safe and cost-effective manner, and

participate with other DOT agencies in implementation of common-use systems;

(4) retain existing responsibilities, under policy guidance from OST/P, for direct coordination with DOD on matters related to specific navigation and positioning systems operated by the individual elements of DOT; and

(5) retain existing responsibilities, under policy guidance from OST/P, for international coordination on navigation and positioning matters for their appropriate transportation mode.

The Secretary of Transportation, under 49 U.S.C. Section 301, has overall leadership 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 SLSDC.

OST/P coordinates radionavigation issues and planning which affect multiple modes of transportation, including those that are intermodal in nature. OST/P also interfaces with agencies outside of DOT on non-transportation uses of radionavigation systems.

The USCG defines the need for, and provides, aids to navigation and facilities required for safe and efficient navigation. 14 U.S.C. Section 81 states the following:

“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 or of 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; and

(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; or (c) required to serve the needs of the air commerce of the United States as requested by the Administrator of the Federal Aviation Administration.

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 Coast Guard may establish, maintain, and operate aids to marine navigation under paragraph (1) of this section by contract with any person, public body, or instrumentality."

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. FAA also has the responsibility to operate aids to air navigation required by international treaties.

MARAD investigates position determination using existing and planned navigation systems, conducts precision navigation experiments, and investigates the application of advanced technologies for navigation and collision avoidance. These efforts are designed to enhance U.S. Merchant Marine efficiency and effectiveness.

The SLSDC has responsibility for assuring safe navigation along the St. Lawrence 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.

FHWA, ITS-JPO, NHTSA, FRA, FTA, and RSPA 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. Due to the increased emphasis on efficiency and safety in land transportation, these organizations are increasing their activities in this area.

Other elements of the Federal government are involved with radionavigation systems in terms of evaluation, research, or operations. For example, 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.

The PDD directs the Department of Transportation to:

- Serve as the lead agency within the U.S. Government for all Federal civil GPS matters,
- Develop and implement U.S. Government augmentations to the basic GPS for transportation applications,
- In cooperation with the Departments of Commerce, Defense, and State, take the lead in promoting commercial applications of GPS technologies and the acceptance of GPS and U.S. Government augmentations as standards in domestic and international transportation systems, and
- In cooperation with other departments and agencies, coordinate U.S. Government-provided GPS civil augmentation systems to minimize cost and duplication of effort.

1.9 DOD/DOT Joint Responsibilities

A Memorandum of Agreement (MOA) between DOD and DOT for radionavigation planning became effective in 1979 and was renewed in 1990. This agreement requires coordination between the DOD and DOT internal management structures for navigation planning. The MOA recognizes that DOD and DOT have joint responsibility to avoid unnecessary overlap or gaps between military and civil radionavigation systems and services. Furthermore, it requires that both military and civil needs be met in a manner cost-effective for the Government and civil user community.

The PDD directs the establishment of a permanent Interagency GPS Executive Board (IGEB), jointly chaired by the Under Secretary of Defense for Acquisition and Technology (OUSD/A&T) and the Assistant Secretary of Transportation for Transportation Policy (OST/P-1). (See Section 1.1 and Figure 1-1.)

Implicit in these joint management responsibilities is assurance of civil sector radionavigation readiness for mobilization in national emergencies. DOD and DOT will jointly:

- Inform each other of the development, evaluation, installation, and operation of radio aids to navigation with existing or potential joint applications.
- Coordinate all major radionavigation planning activities to ensure consistency while meeting diverse navigational requirements.
- Attempt, where consistent with diverse requirements, to utilize common systems, equipment, and procedures.
- Undertake joint programs in the research, development, design, testing, and operation of radionavigation systems.
- Publish a single joint DOD/DOT FRP to be implemented by internal departmental actions. This plan will be reviewed and updated biennially.
- Assist in informing or consulting with other government agencies involved in navigation system research, development, operation, or use, as necessary.
- Coordinate on polices and procedures for in-band GPS testing activities.

1.10 Department of State Responsibilities

The PDD directs that the Department of State:

- In cooperation with appropriate departments and agencies, consult with foreign governments and other international organizations to assess the feasibility of developing bilateral or multilateral guidelines on the provision and use of GPS services;

- Coordinate the interagency review of instructions to U.S. delegations to bilateral consultations and multilateral conferences related to the planning, operation, management, and use of GPS and related augmentation systems; and

- Coordinate the interagency review of international agreements with foreign governments and international organizations concerning international use of GPS and related augmentation systems.

1.11 Radionavigation Systems Selection Considerations

1.11.1 Background and Approach

Many factors determine the systems selection and transition policies to satisfy diverse user requirements. Systems may be categorized according to operational, technical, economic, institutional and international parameters. System accuracy, integrity, and coverage are the foremost technical parameters, followed by system availability and reliability. Radio frequency spectrum issues must be considered during the selection process. Certain unique parameters, such as anti-jamming performance, apply principally to military needs but also affect civil availability.

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 will be retained until such needs no longer exist or can be met by an acceptable systems 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. The 1996 recommendation reflects policy direction from the PDD, dynamic radionavigation technology, changing user profiles, budget considerations, international activities and input received at radionavigation user conferences sponsored by DOT and DOD.

The Federal Government will maintain contacts with users of radionavigation systems. Input received will be considered in the decision-making process on radionavigation systems. Developments in GPS augmentations and the changing needs of users will be reviewed. The status and impact of commercial 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 may be given to the possibility of phasing over their operation to the private sector.

At that point in time when the need or economic justification for a particular system appears to be waning, the Department operating the system will provide notification to the appropriate Federal agencies and to the public, by publication in the Federal Register, of the proposed discontinuance of service.

DOD will decide whether a given system is necessary to meet military requirements and if so, the system will be retained as part of the systems plan. 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 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) consultations with U.S. allies and civil users, and (3) DOD/DOT deliberations.

It must also be kept in mind that the provision of Government services for meeting user requirements is subject to the budgetary process, including authorizations and appropriations by Congress, and priorities for allocations among programs by agencies.

1.11.2 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, under the sea, and in and above the atmosphere. Other factors that affect the selection process are:

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

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.

The activities experienced in activation of the maritime Ready Reserve Force during Desert Shield/Desert Storm have identified a potential need for improved navigation accuracy for ships involved in military sealift support. New GPS receiver concepts for systems with optional security modules are under consideration to be used when commercial ships are called into use in national emergencies.

C. *Review and Validation*

The DOD radionavigation system requirements review and validation process:

- Identifies the unique components of mission requirements.
- Identifies technological deficiencies.
- Determines, through interaction with DOT, the impact of new military requirements on the civil sector.
- Investigates system costs, user populations, and the relationship of candidate systems to other systems and functions.

1.11.3 *Technical Considerations*

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

- Received signal strength
- Spectrum availability
- Multipath effects
- Signal accuracy
- Signal acquisition and tracking continuity
- Signal integrity
- System availability
- Vehicle dynamic effects
- Signal coverage
- Noise effects
- Propagation

- Susceptibility to radio frequency (RF) interference (natural or man-made)
- Installation requirements
- Environmental effects
- Human factors engineering
- Reliability

1.11.4 *Economic Considerations*

The Government must continually review the costs and benefits of the navigation systems it provides. At the present time, there are several systems being operated by FAA, USCG, DOD and others. This continuing analysis can be used both for setting priorities for investment in new systems, and determining the appropriate mix of older systems to be retained. Only those systems that serve a significant number of users and provide the economic benefits in excess of costs should continue in operation. In some cases duplicate systems will have to be maintained for safety reasons and to allow adequate time for the transition to newer more accurate systems; however, older systems must be evaluated to determine whether or not their level of use is cost-effective.

The benefits from Government-operated navigation systems include improvements in economic productivity, operating efficiency, and accuracy in determining location in a common coordinate system. These factors allow planning for more fuel efficient routes and can prevent inadvertent diversions from the planned routes. Fuel savings can be in the billions of dollars. More precise location information can also be an important factor in preventing accidents. The efficiency benefits generally are the largest in dollar terms, but the safety benefits are very significant in justifying navigation systems.

The costs of navigation systems include capital investment, operating costs, and maintenance. These costs are borne by both the Government and the user. For new or replacement systems, the capital costs are significant. For existing systems, the operating and maintenance costs are the most important. Obtaining valid cost estimates is critical to analyzing the need for navigation systems.

Life cycle cost analysis is another important tool in decisions on navigation systems. Both DOD and DOT are aware of the need to minimize the life cycle costs in order to ensure the continued operation of navigation systems.

1.11.5 *Institutional Considerations*

The Department of Transportation Strategic Plan and the PDD support enhancement of GPS for civil applications and acceptance and integration of GPS into peaceful civil, commercial, and scientific applications worldwide. In order to accomplish this, there is a need to work with Congress, and all other interested parties, to develop a comprehensive, continuing and reliable funding program for the transportation navigation and positioning infrastructure.

A. Cost Recovery for Radionavigation Services

Use of present Federal radionavigation services cannot be easily measured; therefore, it would be difficult to assess direct user charges. Direct user charges normally involve a fee for each use of a specific system. Cost recovery for radionavigation services is either through general tax revenues or through transportation trust funds which are generally financed with indirect fees. These fees usually take the form of a fuel tax or value-added tax and can be used to pay all or part of an agency’s costs.

It has been the general policy of the U.S. Government to recover the costs of Federally provided services that provide benefits to specific user groups. DOT plans to conduct a detailed analysis of costs and cost recovery mechanisms.

At this point, the DOD and USCG operated systems are financed with general tax revenues. Aviation navigation systems are purchased with trust fund revenues and the systems are operated with a mix of general tax funds and trust funds. Introduction of GPS services has greatly increased the number of users to include automobiles, trains, transit, and land surveyors. The question is whether or not there is a better method for recovering the costs of GPS and other navigation systems that have widespread use. The Government will continue to study this issue.

B. Signal Availability

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 systems operated by the U.S. Government will remain available for peaceful use subject to direction by the NCA in the event of a real or potential threat of war or impairment to national security.

C. Role of the Private Sector

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

For certain applications such as landing, positioning, and surveying, in areas where Federal systems are not justified, a number of privately operated systems are available to the user as an alternative or adjunct service. One application of privately provided DGPS supports Special Category I (SCAT-I) precision approaches. SCAT-I approaches are specially authorized by the FAA based on appropriate airworthiness and operational approval processes, an aircraft operator’s demonstrated capability and equipment, and the availability of approved ground equipment. Several commercial concerns are also offering DGPS services for positioning and surveying applications. All communications links, including those used to transmit DGPS corrections, are subject to constraints as directed by the NCA.

There is current interest in an increased private sector role in Federally provided radionavigation systems. A goal of the PDD is to encourage private sector investment in and use of U.S. GPS technologies and services. Additionally, the U.S. Government will not conduct activities that preclude or deter commercial GPS activities, except for national security or public safety reasons. Some of the factors to be considered in examining increased private sector involvement include:

- Consideration of phase-over to private operation as a viable alternative to phaseout of a Federally operated radionavigation service.
- Cost savings to the Federal Government.
- Impact of privately operated services on usage and demand for Federally operated services.
- Impact of permitting privately operated systems to provide basic safety of navigation services in conjunction with communications services.
- Need for a Federally provided safety of navigation service even if commercial services are available.
- Liability considerations.
- Radio frequency spectrum issues.

1.11.6 International Considerations

Radionavigation services and systems should be technically and politically acceptable to diverse international groups, including NATO and other allies, ICAO, the International Telecommunications Union (ITU), and the International Maritime Organization (IMO).

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. The International Association of Lighthouse Authorities (IALA) also develops international radionavigation guidelines. IMO is 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.

The FRP also takes into account the possible future use of internationally shared systems. For example, the Russian Global Navigation Satellite System (GLONASS) achieved a full constellation of space vehicles in December 1995. The system has since been declared operational, and there have been at least 20 satellites in continuous operation since the beginning of 1996. The Foreign Minister of the Russian Federation has offered the use of GLONASS on behalf of Russia to both IMO and ICAO. Both ICAO and IMO have accepted this offer. The U.S. supports the ICAO position.

In addition to technical and economic factors, international interests must also be considered in the determination of a system or systems to best meet civil user needs. Further international consultations will be required to resolve the issues.

Department of State responsibilities for international cooperation on GPS are discussed in Section 1.10 above.

1.11.7 Radio Frequency Spectrum Considerations

Radionavigation services are major users of the radio frequency spectrum in the United States. Robust and satisfactory radionavigation services require adequate spectrum bandwidth, with the highest level of integrity and availability. Spectrum engineering and spectrum policy for radionavigation systems operated by the Federal government are key elements which help support the Federal radionavigation systems planning process.

The certification and use of radionavigation services is the shared responsibility of the DOD and DOT with delegation of spectrum responsibilities to the FAA, USCG, and DOD frequency management authorities. A key element in the certification of a navigational system is electromagnetic compatibility analysis, which helps determine its operational criteria and limits (e.g., power, channel spacing, and total bandwidth). Spectrum policy for DOT is coordinated through OST.

Nationally, the National Telecommunications and Information Administration (NTIA) promulgates policies, regulations, and technical standards for all Federal Government users of the radio spectrum. The Federal Communications Commission (FCC) manages all non-Government U.S. uses of spectrum. The principal advisor to NTIA is the Interdepartmental Radio Advisory Committee (IRAC). DOT and its modal administrations are represented on the IRAC by the FAA and USCG. The FAA represents itself; the USCG represents all other modal administrations and OST. The FCC also has liaison representation on the IRAC.

Because navigation and transportation systems often cross international boundaries, many spectrum issues need coordination on an international level. The International Telecommunications Union (ITU), a specialized organization of the United Nations, has been established to coordinate international telecommunications policy and radio spectrum uses. Policy is developed and major decisions are taken at ITU World Radio Conferences (WRC) held every two years. Official U.S. positions for these conferences are developed by the Department of State after coordination with the public and private sectors through NTIA and FCC. The ITU uses the procedures provided for in the Radio Regulations (developed through international agreement by the WRC) to manage use of the radio spectrum on a worldwide basis.

ICAO, also a specialized organization of the United Nations, undertakes activities having a strong influence on the aeronautical spectrum management process as it uniquely applies to aviation. ICAO develops Standards and Recommended Practices (SARPs) which are applied in the areas of communications, navigation and surveillance (CNS) in support of aircraft operations. ICAO provides inputs for the ITU WRC. The International Maritime Organization (IMO), another specialized organization of the United Nations, similarly provides input to the ITU WRC concerning maritime matters.

For DOT, the FAA and the USCG participate in international organizations chartered with spectrum coordination. The FAA pursues these issues through ICAO and the ITU; the USCG pursues these issues through IALA and IMO.

The FAA and the USCG are Federal users of spectrum as providers and operators of radionavigation services. The FAA use of spectrum is primarily in support of aeronautical safety services that operate within the National Airspace System (NAS). This spectrum must be free from interference due to the safety of life aspects of FAA services. The USCG also uses spectrum as a provider of radionavigation systems. These systems include differential GPS beacons (285-325 kHz), Omega (9-14 kHz), Loran-C (90-110 kHz), maritime radiobeacons (285-325 kHz), and radar transponder beacons (RACONS) (2900-3100 MHz and 9300-9500 MHz).

The DOT (FHWA, FTA, and NHTSA) is developing Intelligent Transportation Systems (ITS) in conjunction with the private sector and state and local governments. Many ITS applications will make use of GPS and other radiodetermination systems and will require communication links to transmit DGPS corrections and location information in an integrated systems context. The ITS program is striving to make use of existing services wherever possible. However, some spectrum for ITS purposes will most likely be necessary.

The long-term planning reflected in this document includes forecasts that some current aeronautical radionavigation systems may be replaced by new systems based on satellite technology and associated terrestrial elements. The planned phaseout of such present systems offers the potential for making spectrum available to support future enhancements and services for civil aviation communications, navigation, and surveillance (CNS) safety of life systems. The long-term planning impacting both the phaseout of some present radionavigation elements in later years, and the implementation of new CNS system elements that would utilize the available spectrum, necessarily requires domestic (and, in many cases, international) coordination and development, taking into account industry, the user community, the ITU, and ICAO.

The FAA and the rest of the civil aviation community are currently evaluating a number of future aeronautical CNS applications for potential implementation in certain frequency bands after the navigational aids currently utilizing them have been partially or completely decommissioned. These bands include:

- 108-117.975 MHz
- 328.6-335.4 MHz

- 960-1215 MHz
- 5000-5250 MHz

In some cases, more than one band is being considered for a single system, either because dual-band operation may be required for improved availability or because the evaluation of alternative bands is not yet complete for the system in question.

The FAA has undertaken a broad study, based on Recommendation 2.6 from the Report of the White House Committee on Safety and Security, to fully justify spectrum needs of civil aviation so that NAS modernization plans will not be compromised. Results of this study will be incorporated in the next edition of the Federal Radionavigation Plan.

1.11.8 Criteria for Selection

Criteria have been defined to compare alternative radionavigation system 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.*

- Military Operations: At a minimum, radionavigation services to support accomplishment of DOD tactical and strategic missions should be provided in an effective and efficient manner.
- Transportation Safety: At a minimum, radionavigation services sufficient to allow safe transportation should be provided.
- Economic Efficiency: To the extent possible and consistent with cost-effectiveness, radionavigation services which benefit the economy should be provided.

B. *Viability: Radionavigation systems should be responsive and flexible to the changing operational and technological environments.*

Evolving Technology: Research and introduction of new systems and concepts should be considered, particularly where unmet requirements or cost savings exist. Research, at the appropriate level, should continue for the life of the system.

- Orderly Transition: Modification and transition of systems should occur in an orderly manner to accommodate technical improvements.
- Flexibility: Radionavigation services should be provided to a variety of user classes with the minimum number of systems.
- Coverage: Radionavigation services should be provided in all relevant operating areas.

C. Standardization: A necessary degree of standardization and interoperability should be recognized and accommodated for both domestic and foreign operations.

- Civil/Military Interoperability: The basic capabilities to permit common use and common operational procedures by civil and military users should be provided.

- Multimodal/Intermodal Interoperability: The basic capability to support the operations of the various elements of a civil multimodal passenger freight system across modal lines should be considered.

- Equipment Standardization and Compatibility: Civil and military navigation equipment should be compatible to the extent feasible. In addition, the number of transmission formats should be kept to a minimum in meeting diverse civil requirements.

D. Costs: The required level of service should be achieved in an economical manner.

- 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.

- Transition Period Cost: Parallel (new and old) system operations should be carried out over a suitable transition period in consideration of user investment cost penalties and to permit equipment replacement to occur at reasonable intervals.

2

Radionavigation System 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 aviation and maritime users, and for military users in missions similar to civil users (e.g., 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. While phases of navigation are not as applicable to land transportation due to the greater flexibility afforded land users to assess their position, requirements will differ depending on what the user is trying to do, the type of transportation system in use, and where in that particular transportation system the user is. For example, tracking hazardous cargo on a truck is likely to involve more stringent requirements than a route guidance function for a typical interurban traveler.

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 radionavigation system performance in Section 3.

Most of today's transportation systems function modally, with interfaces between the various elements of their operations at ports or terminals. Future systems will operate far more intermodally, with a supporting electronic infrastructure that spans and functions across modal lines throughout the transportation system. It is important that consideration should be given to assuring the interoperability of radionavigation systems across modal lines, as well as within the individual modes using the systems themselves.

2.1 Civil Radionavigation System 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 by the operating administration, from other Federal agencies, from the user public, or as required by Congress. User conferences have often highlighted user needs not previously defined.

Radionavigation services provide civil users with the following:

- Service adequate for safety.
- Economic performance/benefit enhancement.
- Support of a large number of users.
- Continuous availability for fix information.

In transition planning, radionavigation system replacement candidates must be reviewed 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.

It must also be kept in mind that the provision of Government services for meeting user requirements is subject to the budgetary process, including authorizations and appropriations by Congress, and priorities for allocations among programs by agencies.

2.1.1 Process

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

- Evaluation of the acceptable level of safety risks to the Government, user, and general public as a function of the service provided.

- 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 service desired measured against the benefits obtained.
- Evaluation of the total cost impact of any government decision on radionavigation system users.

2.1.2 User Factors

User factors requiring consideration are:

- Vehicle size, speed, and maneuverability.
- Regulated and unregulated traffic flow.
- User skill and workload.
- Processing and display requirements for navigation and positioning information.
- Environmental constraints; e.g., weather, terrain, or man-made obstructions.
- Operational constraints inherent to the system.
- Safety constraints.
- Economic benefits.

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

- Activity of the user; e.g., recreational boaters, air taxi, general aviation, mineral exploration, helicopters, commercial shipping, and positioning, surveying, and timing.
- Vehicle performance variables such as fuel consumption, operating costs, and cargo value.
- Cost/performance trade-offs 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.

2.2 Civil Air Radionavigation Requirements

2.2.1 Phases of Air Navigation

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

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

1. Oceanic En Route: This subphase covers operations over ocean areas generally characterized by low traffic density and no independent surveillance coverage.

2. Domestic En Route (High Altitude and Low Altitude Routes): Operations in this subphase are typically characterized by moderate to high traffic densities. This necessitates narrower route widths than in the oceanic en route subphase. Independent surveillance is generally available to assist in ground monitoring of aircraft position.

3. Terminal Area: Operation in the terminal area 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.

4. 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.

The approach/landing phase is that portion of flight conducted immediately prior to touchdown. It is generally conducted within 20 nautical miles (nm) of the runway. Two subphases may be classified as nonprecision approach and precision approach and landing.

1. Nonprecision Approach: Nonprecision approaches provide a landing aircraft with horizontal position information (2-dimensional approaches).

2. Precision Approach and Landing: Precision approach and landing aids provide landing aircraft with vertical and horizontal guidance and positioning information (3-dimensional approaches).

2.2.2 General Requirements for Aviation Navigation Systems

Aircraft navigation is the process of piloting 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 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 navigation avionics when operating under Instrument Flight Rules (IFR) or above Flight Level (FL) 180 (18,000 ft).

Aircraft separation criteria, established by the 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, in part, by a stipulated probability that performance of the navigation system will remain within a specified error budget.

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 adequately see and avoid other aircraft when operating using see-and-avoid rules.

The following are basic requirements for the aviation navigation systems. "Navigation system" means all of the elements necessary to provide 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 address the many different combinations of operating conditions encountered in various parts of the world. Requirements applicable to the most exacting region may be considered extravagant when applied to other regions. In general, the requirements are:

a. The navigation system must be suitable for use in all aircraft types which may require the service without unduly limiting the performance characteristics or utility of those aircraft types; e.g., maneuverability and fuel economy.

b. The navigation system must be safe, reliable, and 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 near 100 percent and, to the extent feasible, should provide timely alarms in the event of failure, malfunction, or interruption.

d. The navigation system must recover from a temporary loss of signal without the need for complete resetting.

e. The navigation system must provide in itself maximum practicable protection against the possibility of input blunder, incorrect setting, or misinterpretation of output data.

f. The navigation system must provide adequate means for the pilot to check the accuracy of airborne equipment.

g. The navigation information provided by the systems must be free from unresolved ambiguities of operational significance.

h. 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.

i. In conjunction with other flight instruments, the navigation system shall provide information to the pilot and aircraft systems for performance of the following functions:

- Continuous determination of position of aircraft.
- Continuous track deviation guidance.
- Continuous determination of distance along track.
- Position reporting.
- Manual or automatic flight.

j. The navigation system must be capable of being integrated into the overall ATC system.

k. 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.

l. 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 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.

m. The navigation system must permit the establishment and the servicing of any practical defined system of routes for the appropriate phases of flight.

n. 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.

o. The navigation system must be capable of providing the information necessary to permit maximum utilization of airports and airspace.

p. The navigation system must be cost-effective to both the Government and the users.

q. The navigation system must be designed to reduce 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.

r. The navigation system must compensate for signal fades or other propagation anomalies within the operating area.

s. The navigation system must be capable of furnishing reduced service to aircraft with limited equipment.

t. The navigation system may be capable of being coupled with the aircraft flight control system to provide automatic tracking.

2.2.3 Navigation Signal Error Characteristics

The signal error 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. Under certain conditions, 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 unpredictably varying error component becomes the critical element to be considered in the design of navigation systems. The rates of change of both the “bias-like” and the “noise-like” components are also important factors, 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 be troublesome and result in disconcerting indications to the pilot. An example of one of these would be a “scalloped” 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. Noise-like 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 or incorrect.

2.2.4 Current Aviation Navigation Accuracy Requirements for Phases of Flight

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

2.2.4.1 En Route/Terminal Phase

The en route/terminal phase of air navigation includes the following subphases:

- Oceanic En Route
- Domestic En Route
- Terminal Area
- Remote Area

The general requirements in Section 2.2.2 are applicable to the en route/terminal phase of flight. In addition, to facilitate aircraft navigation in this phase, the system must be capable of being operationally integrated with the system used for approach and landing.

Navigation in the vertical plane is also required for safe and efficient flight. 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 +350 feet (3 sigma). This error is comprised of +250 feet (3 sigma) aircraft altimetry system error, of which the altimeter error is limited to +125 feet by Technical Standard Order (TSO) C-10B below FL 290. Changes are being considered to reduce the vertical separation between FL 290 and FL 410 to 1,000 feet. New performance requirements will be developed.

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

Table 2-1. Controlled Airspace Navigation Accuracy Requirements

PHASE	SUB-PHASE		ALTITUDE FL/FT	TRAFFIC DENSITY	ROUTE WIDTH (nm)	SOURCE ACCURACY CROSS -TRACK (95%, nm)		SYSTEM USE ACCURACY CROSS -TRACK (95%, nm)
EN ROUTE/ TERMINAL	Oceanic		FL 275 to 400	Normal	60*	12.4*		12.6*
	Domestic		FL 180 TO 600	Low	16	2.8		3.0
				Normal	8	2.8		3.0
			500 FT to FL 180	High	8	2.8		3.0
	Terminal		500 FT to FL 180	High	4	1.7		2.0
APPROACH AND LANDING	Nonprecision		250 to 3,000 FT	Normal	N/A	0.3		0.6
	Precision	CAT I	N/A	Normal	N/A	+/-18.2 **	+/-7.7 to +/-4.4 ***	N/A
						CAT I Decision Height Point ****		
		CAT II	N/A	Normal	N/A	+/-6.5 **	+/-1.7 ***	N/A
						CAT II Decision Height Point ****		
		CAT III	N/A	Normal	N/A	+/-4.1 **	+/- 0.6 ***	N/A
						At Runway Threshold ****		

* *North AtlanticTrack System requirements.*
** *Lateral position accuracy in meters.*
*** *Vertical position accuracy in meters.*
**** *Assumes a 3° glideslope and 8,000 ft. distance between runway threshold and localizer antenna. It may be possible to meet CAT III touchdown performance requirements while applying the CAT II requirement down to the runway.*

2.2.4.1.1 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 (e.g., position reports and timing).

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

1. The standard deviation of the lateral track errors shall be less than 6.3 nm, 1 sigma (12.6 nm, 2 sigma).
2. The proportion of the total flight time spent by aircraft 30 nm or more off track shall be less than 5.3 x 10-4; i.e., less than 1 hour in 2,000 flight hours.
3. The proportion of the total flight time spent by aircraft between 50 and 70 nm off track shall be less than 1.3 x 10-4; i.e., approximately 1 hour in 8,000 flight hours.

Changes are being considered to reduce the route separation in parts of the Pacific Ocean to 50 nm. New performance requirements will be developed.

2.2.4.1.2 Domestic En Route

Domestic air routes are designed to provide airways that are as direct as practical between city pairs having significant air traffic. For VOR-defined routes, via navaids or radials, the protected airspace at FL 600 and below is 4 nm on each side of the route to a point 51 nm from the navaid, then increases in width on either side of the centerline at a 4.5 degree angle to a width of 10 nm on each side of the route at a distance of 130 nm from the navaid.

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 distance measuring equipment (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). FTE 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:

Error Component	2 Sigma Deviation Values	Source
VOR Ground	1.4^{o}	Semi-Automatic Flight Inspection (SAFI) System
VOR Air	+3.0^{o}	Equipment Manufacturer
Course Selection (CSE)	+2.0^{o}	FAA Tests
Flight Technical (FTE)	+2.3^{o}	FAA Tests
System Use Accuracy (95% Confidence)	+4.5^{o}	(RSS derived)

2. Range Accuracy

Where DME service is used, the system use accuracy is defined as +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 +0.2 nm plus 1 percent of the distance (2 sigma).

3. Area Navigation (RNAV)

RNAV computation equipment provides latitude and longitude coordinate navigation capability. When RNAV 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 (Ref. 2), is +0.5 nm. RNAV system performance and route design is based on the following error budget:

Error Component	2 Sigma Deviation Values	Source
VOR Ground	+1.4^{o}	SAFI
VOR Air	3.0^{o}	Equipment Manufacturer and FAA Tests
DME Ground	+0.1 nm	SAFI

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

Error Component	2 Sigma Deviation Values	Source
DME Air	+0.2 nm	Equipment Manufacturer* + 1% of Range
FTE	+1.0 nm	FAA Tests**
CSE	$+2.0^{o}$	FAA Tests
RNAV System	+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.

2.2.4.1.3 Terminal Area

Terminal routes provide transitions from the en route phase to the approach phase of flight. The accuracy capability of navigation systems using 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 system use accuracy requirement is +2 nm (95 percent) within 25 nm of the facility, based on the RSS the combination of error elements.

2.2.4.1.4 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 +10 nm.

2.2.4.1.5 Operations Between Ground Level and 5,000 Feet Above Ground Level (AGL)

Operations between ground level and 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:

- Range from shore to 300 nm.
- Minimum en route altitude of 500 feet above sea level or above obstructions.
- Accuracy adequate to support routes +4 nm wide or narrower with 95 percent confidence.

- Minimum descent altitude to 100 feet in designated areas.

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

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

2.2.4.2 Approach/Landing Phase

This phase of instrument flight includes two types: (1) nonprecision approach, or (2) precision approach and landing.

The general requirements of Section 2.2.2 apply to the approach/landing phase. In addition, specific procedures and clearance zone requirements are specified in TERPS (United States Standard for Terminal Instrument Procedures, FAA Handbook 8260.3B) (Ref. 3).

Altimetry accuracy requirements are established in accordance with FAR 91.411 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 nonprecision approaches.

2.2.4.2.1 Nonprecision Approach

Nonprecision 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 RNAV for nonprecision approaches are specified in Reference 4.

The achieved capability for nonprecision approaches varies significantly, depending on the location of the navigational facility in relation to the fix location and type of navigational system used. Approximately 30 percent of the nonprecision approach fixes based on VOR in the U.S. achieve a cross track navigational accuracy of +100 meters (2 sigma) at the missed approach point (MAP). This accuracy is based upon the +4.5 degrees VOR system use accuracy and the MAP being less than 0.7 nm from the VOR facility.

Nonprecision RNAV approaches must satisfy their own criteria and are based on the obstacle clearance areas shown in Figure 2-1. The width of the intermediate approach trapezoid primary areas decreases from 4 nm (2 nm each side of the route centerline) at the end of the intermediate fix or waypoint displacement area to 2 nm

(1 nm each side of the route centerline) at the final approach fix or waypoint. Primary obstacle clearance areas further narrow to the width of the runway waypoint fix displacement area at its furthest point. Secondary areas (not depicted) also extend upward and outward from the sides of the primary area.

The integrity time-to-alarm requirement for nonprecision approaches provides the pilot with either a warning or a removal of signal within 10 seconds of the occurrence of an out-of-tolerance condition.

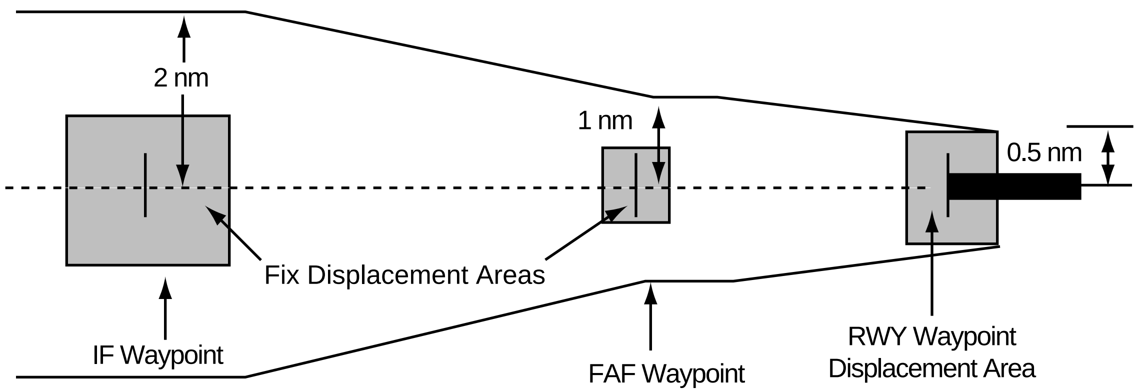


Figure 2-1. RNAV Nonprecision Approach Protected Areas

2.2.4.2.2 Precision Approach and Landing

A precision approach and landing aid provides a landing aircraft with vertical and horizontal guidance and position information. The current worldwide standard systems for precision approach and landing are the Instrument Landing System (ILS) and the Microwave Landing System (MLS). 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 shown in Table 2-1.

Precision approach and landing systems are required to warn the pilot of an out-of-tolerance condition during precision approaches by removing these signals from service. The response time for providing these warnings varies from six seconds for Category I to two seconds for Category II/III.

2.2.5 Future Aviation Navigation Requirements

Future aviation navigation requirements will be based on new criteria using the concept of required navigation performance (RNP). This concept is being developed such that unified criteria will be established for airworthiness approval, ground equipment approval (if required), operating approval, establishment of operating minima and obstacle clearance assessment.

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 separation less than the current standard of 2,000 feet. 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 introduction of 1,000-foot vertical separation at all flight levels.

2.2.5.1 En Route/Terminal Phase

2.2.5.1.1 Oceanic En Route

Current 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 and requires a lateral track error less than 12.6 nm (95 percent). More accurate and reliable aircraft position data will greatly contribute to reductions in lateral separation, resulting in greater flexibility and the ability to fly user-preferred routes. Efforts are under way to reduce some route separations in the Pacific area to 50 nm. The navigation requirements for this are being developed.

2.2.5.1.2 Domestic En Route

At the present time, the number of VOR/DMEs is sufficient to allow most routes to have widths of +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 may soon exceed capacity. More use of RNAV will allow the implementation of random and parallel routes not possible with the use of current VOR/DME facilities, thus easing the capacity problem. 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.

2.2.5.1.3 Terminal Area

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 avionics can provide cross track navigational accuracies better than +500 meters (2 sigma) in terminal areas using the current VOR/DME facilities. Similarly, GPS-based avionics deliver better accuracies and performance than VOR/DME.

2.2.5.1.4 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, nondirectional beacons (NDB), Omega, and privately owned facilities such as TACAN are being used in combination to meet the user navigational needs in these areas. GPS, 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.

2.2.5.2 Approach/Landing Phase

2.2.5.2.1 Nonprecision Approach

Nonprecision approach obstacle clearance areas may be reduced to take advantage of the increased performance by augmented GPS.

2.2.5.2.2 Precision Approach and Landing

Future requirements for precision approaches will be developed for specific systems using the RNP concept. The RNP concept provides a framework to drive requirements based on the need to avoid obstacles and place the aircraft in a position to land.

2.3 Civil Marine Radionavigation Requirements

2.3.1 Phases of Marine Navigation

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

2.3.1.1 Inland Waterway

Inland waterway navigation is conducted in restricted areas similar to those for harbor entrance and approach. However, in the inland waterway case, the focus is on nonseagoing 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, personnel, 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.

2.3.1.2 Harbor Entrance and Approach

Harbor entrance and approach navigation is conducted 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, harbor entrance 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 in harbor entrance and approach. 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 phase of harbor entrance and approach is 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.

2.3.1.3 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 meters in 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:

- 50 nautical miles from land.
- The outer limit of offshore shoals, or other hazards on the continental shelf.
- 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.

2.3.1.4 Ocean Navigation

Ocean navigation is that phase in which a ship is beyond the continental shelf (200 meters in 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.

2.3.2 Current Marine Navigation 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 above 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, navigation accuracy (beyond that needed for safety) is particularly important 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 and at the same time avoid underwater obstructions or restricted areas provides important economic benefits. Search and Rescue (SAR) effectiveness is similarly dependent on accurate navigation in the vicinity of a maritime distress incident.

For 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 required to carry only minimal navigational equipment, and even then do so only if persuaded by individual cost/benefit analysis, this governmental policy helps to promote maritime safety through a simultaneous economic incentive.

Tables 2-2, 2-3, 2-4, and 2-5 identify system performance needed to satisfy maritime user requirements or to achieve special benefits. The requirements are related to safety of navigation. The Government recognizes an obligation to satisfy these requirements for the overall national interest. The benefits are specialized requirements or characteristics needed to provide special benefits to discrete classes

Table 2-2. Current Maritime User Requirements for Purposes of System Planning and Development - Inland Waterway Phase

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS								
	ACCURACY (meters, 2drms)		COVERAGE	AVAILABILITY	RELIABILITY	FIX INTERVAL	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY
	PREDICTABLE	REPEATABLE							
SAFETY OF NAVIGATION ALL SHIPS & TOWS	2-5	2-5	US Inland Waterway Systems	99.9%	*	1-2 seconds	Two	Unlimited	Resolvable with 99.9% confidence
SAFETY OF NAVIGATION RECREATION BOATS & SMALLER VESSELS	5-10	5-10	US Inland Waterway Systems	99.9%	*	5-10 seconds	Two	Unlimited	Resolvable with 99.9% confidence
RIVER ENGINEERING & CONSTRUCTION VESSELS	0.1**-5	0.1**-5	US Inland Waterway Systems	99%	*	1-2 seconds	Two or Three	Unlimited	Resolvable with 99.9% confidence

* Dependant upon mission time

** Vertical dimension

Table 2-3. Current Maritime User Requirements/Benefits for Purposes of System Planning and Development - Harbor Entrance and Approach Phase

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS								
	ACCURACY (meters, 2drms)		COVERAGE	AVAILABILITY	RELIABILITY	FIX INTERVAL	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY
	PREDICTABLE	REPEATABLE							
SAFETY OF NAVIGATION - LARGE SHIPS & TOWS	8-20***	-	US harbor entrance and approach	99.7%	**	6-10 seconds	Two	Unlimited	Resolvable with 99.9% confidence
SAFETY OF NAVIGATION - SMALLER SHIPS	8-20	8-20	US harbor entrance and approach	99.9%	**	***	Two	Unlimited	Resolvable with 99.9% confidence
RESOURCE EXPLORATION	1-5*	1-5*	US harbor entrance and approach	99%	**	1 second	Two	Unlimited	Resolvable with 99.9% confidence
ENGINEERING & CONSTRUCTION VESSELS HARBOR PHASE	.1****-5	.1****-5	Entrance channel & jetties, etc.	99%	**	1-2 seconds	Two and Three	Unlimited	Resolvable with 99.9% confidence

BENEFITS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS								
FISHING, RECREATIONAL & OTHER SMALL VESSELS	8-20	4-10	US harbor entrance and approach	99.7%	**	***	Two	Unlimited	Resolvable with 99.9% confidence

* Based on stated user need.

** Dependent upon mission time.

*** Varies from one harbor to another. Specific requirements are being reviewed by the Coast Guard.

**** Vertical dimension.

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 (meters, 2drms)		COVERAGE	AVAILABILITY	RELIABILITY	FIX INTERVAL	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY
	PREDICTABLE	REPEATABLE							
SAFETY OF NAVIGATION - ALL SHIPS	0.25nm (460m)	-	US 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)	-	US coastal waters	99.	**	5 minutes	Two	Unlimited	Resolvable with 99.9% confidence

BENEFITS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS								
COMMERCIAL FISHING (INCLUDING COMMERCIAL SPORT FISHING)	0.25nm (460m)	50-600 ft (15-180m)	US coastal/ fisheries areas	99%	**	1 minute	Two	Unlimited	
RESOURCE EXPLORATION	1.0-100m*	1.0-100m*	US coastal areas	99%	**	1 second	Two	Unlimited	
SEARCH OPERATIONS, LAW ENFORCEMENT	0.25nm (460m)	300-600 ft (90-180m)	US coastal/ fisheries areas	99.7%	**	1 minute	Two	Unlimited	
RECREATIONAL SPORTS FISHING	0.25nm (460m)	100-600 ft (30-180m)	US 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 - Ocean Phase

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS									
	ACCURACY (2 drms)			COVERAGE	AVAILABILITY	RELIABILITY	FIX INTERVAL	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY
	PREDICTABLE	REPEATABLE	RELATIVE							
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 MEET REQUIREMENTS									
LARGE SHIPS MAXIMUM EFFICIENCY	0.1-0.25nm* (185-460m)	-	-	Worldwide, except polar regions	99%	**	5 minutes	Two	Unlimited	Resolvable with 99.9% confidence
RESOURCE EXPLORATION	10-100m*	10-100m*	-	Worldwide	99%	**	1 minute	Two	Unlimited	Resolvable with 99.9% confidence
SEARCH OPERATIONS	0.1-0.25nm (185-460m)	0.25nm	0.1nm (185m)	National maritime SAR regions	99%	**	1 minute	Two	Unlimited	Resolvable with 99.9% confidence

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

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.

2.3.2.1 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 entrance and approach navigation. The long, ribbon-like nature of the typical inland waterway presents special problems to the prospective user of precise, land-based area navigation systems. Continual shifting of navigable channels in some unstable waters creates additional problems to the prospective user of any radionavigation system which provides position measurements in a fixed coordinate system.

Special waterways, such as the Saint Lawrence River and some Great Lakes passages, are well defined, but subject to frequent fog cover which requires ships to anchor. This imposes a severe economic penalty in addition to the safety issues. If a fog rolls in unexpectedly, a ship may need to proceed under hazardous conditions to an anchorage clear of the channel or risk stopping in a channel. Current requirements for the inland waterway phase of navigation are provided in Table 2-2.

2.3.2.2 Harbor Entrance and Approach Phase

The pilot of a vessel in restricted waters must direct its movement with great accuracy and precision to avoid grounding in shallow water, hitting submerged/partially submerged rocks, and colliding 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 a 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 entrance and approach environment is to present the position information on some form of electronic display. This would provide 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 entrance and approach environment, while the role of visual aids and radar escalates.

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 2-3 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 less than 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.

Minimum Performance Criteria: The radionavigation system accuracy required to provide useful information in the harbor entrance and 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) 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 user conferences have indicated that for many mariners, the radionavigation system becomes a secondary tool when entering the harbor entrance and approach environment.

Continuing efforts are being directed toward verifying user requirements and desires for radionavigation systems in the harbor entrance and approach environment.

2.3.2.3 Coastal Phase

There is a 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.

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

- 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.
- The need to define accurately, for purposes 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.

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 boaters 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.

2.3.2.4 Ocean Phase

The requirements for safety of navigation in the ocean phase for all ships are given in Table 2-5. 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.

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 2 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 99 percent.

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.

Minimum Performance Criteria: Economic efficiency in transoceanic 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 2-5. The predictable accuracy benefits 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 2-5, the required fix interval may range from as low as once per 5 minutes to as high as once per minute. Signal availability must be at least 95 percent and approach 99 percent for all users.

2.3.3 Future Marine Navigation Requirements

The marine radionavigation 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 principal factors which will impact future requirements are safety, economics, environment, and energy conservation.

Special radionavigation requirements may arise from new environmental laws and regulations designed to reduce marine vessel casualty events. Also, the role of commercial ships in military sealift missions may require additional navigation systems capabilities.

2.3.3.1 Safety

2.3.3.1.1 Increased Risk from Collision and Grounding

Hazardous cargoes (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 and grounding. Economic constraints also cause vessels to be operated in a manner which, although not unsafe, places more stringent demands on all navigation systems.

2.3.3.1.2 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, improved navigational performance is needed.

2.3.3.1.3 Greater Need for Traffic Management/Navigational Surveillance Integration

The foregoing trends underlie the importance of continued 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 is expected to play an increasingly important role in such areas as VTS.

2.3.3.2 Economics

2.3.3.2.1 Greater Congestion in Inland Waterways and Harbor Entrances and Approaches

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.

2.3.3.2.2 All Weather Operations

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

2.3.3.3 Environment

As onshore energy supplies are depleted, resource exploration and exploitation will move farther offshore toward 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 summary, 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.

2.3.3.4 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.

2.4 Space Radionavigation Requirements

2.4.1 Mission Phases

For Earth-orbiting space activities, the mission phases can be generally categorized as the ground launch phase, the on-orbit phase, and the reentry and landing phase. In addition to the government sponsored space activities coordinated by NASA, there is a growing U.S. commercial space transportation industry seeking to launch both government and private payloads. There is also a growing private sector presence in space commerce that reflects sizable investments in such emerging uses as materials processing, land mobile services, radiodetermination, and remote sensing.

2.4.1.1 Ground Launch Phase

This phase is defined as that portion of the mission from the point at which a vehicle leaves the launch pad to the point wherein the vehicle inserts the payload into Earth orbit.

2.4.1.2 On-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 launch vehicle may deploy a satellite or perform positional maneuvers in support of onboard experiments. Vehicles capable of reentry may also retrieve a satellite for return to Earth. This phase essentially ends when the vehicle has completed its mission or initiates de-orbit maneuvers. In this phase, free-flying spacecraft perform their experiments and 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 either retrieved by a reentry vehicle or returns to Earth on its own.

2.4.1.3 Reentry and Landing Phase

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

2.4.2 Current Space Radionavigation Requirements

The use of GPS for space applications fall into two basic categories:

1. Onboard spacecraft vehicle navigation support where GPS and GPS augmentations will be used in near real-time applications for navigation and attitude determination. In this role, onboard navigation and attitude accuracy requirements are:

- Three-dimensional position error not to exceed 10 cm (1 sigma).
- Three-dimensional velocity error not to exceed 0.1 m/sec (1 sigma).
- Attitude determination error not to exceed 0.1 degree in each axis (1 sigma).
- Clock offset error between coordinated universal time (UTC) and onboard receiver time not to exceed 1 microsecond (1 sigma).

2. Scientific data analysis support where GPS will be used in a post-processing mode to accurately locate instrument position in space when measurements are taken. Current accuracy requirements are to determine three dimensional position within 5 cm. However, more accurate positioning in the 1 to 2 cm range may be required in the future for some earth observation instruments. Several programs conducted or supported by NASA are evaluating GPS for spacecraft position determination. TOPEX/POSEIDON, launched on August 10, 1992, is using a high-accuracy dual-band GPS flight receiver on an experimental basis. Based on successful experiments conducted on the Space Shuttle and on the TOPEX/POSEIDON and EUVE instrumented satellites, NASA is planning to implement GPS as an operational system on many future missions including the Space Shuttle and International Space Station Alpha (ISSA).

Planned and proposed future NASA spacecraft will require continued use of GPS. Examples of GPS applications include the following:

- ISSA is being designed to implement GPS for navigation, attitude determination, and Universal Time distribution. GPS will support onboard ISSA system control functions as well as various experimenter data capture processes.
- The Space Shuttle will implement GPS for the on-orbit and reentry and landing mission phases by 2000. Also, research will be conducted in the use of GPS during the Space Shuttle’s ground launch phase.
- New small satellite programs to explore low cost access to space will implement GPS for navigation, time, and attitude determination functions. The use of low cost onboard GPS receivers for these basic functions will become a significant factor in providing inexpensive access to space for future NASA and commercial small satellite projects.
- Where scientific data position accuracy is required with precision greater than that readily available from the GPS receiver onboard a spacecraft, a refinement of post-pass orbit data will be used. NASA has developed post-pass orbit data processing techniques using GPS on the TOPEX/POSEIDON satellite that provide accuracy at the 5 cm level. In order to accomplish this, some internal receiver parameters must be available for downlink with the science data.
- In addition to use of GPS for scientific data positioning in a post processing mode, NASA is investigating the use of WAAS and eventually GNSS for real

time position information. Current research indicates that real time accuracy at the 10 cm level may be achievable.

- GPS tracking is being used by the NASA Deep Space Network (DSN) to improve knowledge of the Earth's pole position and speed of rotation. The use of GPS for this purpose is making a significant reduction in demand for measurements with deep space antennas, thus realizing cost savings. The centimeter level accuracy available with GPS tracking for geocentric correction to deep-space antenna coordinates is significantly improving the deep-space tracking error budget.
- The use of GPS at satellite altitudes extending from low earth orbit (LEO) out to geosynchronous earth orbit (GEO) altitudes will be explored by NASA in conjunction with other organizations.
- Potentially, GPS will be a primary real-time position information source for launch vehicles including the new returnable launch vehicle.

2.5 Civil Land Radionavigation Requirements

In comparison with the air and marine communities, phases of land navigation are not well defined. Radionavigation requirements are more easily categorized in terms of applications. The land navigation applications fall into three basic categories; highway, transit, and rail applications. Ongoing work on Intelligent Transportation Systems (ITS), which includes research and development (R&D) and operational test programs funded by the Department of Transportation's modal administrations (including FHWA, FTA, and NHTSA) as well as by State and local governments and private industry, will aid in clarifying and validating user requirements.

2.5.1 Categories of Land Transportation

2.5.1.1 Highways

Radionavigation techniques in highway applications are used autonomously or are integrated with vehicle-to-roadside communications and map-matching techniques to provide various user services. These are public sector operational tests ongoing for integrated ITS systems, where radionavigation is a part of the system. However, a number of consumer products and products for use by the public sector are on the market today. Deployment of these systems is accelerating at a rapid pace. Vehicle location systems for emergency service, providers of mayday services, route navigation for private automobiles, and tracking and scheduling of commercial vehicles are in use. Examples of systems in development include augmentation of GPS vehicle location data by providing DGPS correction values over wireless communications. Also under development is a system for vehicle location monitoring using GPS integrated with wireless packet data systems. Examples of systems used in operational tests for ITS funded by FHWA include the use of radionavigation for automatic vehicle location for mayday response, route guidance, mass transit scheduling, and mileage determination. Examples of systems that are fielded and operational include radionavigation for dispatching roadside assistance vehicles and automated location tracking and scheduling of commercial vehicles. In addition to these examples, radionavigation is used by various highway departments for asset management by using GPS coordinates to identify locations of bridges, highway signs, and overpasses. Table 2-6 shows examples of ITS user services requiring the use of radionavigation. A complete description of all of the ITS user services can be found in ITS System Architecture documentation (Ref. 5).

Table 2-6. ITS User Services Requiring Use of Radionavigation

Travel and Transportation Management Pre-Trip Travel Information En Route Driver Information Route Guidance Incident Management Travel Demand Management
Public Transportation Operations Public Transportation Management Personalized Public Transportation
Commercial Vehicle Operations Commercial Fleet Management
Emergency Management Emergency Vehicle Management Emergency Notification and Personal Security
Advanced Vehicle Control and Safety Systems Intersection Collision Avoidance

2.5.1.2 Transit

Transit systems also benefit from the same radionavigation-based technologies. Automatic vehicle location techniques assist in fleet management, scheduling, real-time customer information, and emergency assistance. In addition, random route transit operations will benefit from route guidance in rural and low density areas. Also, services such as automated transit stop annunciation are being investigated. Benefits of radiolocation for public transit, when implemented with a two-way communications system, have been proven in a number of deployments across the U.S. Improvements in on-time performance, efficiency of fleet utilization, and response to emergencies have all been documented. Currently, there are over 10,000 buses in cities that employ automatic vehicle location using GPS for these fleet management functions and the deployment is spreading rapidly.

2.5.1.3 Rail

The railroad industry may benefit from the use of radionavigation systems to aid in train location determination, monitoring, scheduling and management. These systems would provide precise location and speed information regarding trains and maintenance-of-way equipment to new positive train control systems that are being designed and tested to prevent collisions and overspeed accidents. Currently, the private sector, in cooperation with Federal and State agencies, is evaluating the use of augmented GPS, in combination with other navigation technologies, for positive train control.

Private sector freight railroads and public sector passenger and commuter railroads own and maintain their rights-of-way, and many are using GPS for surveying to establish more accurate track maps and property inventories.

2.5.2 Current Land Transportation Requirements

For the functions of collision avoidance and automated highway operation, there has been a trend to make these functions self contained as opposed to using radionavigation services. However, because these technologies are still in the research stage, dependence on radionavigation remains a possibility with its attendant stringent accuracy requirements.

Requirements for use of radionavigation systems for land vehicle applications continue to evolve. Many civil land applications that use radionavigation systems are now commercially available. Examples of highway user applications that are now available include in-vehicle navigation and route guidance, automatic vehicle location, automated vehicle monitoring, automated dispatch, and hazardous materials tracking. Other applications continue to be investigated and developed, including resource management, highway inventory control, and positive train separation. At the present time, there are many hundreds of thousands of GPS receivers in use for surface applications. Many of these are finding their way into land vehicle applications.

In order for some of the envisioned applications to be useful, they need to be coupled with a variety of space and terrestrial communication services that relay information from the vehicle to central dispatch facilities, emergency service providers, or other destinations. An example of such an application includes relaying the status of vehicle onboard systems and fuel consumption to determine allocation of fuel taxes.

ITS operational tests are yielding results that make it clear that large scale deployment will include a number of navigation mechanisms shared with other systems and services. For example, several ITS operational tests use GPS, which is already being shared with numerous other systems and communities, along with radiobeacon systems and other radiolocation systems. Such an approach for sharing brings benefits of more efficient use of the scarce radio frequency spectrum as well as reduction of capital cost of infrastructure and related operations, administration and maintenance costs.

The navigation accuracy, availability, and integrity needs and requirements of land modes of transportation, as well as their associated security needs and requirements (including continuity of service), have been documented in the December 1994 *A Technical Report to the Secretary of Transportation on a National Approach to Augmented GPS Services* and the December 1993 *Report of the Joint DOD/DOT Task Force - The Global Positioning System: Management and Operation of a Dual Use System* (Ref. 6, 7). Examples of land transportation positioning and navigation system accuracy needs and requirements are shown in Table 2-7.

Table 2-7. Land Transportation Positioning/Navigation System Accuracy Needs/Requirements

MODE	ACCURACY (METERS) 95%
Highways:	
Navigation and route guidance	5-20
Automated vehicle monitoring	30
Automated vehicle identification	30
Public safety	10
Resource management	30
Accident or emergency response	30
Collision avoidance	1
Geophysical survey	5
Geodetic control	Submeter
Rail:	
Position location	10-30
Train control	2
Transit:	
Vehicle command and control	30-50
Automated voice bus stop annunciation	5*
Emergency response	75-100
Data collection	5

* *25-30 meters before the bus stop.*

Of special interest is the concept of collision avoidance. There has been a trend to move away from infrastructure based systems towards more autonomous, vehicle based systems. It is too early in the development of these applications to determine what final form they will take, but an appropriate mix of infrastructure and vehicle based systems will likely occur that may incorporate radionavigation services.

Railroads have been conducting tests of GPS and differential GPS for over a decade to determine the requirements for train and maintenance operations. In June 1995, FRA published its report, *"Differential GPS: An Aid to Positive Train Control,"* (Ref. 8) which concluded that differential GPS could satisfy the Location Determination System requirements for the next generation positive train control systems. In November 1996, FRA convened a technical symposium on *"GPS and its Applications to Railroad Operations"* to continue the dialogue on accuracy, reliability, and security requirements for railroads.

Integrity requirements for land transportation functions are dependent on specific implementation schemes. Integrity values will probably range between 1 and 15 seconds, depending on the function. In order to meet this integrity value, GPS will most likely not be the sole source of positioning. It will be combined with map-matching, dead reckoning, and other systems to form an integrated approach, ensuring sufficient accuracy, integrity, and availability of the navigation and position solution to meet user needs. Integrity needs for rail use are 5 seconds for most functions. Those for transit are under study and are not available at this time. Availability for all functions, highways, transit and rail, is estimated as 99.7 percent.

While the Government has no statutory responsibility to provide radionavigation services for land radionavigation applications or for non-navigation uses, their existence and requirements are recognized in the Federal radionavigation systems planning process. Accordingly, the Government will attempt to accommodate the requirements of such users.

2.6 Requirements for Non-Navigation Applications

The use of radionavigation systems, especially GPS, for non-navigation applications is very large and quite diverse. Most of these applications can be grouped under the following five broad headings:

- Geodesy and surveying
- Mapping, charting, and geographic information systems (GIS)
- Geophysical applications
- Meteorological applications
- Timing and frequency

The nature of these applications is discussed in sections 2.6.1 through 2.6.5 below.

2.6.1 Geodesy and Surveying

Since the mid-1980s, the geodesy and surveying community has made extensive use of GPS for worldwide positioning. Today, GPS is used almost exclusively by the geodesy and surveying community to establish geodetic reference networks. The National Geodetic Survey (NGS) currently uses GPS to provide the Federal component of the National Spatial Reference System (NSRS) through the establishment of a small number of monumented points (about 1200) positioned using GPS, and the provision of GPS observations from a nationwide GPS network of Continuously Operating Reference Stations (CORS) for use in post processing applications. The CORS system currently provides data over the Internet from 75 stations, including the USCG stations and U.S. Army Corps of Engineers (USACE) stations. Stations to be established by components of DOT to support air navigation (e.g., WAAS) and land navigation will be included in CORS as they become available.

GPS is used extensively in a large number of surveying applications. These include positioning of points in support of reference system densification, mapping control, cadastral surveys, engineering projects, and terrain mapping. These applications involve both positioning of fixed points and after-the-fact positioning of moving receivers using kinematic methodologies. All high-accuracy (few centimeter) geodetic and surveying activities involve DGPS techniques using the carrier phase observable.

2.6.2 Mapping, Charting and Geographic Information Systems (GIS)

GPS technology is extensively used to provide positions of elements used to construct maps, charts, and GIS products. These have many applications, including supporting air, sea, and land navigation. Almost all positioning in this category is DGPS positioning and involves the use of both code range and carrier phase observations, either independently or in combination. Many groups at all government levels, as well as universities and private industry, have established fixed reference stations to support these applications. Most of these stations are designed to support after-the-fact reduction of code range data to support positioning at the few decimeter to few meter accuracy level. Examples of this type of positioning application include 1) location of roads by continuous positioning of the vehicle as it traverses the roads, and 2) location of specific object types such as manhole covers by occupying their locations. Another very important mapping/GIS application of GPS is post mission determination of the position and/or attitude of photogrammetric aircraft. For this application, code range or carrier phase data is used depending upon the accuracy required. The use of GPS for this purpose is so cost effective that it is becoming the preferred method of positioning photogrammetric aircraft.

2.6.3 Geophysical Applications

The ability of GPS carrier phase observations to provide centimeter level differential positioning on regional and worldwide bases has lead to extensive applications to support the measurement of motions of the Earth's surface associated with such phenomena as motions of the Earth's tectonic plates, seismic (earthquake related) motions, and motions induced by volcanic activity, glacial rebound, and subsidence due to fluid (such as water or oil) withdrawal. The geodetic and geophysical communities have developed an extensive worldwide infrastructure to support their high accuracy positioning activities.

The geophysical community is moving rapidly from post processing to real time applications. In southern California and throughout Japan, GPS station networks currently transmit data in real time to a central data facility to support earthquake analysis. The International GPS Service for Geodynamics (IGS) is moving to provide the ability to compute satellite orbit information, satellite clock error, and ionospheric corrections in real time. Many projects for the monitoring of motion are currently being supported by the National Science Foundation (NSF), the U.S. Geological Survey, and NASA, as well as state, regional, and local agencies.

Another geophysical application is the determination of the position, velocity, and acceleration of moving platforms carrying geophysical instrumentation both to determine the position of measurements and to provide a means of computing measurement corrections. An example of this is the use of GPS in conjunction with an aircraft carrying a gravimeter. Here, GPS is used not only to determine the position of measurements but also to estimate the velocity and acceleration necessary for corrections to the observations. GPS position measurements are also being used extensively to monitor motions of glaciers and ice sheets.

2.6.4 Meteorological Applications

The international meteorological community launches several hundred thousand weather radiosondes and dropwindsondes each year worldwide to measure such atmospheric parameters as pressure, temperature, humidity, and wind speed and direction. Omega and Loran-C are currently used operationally to track these instrument packages; however, the meteorological community is developing the capability to replace Omega and Loran-C with GPS. GPS-based upper-air systems will be in wide use by the turn of the century. GPS also has been shown to have an important non-positioning meteorological application. Measurements of refraction of the two GPS carrier phases can be used to provide continuous estimates of total precipitable water vapor. The ability to provide accurate water vapor information has been demonstrated in the research mode. Development of research meteorological GPS station networks has begun.

2.6.5 Time and Frequency Applications

GPS is being used extensively for communication network synchronization by, for example, telephone companies. Power companies are using GPS for measuring phase differences between power transmission stations, for event recording, for post disturbance analysis, and for measuring and relative frequency of power stations. GPS is also being used for worldwide time transfer. Another timing application of GPS is synchronization of clocks to support astronomical observations such as Very Long Baseline Interferometry (VLBI)/pulsar astronomical observations.

2.6.6 Summary of Requirements

Almost all non-navigation uses of GPS involving positioning have accuracy requirements that necessitate differential positioning and therefore augmentation through the use of one or more reference stations located at point(s) of known position. The accuracy requirements for various applications are indicated in Table 2-8 and lie in the few millimeter to few meter range. Non-navigation requirements differ from navigation requirements in several respects. Many non-navigation applications do not have real time requirements and can achieve their objectives through post processing of observations. This reduces communications needs and means that reliability and integrity requirements are much less stringent. Even when real time applications exist the penalties for data loss are usually economic rather than related to safety of life and property considerations. However, non-navigation uses have much more stringent accuracy requirements in many cases.

There are several consequences of these accuracy requirements. First, the carrier phase observable is used in many non-navigation applications rather than the code range observable, which is the primary observable used on most navigation applications. Second, two carrier phase frequencies are essential to achieve the few millimeter to few centimeter accuracies needed for many applications. Dual frequency carrier phase capability is also required for recovery of precipitable water vapor information in support of meteorological applications. The non-navigation GPS user community has developed an extensive worldwide augmentation infrastructure to support their applications. Under the auspices of the International Association of Geodesy (IAG), the IGS has been established. The IGS operates a worldwide network of GPS stations. Data from these stations is used to produce high accuracy (better than 10 cm) orbits and to define a worldwide reference coordinate system accurate at the 1 cm level. Currently, the high accuracy orbits are produced a few days after the fact. However, slightly less accurate orbits are being produced with less that 24 hour delay and IGS members are rapidly moving toward this production of real time orbits at the few decimeter level. Member groups of the IGS are also moving toward the production of satellite clock corrections and ionospheric corrections in real time.

In addition to these integrated worldwide efforts many groups at national, state, and local levels have or are in the process of establishing networks of GPS reference stations. The bulk of these station networks now in existence provide observational

Table 2-8. Requirements for Surveying, Timing and Other Applications

Surveying

TASK	MINIMUM PERFORMANCE CRITERIA								Remarks
	Accuracy - 1 Sigma				Coverage %	Availability %	Interval		
	Position						Measurement Recording (seconds)	Solution Fix	
	Absolute (m)		Relative (cm)						
	Horizontal	Vertical	Horizontal	Vertical					
STATIC SURVEY	0.3	0.5	1.0	2.0	99	99	5	30 min.	0 - 25 km
GEODETIC SURVEY	0.1	0.2	1.0	2.0	99	99	5	4 hrs.	0 - 6000 km
RAPID SURVEY	0.3	0.5	2.0	5.0	99	99	1	5 min.	0 - 20 km
“ON THE FLY” KINEMATIC SURVEY	0.3	0.5	2.0	5.0	99	99	0.1 - 1.0	0.1 - 1.0 sec.	0 - 20 km Real Time
HYDROGRAPHIC SURVEY			300	15	99	99	1	1 sec.	

Timing and Other Applications

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS								
	ACCURACY (2 drms)			COVERAGE	AVAILABILITY	FIX INTERVAL	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY
	PREDICTABLE	REPEATABLE	RELATIVE						
COMMUNICATIONS NETWORK SYNCHRONIZATION	-	1 part in 10^{-10} (freq)*	-	Nationwide	99.7%	Continuous	N/A	Unlimited	N/A
SCIENTIFIC COMMUNITY	-	1 part in 10^{-10} (freq)	-	Worldwide	99.7%	Continuous	N/A	Unlimited	N/A
METEOROLOGY	Velocity 1m/sec	-	-	-	TBD	TBD	TBD	-	TBD
POWER NETWORK SYNCHRONIZATION	-	1ms**	-	North America	99.7%	1 second	Two	Unlimited	Resolvable with 99.9% confidence

* Proposed ITU Standard based on American Telephone and Telegraph “Stratum 1 Requirement”.
** At any substation. 8ms (1/2 cycle) systemwide.

data that can be used to compute correction information needed to perform code range positioning at the few decimeter to few meter level. Increasingly, reference station networks that provide both carrier phase and code range observations are being introduced. Almost all of these reference station networks support post processing at present, but many state groups are looking toward providing code range correctors in real time. The nature of GPS reference station requirements of non-navigation users is cost as well as accuracy driven. Thus, where real time code range positioning is not required and user equipment cannot receive real time correctors it may be more cost effective to perform post processing rather than upgrade equipment. Also, if user equipment and software is designed to use local area DGPS correctors, as is currently the case for most non-navigation users employing code range positioning, it is cost effective to continue to use local area DGPS if possible. With high accuracy carrier phase positioning in areas such as surveying, minimizing the observation time required to achieve a given accuracy is an important cost consideration. Thus, observation time minimization may result in a need for GPS reference stations at intervals of 40 to 200 km to meet carrier phase positioning requirements.

Geophysical users have special references station requirements in that they are using fixed stations to monitor motions and must place reference stations at spacings and at locations that allow them to monitor the motions of interest. Organizations such as USACE have positioning requirements for hydrographic surveys to locate waterway channels, construction and obstructions. Meeting these requirements necessitates the establishment of DGPS stations along inland waterways.

2.7 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.

2.7.1 General Requirements

Military navigation systems should have the following characteristics:

- Worldwide coverage.
- User-passivity.
- Capability of denying use to the enemy.
- Support of unlimited number of users.
- Resistance to spoofing (imitative navigational signal deceptions), interference, jamming, and intrusion.
- Resistance to natural disturbances and hostile attacks.

- Effectiveness of real time response.
- Availability for combined military operations with allies.
- Are accommodated in appropriate radionavigation bands.
- Use of common grid for all users.
- Position accuracy that is not degraded by changes in altitude for air and land forces or by time of year or time of day.
- Accuracy when the user is in high “G” or other violent maneuvers.
- Maintainable by operating level personnel.
- Continuous availability for fix information.
- Non-dependence on externally generated signals.
- Provides method for ensuring system integrity, to include an annunciation system to alert users when the system should not be used.
- Continuously reliable for navigation.

The ideal military positioning/navigation system should be totally self-contained so that military platforms are capable of performing all missions without reliance on information from outside sources. 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 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. Currently, the DOD is unable to conduct some military missions with the precision and accuracy demanded without some aid from external radionavigation systems. However, there has been significant progress in the development of reliable self-contained systems (inertial systems, Doppler systems, geomagnetic navigation, and terrain/bottom contour matching).

While the survivability of any radionavigation system is scenario-dependent, in almost any scenario the GPS is considered more survivable than other systems because:

- Moving transmitters in space are less vulnerable than ground-based transmitters.
- Spread spectrum transmission techniques protect against jamming.
- Anti-spoofing is available.
- Transmitters are hardened against electromagnetic pulse (EMP).

DOD must invest in reliable, accurate, self-contained systems that are uniquely tailored to match platform mission requirements. Therefore, the DOD POS/NAV architecture will be based upon GPS, which provides accurate worldwide positioning, velocity and time, backed by modern, accurate, and dependable self-contained systems.

2.7.2 Service Requirements

The CJCS 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.

3

Radionavigation System Use

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 radionavigation systems which meet most of the current and projected civil user requirements for safety of navigation, promotion of reasonable economic efficiency, and positioning and timing applications. These systems are adequate for the general navigation of military craft as well, but none completely satisfies all the needs of military missions or provides highly accurate, three-dimensional, worldwide navigation capability. GPS satisfies many of these general and special military requirements. GPS has broad potential for satisfying current civil user needs or for responding to new requirements that present systems do not satisfy. It could ultimately become the primary worldwide system for military and civil navigation and position location.

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. Detailed descriptions of the existing and proposed radionavigation systems are given in Appendix A. Figure 3-1 provides estimates of the current numbers of users of Federally provided radionavigation systems.

The following sections describe the approach employed to define the needs, requirements, and degree to which existing systems satisfy user needs.

3.1.1 Air Navigation

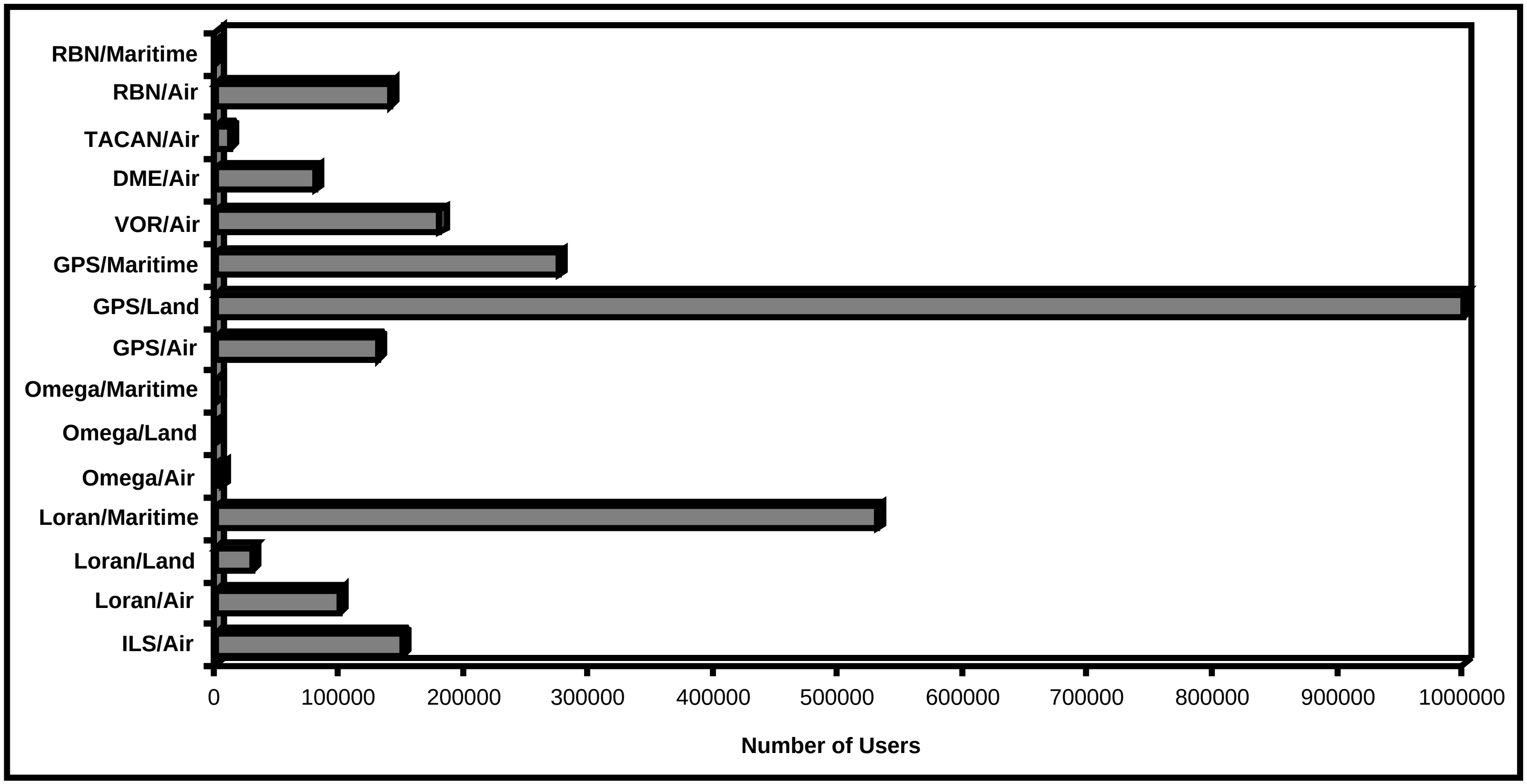
VOR/DME forms the basis of a safe, adequate, and trusted international air navigational system, and there is a large investment in ground equipment and avionics by both the Government and users. In view of this, it is intended to maintain the VOR/DME system at its present capability for a reasonable transition period after augmented GPS is approved as a primary navigation system. The current ICAO protection date extends to January 1, 1998.

As evidenced by user conferences and aircraft equipage, there is increasing interest and usage of GPS and Loran-C for air navigation. Both systems are certified as supplemental systems. In 1994, unaugmented GPS was also approved as a primary system for use in oceanic and remote airspaces. The WAAS, which is envisioned to be operational in 1998, is expected to be certified as a primary navigation system. This will allow termination of many existing ground-based radionavigation aids after an adequate transition period to allow users to equip with WAAS avionics.

Oceanic En Route: Oceanic en route air navigation is currently accomplished using inertial reference system/flight management computers, inertial navigation systems (INS), Omega, Loran-C, GPS, or a combination of these systems. Use of Doppler and celestial navigation are also approved. 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. It is also used by pilots operating under Visual Flight Rules. The U.S. and all other member states of ICAO have agreed to provide VOR/DME service to international air carriers up to January 1, 1998. Loran-C, Omega, and inertial systems are also used for domestic en route navigation. When inertial systems are used, their performance must be monitored through the use of an approved externally referenced radio aid to navigation. Loran-C and GPS both are approved as supplemental systems. GPS is also approved as a primary system for use in remote areas, and distance information based on GPS can be used to provide separation between aircraft in accordance with current DME standards.

Terminal: Terminal air navigation requirements are presently met using VOR, VOR/DME, VORTAC, TACAN, NDB, GPS, or Loran-C. Loran-C and GPS are approved as supplemental systems.



Sources: FAA, USCG, FHWA, DOD, Aircraft Owners and Pilots Association and the U.S. GPS Industry Council

Figure 3-1. Estimated Current U.S. Radionavigation System User Population

Approach and Landing: Nonprecision approach navigation requirements are presently met using ILS localizer, VOR, VOR/DME, VORTAC, TACAN, GPS, Loran-C, or NDB. Loran-C and GPS are approved as supplemental systems. Precision approach and landing requirements are presently met by ILS (Categories I, II, and III) and MLS (a limited number of Category I systems only).

3.1.2 Marine Navigation

Marine navigation comprises four major phases: inland waterway, harbor entrance and approach, coastal, and oceanic. 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, the most promising system to meet the most stringent requirements of the harbor entrance and approach and inland waterway phases of marine navigation is DGPS. With regard to the coastal phase of navigation, DGPS will provide the navigational features currently being met by Loran-C as it is used in the repeatable mode 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 been developed. Visual and audio aids to navigation, radar, and intership communications are presently used to enable safe navigation in those areas. However, DGPS is expected to play an increasing role in this phase of navigation.

Harbor Entrance and Approach Phase: Navigation in the harbor entrance and approach areas is accomplished through use of fixed and floating visual aids to navigation, radar, and audible warning signals. The growing desire 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 and investigation of the use of radio aids to navigation. DGPS is anticipated to meet the navigational needs for this phase of navigation, but it will be necessary to integrate it with an electronic chart display information system (ECDIS). DGPS coverage includes all coasts of the continental U.S. and parts of Alaska, Hawaii, and the Great Lakes. The system provides between 2 and 20 meter accuracy.

Coastal Phase: Requirements for operation within the coastal area are now met by Loran-C, which was fully implemented by 1980. GPS now also meets these needs. Radio Direction Finders (RDF), required in some merchant ships by international agreement for search and rescue purposes, are also used with the radiobeacon system for navigation.

Ocean Phase: Navigation on the high seas is accomplished by the use of dead-reckoning, celestial fixes, self-contained navigation systems (e.g., inertial systems), Loran-C, Omega, and GPS. GPS reached its Initial Operational Capability (IOC) on December 3, 1993, and is now the system of choice for this phase of marine navigation. 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.

3.1.3 Land Navigation

GPS, in conjunction with other systems, is used in land vehicle navigation. Government and industry have sponsored a number of projects to evaluate the feasibility of using existing and proposed radionavigation systems for land navigation. Operational tests have been completed that use in-vehicle navigation systems and electronic mapping systems to provide real-time route guidance information to drivers. GPS and Loran-C are used for automatic vehicle location for bus scheduling and fleet management. Operational tests are either planned or in progress to use radionavigation for route guidance, in-vehicle navigation, providing real-time traffic information to traffic information centers, and improving emergency response. Several transit operational tests will use automatic vehicle location for automated dispatch, vehicle re-routing, schedule adherence, and traffic signal pre-emption. Railroads have tested and continue to test GPS as a part of positive train control systems for freight as well as high-speed passenger train operations. GPS, Loran-C, and dead-reckoning/map-matching are being developed as systems that take advantage of radionavigation systems and at the same time improve safety and efficiency of land navigation.

3.1.4 Uses Other Than Navigation

These uses are concerned primarily with the application of GPS for geodesy and surveying, positioning in support of mapping, charting, and geographical information systems, monitoring of Earth motions, meteorological parameter monitoring, and time and frequency determination. Users with these applications represent a large percentage of the GPS user community and involve all levels of government, academia, and industry. Many of the products supported by these applications are those traditionally provided by the Federal government. These include the National Spatial Reference System, nautical and aeronautical charts, weather prediction, earthquake studies, and inland waterways management. In the Inland Waterways, Harbor Entrance and Approach and Coastal Phases, DGPS is being used extensively by the U.S. Coast Guard to position floating aids as well as fixed aids to navigation. Additionally, the U.S. Army Corp of Engineers is using DGPS to conduct surveying, aid positioning, dredging operations, and revetment maintenance.

Many applications of GPS and augmented GPS are anticipated for Federal, state, and local governments, industry, and consumers. The Government does not have a responsibility under law to provide radionavigation systems for these users. However, these applications represent a large (and growing) percentage of the civil radionavigation user community and are recognized in the radionavigation planning process.

3.1.5 Space Applications

There are numerous uses of GPS for space navigation; many are discussed in Section 2. Several spacecraft, including the ISSA, the Space Shuttle, the Student Nitrous Oxide Explorer, and the small satellites Lewis and Clark are using or will be using GPS for navigation. Some of these spacecraft will use GPS for support of instrument pointing, scientific data processing, and, in the case of the Space Shuttle, during approach and landing as well as on orbit. The private sector is also implementing the use of GPS in space applications.

3.2 Existing and Developing Systems - Status and Plans

Figure 3-2 shows the operating plans for Federally provided common-use radionavigation systems.

3.2.1 Global Positioning System (GPS)

GPS is a space-based positioning and navigation system designed to provide worldwide, all weather, passive, three-dimensional position, velocity, and time data to a variety of civil and military users. GPS provides a Standard Positioning Service for all users and a Precise Positioning Service for authorized users.

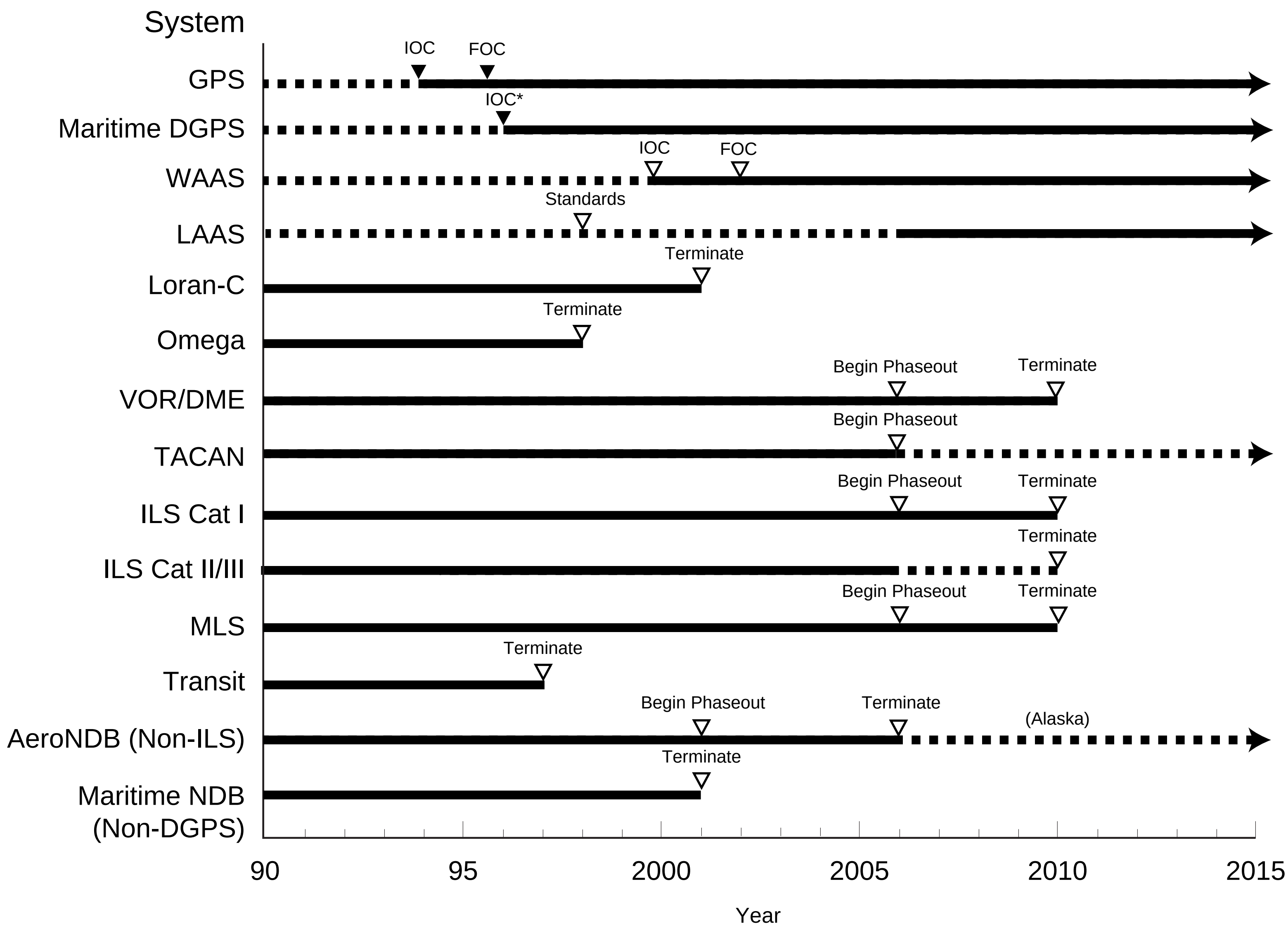
A. User Community

The GPS user community has grown exponentially in the past two years and that growth is expected to continue. Rapid growth has occurred in all modes of transportation. Non-transportation use is also growing at a rapid rate and includes users employed in surveying, farming, resource exploration, and law enforcement. The GPS signal specification defines the SPS which is designed to support civil GPS applications. The GPS Precise Positioning Service (PPS) is restricted to U.S. Armed Forces, U.S. Federal agencies, and selected allied Armed Forces and governments. These restrictions are based on national security considerations.

B. Operating Plan

GPS will be the primary Federally funded radionavigation system for the foreseeable future. Initial Operational Capability (IOC) was declared December 8, 1993 when the DOD determined that the SPS, described in memoranda of agreement between the DOD and DOT, could be sustained. The USCG and FAA subsequently authorized GPS for civil transportation use. DOD Full Operational Capability (FOC) was announced on July 17, 1995 after the 24-satellite constellation was completely tested for military functionality (a milestone that does not have any significant impact on civil users).

All routine command and control functions are performed from the Master Control Station in Colorado Springs, Colorado using its dedicated network of remote monitor stations and ground antennas. The GPS constellation is configured and



* See Section 3.2.2.1B

Figure 3-2. Radionavigation Systems Operating Plan

operated to provide the SPS signals to civil users in accordance with the GPS Standard Positioning Service Signal Specification (Ref. 9). The DOD will maintain a 24-satellite constellation. Replacement satellites will be launched on an expected failure strategy (a replacement satellite is launched when there are indications that a satellite should be replaced).

The DOD and DOT have agreed that representatives from the DOT will be located within the Master Control Station and at the GPS Joint Program Office to participate in the day-to-day system operations, system development, and future requirements definitions.

Any planned disruption of the SPS in peacetime will be subject to a minimum of 48-hour advance notice provided by the DOD to the USCG Navigation Information Service (NIS) and the FAA Notice to Airman (NOTAM) system. A disruption is defined as periods in which the GPS is not capable of providing SPS as specified in the GPS Standard Positioning Service Signal Specification (Ref. 9). Unplanned system outages resulting from system malfunctions or unscheduled maintenance will be announced by the NIS and NOTAM systems (see Appendix A) as they become known.

The FAA's GPS overlay initiative, which permits use of GPS to fly most existing NPA procedures, is of particular significance in achieving early operational benefits from GPS. The convenience of GPS for executing the thousands of existing VOR- and NBD-based NPAs was made immediately available to suitable equipped aircraft. In addition to "overlay" NPAs, the FAA is moving aggressively to produce and publish GPS-based NPAs for runways without existing approaches, as well as improved approaches (lower minimums) for runways with existing NPAs. The FAA developed more than 500 such approaches in 1995 and an additional 500 in 1996; as of April 1997, more than 700 of these approaches had been published. Initial development of WAAS-based precision approach procedures will commence in 1998 to support WAAS commissioning. A precision approach based on WAAS criteria will be designed for each runway end that is currently served by an existing conventional approach procedure. In addition, an NPA procedure will be developed with each precision approach procedure. The NPA will be usable by both WAAS and TSO-C129 receivers.

C. Spectrum

The L1 links of GPS and the Russian GLONASS system, the present principal elements of the ICAO GNSS, operate in the 1559-1610 MHz frequency band. This is the sole band that is identified worldwide for the satellite-based aeronautical radionavigation requirements of civil aviation. The GPS L1 carrier frequency is 1575.42 MHz. WAAS, when it becomes operational, will utilize the same band and carrier frequency as GPS L1. Additionally, a system of pseudolites which would share the GPS L1 frequency has been proposed as an enhancement for LAAS.

The GPS L2 link shares the 1215-1260 MHz frequency band with the GLONASS L2 link and with the nationwide joint surveillance system radar network operated by DOD and FAA. The GPS L2 carrier frequency is 1227.6 MHz.

A second civil frequency is planned to enhance the ability of GPS to support civil users. It is needed for mitigation of ionospheric-delay estimation errors and as a backup for the GPS L1 link. A specific frequency for this purpose is to be identified.

3.2.2 GPS Augmentations

Unaugmented GPS will not meet all performance requirements for aviation, for the harbor entrance and approach phase of marine navigation, or for many land transportation applications. For example, an aircraft must have at least five satellites in view above a mask angle of 7.5 degrees in order to provide receiver autonomous integrity monitoring (RAIM). This condition is not always satisfied with the existing GPS constellation, resulting in so-called “RAIM holes” and limiting GPS to use as a supplemental navigation system. To meet the requirements for Fault Detection and Exclusion (FDE), at least six satellites with good geometry are necessary. Some type of augmentation is required for GPS to meet the requirements of an airspace.

GPS 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, and the implementation of Selective Availability (SA).

Adverse effects of these variances may be substantially reduced, if not practically eliminated, by differential techniques. In such differential operation, a reference station is located at a fixed point (or points) within an area of interest. GPS signals 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 differential corrections to upgrade the precision and performance of the user’s receiver.

Non-navigation users of GPS who require few-centimeter accuracy or employ post processing to achieve few-decimeter to few-meter accuracy often employ augmentation somewhat differently from navigation users. For post processing applications using C/A code range, the actual observations from a reference station (rather than correctors) are provided to users. The users then compute correctors in their reduction software. Surveyors and other users who need subcentimeter to few-centimeter accuracy in positioning from post-processing use two-frequency carrier phase observations from reference stations, rather than range data. The CORS system is designed to meet the needs of both of the above types of these users.

3.2.2.1 Maritime Differential GPS

The USCG maritime DGPS system provides service for coastal coverage of the continental U.S., the Great Lakes, Puerto Rico, portions of Alaska and Hawaii, and portions of the Mississippi River Basin. Maritime DGPS uses fixed GPS reference stations which broadcast pseudo-range corrections using radionavigation radiobeacons. The USCG DGPS system provides radionavigation accuracy better than 10 meters (2 drms) for U.S. harbor entrance and approach areas.

A. User Community

Initially the U.S. Coast Guard identified four missions to be supported by the implementation of DGPS:

- Harbor Entrance and Approach Phase navigation
- Vessel Traffic Services (VTS)
- Aids to Navigation (ATON) positioning
- Exclusive Economic Zone (EEZ) surveying

The first is the only listed mission that requires navigation capability for both government and public users. The other three are government missions requiring a positioning service. In addition to the four Coast Guard identified missions, the U.S. Army Corp of Engineers (USACE) has partnered with the U.S. Coast Guard to establish DGPS along many of the navigable inland rivers of the U.S. As a result, USACE surveying, positioning, dredging, revetment maintenance, and other navigation related activities are to be accomplished with improved levels of efficiency. When the Coast Guard's DGPS service has been validated to satisfy the USCG DGPS performance specifications (Appendix A, section A.2.2.1), the system will be declared Full Operational Capability (FOC). Once achieved, the Coast Guard will initiate a regulatory project to amend the carriage requirements of the Navigation Safety Regulations to require carriage of DGPS equipment for vessels entering and leaving U.S. waterways.

B. Operating Plan

The USCG declared Initial Operational Capability (IOC) for maritime DGPS service on January 30, 1996. The IOC phase is identified by the system's ability to transmit DGPS signals from 47 of its 48 planned sites along selected portions of the nation's coastline and major inland rivers. During IOC, DGPS signals are provided with full integrity and, when and where available, are fully useable for navigational applications. To expedite service, the USCG entered the IOC phase using existing equipment which cannot meet the high standards (as described in Appendix A, Section A.2.2.1) of a system with full operational capability. The 48th site, located in Key West, will transmit DGPS corrections by the end of 1996.

The USCG DGPS system will achieve FOC when it is capable of meeting the USCG DGPS performance specifications (Appendix A, section A.2.2.1). Several improvements are required to reach these high levels of performance in availability, reliability, and coverage. These improvements, initiated in 1996, include completion of the planned 48-site system, verification of system coverage areas, and installation of replacement beacon transmitters and upgraded beacon antenna systems. As validated needs for maritime DGPS service expand, and funding becomes available, additional sites will be added to the USCG DGPS system.

Recommended standards for maritime DGPS corrections have been developed by the Radio Technical Commission for Maritime Services (RTCM) Special Committee 104. The USCG is represented on this subcommittee and is using the SC-104 standard for its DGPS system. There are DGPS reference stations available in the market today which are compatible with RTCM Special Committee 104 standard.

3.2.2.2 Aeronautical GPS Wide Area Augmentation System (WAAS)

The FAA WAAS is a safety-critical system consisting of the equipment and software which augments GPS. The WAAS provides a signal-in-space to WAAS users to support en route through precision approach navigation. The WAAS users include all certified aircraft using the WAAS for any approved phase of flight. The signal-in-space provides three services: (1) integrity data on GPS and Geostationary Earth Orbit (GEO) satellites, (2) differential corrections of GPS and GEO satellites to improve accuracy, and (3) a ranging capability to improve availability and continuity.

The GPS satellite data is received and processed at widely dispersed sites, referred to as Wide-area Reference Stations (WRS). This data is forwarded to processing sites, referred to as Wide-area Master Stations (WMS), which process the data to determine the integrity, differential corrections, residual errors, and ionospheric information for each monitored satellite and generate GEO satellite parameters. This information is sent to a Ground Earth Station (GES) and uplinked along with the GEO navigation message to the GEO satellites. The GEO satellites downlink this data on the GPS L1 frequency with a modulation similar to that used by GPS.

In addition to providing GPS integrity, the WAAS verifies its own integrity and takes any necessary action to ensure that the system meets performance requirements. The WAAS also has a system operations and maintenance function that provides information to FAA maintenance personnel.

A. User Community

Substantial benefits will accrue to both users and providers as the WAAS becomes operational and the aviation community transitions to WAAS avionics. Near-term user benefits will result from the use of a single navigation receiver that provides area navigation for all phases of flight and a ten-fold increase in runways approved for precision approaches. When combined with necessary improvements in air traffic control automation, additional user benefits are expected to be derived from reduced IFR separations and more efficient routings. Near-term provider benefits will be derived from the decommissioning of redundant navigation systems and more cost-effective instrument approaches. The WAAS is also expected to be used extensively for numerous other civil applications where improved accuracy, integrity and availability are needed.

B. Operating Plan

The FAA is conducting a major system acquisition consisting of the WAAS operational system and functional verification system. The program strategy is to quickly field an initial WAAS which meets the basic requirements, and to enhance the system to meet the full WAAS requirements through a series of contract options. Implementation of the end-state WAAS will be accomplished in an evolutionary fashion over an estimated six-year period. The initial WAAS will include an initial operational system and a functional verification system. It will be upgraded through a series of pre-planned product improvements to eventually meet all the performance requirements of the WAAS end-state system.

Initial WAAS is expected to be commissioned in 1999, and to be certified as a primary means of navigation for en route and terminal operations and limited precision approach service. WAAS is envisioned to reach its full operational capability in 2001 with multiple redundancy to support all phases of flight from en route to Category I precision approaches.

C. Spectrum

The WAAS will operate as an overlay on the GPS L1 link and will share the 1559-1610 MHz frequency band with it. WAAS will also require codeless access to GPS L2 signals in the 1215-1260 MHz band to enhance system accuracy until such time as the second coded civil GPS signal is operational. The exact timeline and conditions will be specified in a jointly developed DOD/DOT transition plan to be completed by March 1998.

3.2.2.3 GPS Local Area Augmentation System (LAAS)

The LAAS is a local GPS augmentation where the corrections to GPS (and WAAS) signals are broadcast to aircraft within line of sight of a ground reference station. LAAS is expected to support Category II/III applications. The system is also expected to provide Category I precision approaches at some high capacity airports and at locations where WAAS is unable to provide Category I precision approaches. Moreover, the LAAS will be used in high speed turnoff, missed approach, departure, vertical takeoff, and surface operations.

The FAA is working with U.S. industry and universities to determine the technical feasibility of using satellite-based systems for Category II and III precision approaches. Several cooperative projects have already demonstrated the ability of both advanced code and kinematic carrier phase differential techniques to meet the accuracy requirements of Category III autoland approaches. Several satisfactory integrity techniques have also been demonstrated, but must be validated.

The work in this area is being closely coordinated with the development of local area differential GPS (LADGPS) systems for Special Category I (SCAT-I) precision approaches which are being funded by private industry. The FAA plans to develop LAAS specifications by late 1998 and to develop a prototype system. It is uncertain whether this will lead to a Federally funded full scale development activity and production buy of a large quantity of systems. Procurement depends on a pending investment analysis and the consideration of alternative funding mechanisms. Although the exact date is uncertain, the FAA expects LAAS Category II/III precision approaches to be available for public use by 2005.

The FAA is also conducting research on providing airport surface traffic surveillance and guidance based on LAAS-augmented GPS.

The international community is currently evaluating alternatives for the spectral placement of LAAS. At present, the 108-117.975 MHz frequency band, currently populated by VORs and ILSs, is the leading candidate, but other alternatives such as the 328.6-335.4 MHz and 5000-5250 MHz bands are also being considered. A network of pseudolites sharing GPS L1 spectrum in the 1559-1610 MHz band has been proposed as an enhancement for LAAS.

3.2.2.4 The Continuously Operating Reference Station (CORS) System

The CORS system is a GPS augmentation being established by the National Geodetic Survey (NGS) to support non-navigation, post-processing applications of GPS. The CORS system provides code range and carrier phase data from a nationwide network of GPS stations for access by the Internet. As of September 1996, data were being provided from about 75 stations. NGS will precisely position the CORS relative to the North American datum of 1983 (NAD 83), the legal datum of the U.S., as well as to the accepted international reference system, the IERS Terrestrial Reference Frame (ITRF). This will allow users to relate themselves to a common coordinate system.

The CORS system takes data to a Central Facility from the contributing stations using either the Internet or a telephone packet service (such as x.25). At the Central Data Facility, the data are converted to a common format, quality controlled, and place in files for access via Internet. The data are available via Internet for 31 days, after which they are archived on CD ROM. In addition to the data, the Central Data Facility provides software to support extraction, manipulation, and interpolation of the data. The precise positions of the CORS antennas are computed and monitored. In the future it is planned to compute and provide ancillary data, such as multipath models and tropospheric and ionospheric refraction models, to improve the accuracy of the CORS data.

The observational data provided by the CORS system is being used by government, academia, and industry groups to support most of the applications described in section 2.6 above. Currently, users are downloading about 2 gigabytes of data per month. The largest user group in terms of number of bytes downloaded are academic and government research groups involved in geophysical studies of Earth movement. However, the largest number of users are private industry and Federal, state and local government users involved in surveying, mapping, charting, and GIS applications. These users require lesser quantities of data to support their applications.

NGS has implemented CORS by making use of stations established by other groups, rather than by building an independent network of reference stations. In particular, use is being made of data from stations operated by components of DOT to support real time navigation requirements. More than half of the stations now providing data for the CORS system are the stations of the USCG DGPS system described in section 3.2.2.1 above. Stations of the WAAS network (described in section 3.2.2.2 above) will be CORS compatible, as well as stations that might be established in the future by DOT to support land navigation. Other stations currently contributing data to the CORS system include stations operated by the National Oceanic and Atmospheric Administration (NOAA) and NASA in support of crustal motion activities, stations operated by state and local governments in support of surveying applications, and stations operated by NOAA’s Forecast Systems Laboratory in support of meteorological applications.

3.2.3 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. It is currently designated by the FAA as a supplemental system in the NAS.

A. User Community

Users of Loran-C have been one of the largest communities employing a single radionavigation system. This situation is changing now that GPS has achieved FOC and GPS user equipment continues to drop in price. Use of the system is expected to decline with no growth anticipated. It is anticipated that users will purchase GPS or augmented GPS equipment and begin the transition away from Loran-C.

B. Operating Plan

Loran-C was designated as the Federally provided navigation system for the U.S. coastal areas in 1974. The domestic Loran-C system as it is operated and supported by the USCG consists of 29 transmitting stations comprising 12 Loran-C chains. Included in this chain count is the Russian-American chain and the three Loran-C chains operated in cooperation with Canada. (The coverage of the Loran-C systems is shown in Appendix A.)

Current use of the Loran-C system appears to be leveling off and will most likely decrease as GPS and DGPS fills the market place. The U.S. will terminate operation of the Loran-C system by December 31, 2000. The Coast Guard Authorization Act of

1996 requires, however, that the Department of Transportation prepare a report on the future use and funding of Loran-C. The report will be developed in consultation with users of the Loran-C system and in cooperation with the Secretary of Commerce.

C. Spectrum

Loran-C operates in the 90-110 kHz frequency band. No future civil aeronautical uses are envisioned for that band after Loran-C has been decommissioned.

3.2.4 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 six partner nations. It provides worldwide, all-weather radionavigation capability.

A. User Community

International civil use of Omega includes sole means oceanic aircraft navigation because of its worldwide coverage. It is also approved by the FAA for use as a supplement for domestic high altitude en route airspace navigation.

The precise timing aspects of Omega make it possible to obtain profiles of wind speed and direction from ground level to over 30 km with an Omega-based meteorological upper-air observation system. Omega-equipped meteorological sondes are launched annually from approximately 200 locations around the world.

B. Operating Plan

The eight-station Omega configuration has been operational since August 1982. Omega stations are located in Norway, Liberia, La Reunion Island, Argentina, Australia, and Japan, and in the U.S., in North Dakota and Hawaii. The U.S. operates the two stations located in the U.S. and has bilateral agreements with the partner nations that govern partner nation operation. The USCG has operational control of the system and has operated the system for the FAA since January 1, 1995.

With the achievement of GPS FOC, it is anticipated that aviation users will quickly transition from Omega to GPS. Therefore, the U.S. will terminate its role in the Omega system on September 30, 1997.

C. Spectrum

Omega operates in the 9-14 kHz frequency band. No future civil aeronautical uses are envisioned for that band after Omega has been decommissioned.

3.2.5 VOR and VOR/DME

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. Some VOR stations are used for broadcast of weather information.

A. User Community

Approximately 69 percent of all navaid-equipped general aviation aircraft had more than one VOR receiver in 1993. An even higher percent had at least one VOR but the exact number cannot be derived from the available statistics.

VOR is the primary radionavigation aid in the National Airspace System and is the internationally designated standard short-distance radionavigation aid for 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.

B. Operating Plan

The FAA operates 1012 VOR, VOR/DME, and VORTAC stations including 150 VOR-only stations. The number of stations is expected to remain stable until the VOR/DMEs begin to be decommissioned in 2005. The DOD also operates stations in the U.S. and overseas that are available to all users.

A small increase in the number of users equipped with VOR is expected over the next several years due to an increase in the aircraft population operating in the U.S. During this time, many users that are equipping their aircraft for VFR operation may choose to equip with GPS in preference to VOR. VOR/DME will still be required for IFR flight until the WAAS is approved for primary means navigation. It is then expected that VOR equipage will begin to rapidly decrease.

The current VOR/DME network will be maintained until 2005 to enable aircraft to become equipped with WAAS avionics and to allow the aviation community to become familiar with the system. Plans for expansion of the network are limited to site modernization or facility relocation, and the conversion of sub-standard VORs to a Doppler VOR configuration. The phaseout of the VOR/DME network is expected to begin in 2005 and to be complete by 2010.

C. Spectrum

VOR operates in the 108-117.975 MHz frequency band. It shares the 108-111.975 MHz portion of that band with ILS. The FAA and the rest of the civil aviation community are investigating several potential aeronautical applications of the 108-117.975 MHz band for possible implementation after VOR and ILS have been partially or completely decommissioned. One of those future applications is LAAS. Another is the expansion of the present 117.975-137 MHz air/ground (A/G) communications band to support the transition to, and future growth of, the next-generation VHF A/G communications system for air traffic services.

DME operates in the 960-1027, 1033-1087, and 1093-1215 MHz subbands of the 960-1215 MHz band. It shares those subbands with TACAN. The FAA and the rest of the civil aviation community are investigating potential aeronautical applications of those subbands for implementation after DME and TACAN have been partially or completely decommissioned. These future applications include:

- Automatic Dependent Surveillance, Broadcast (ADS-B), a system that will enable aircraft to report their positions, velocities, and related data automatically during flight.
- Traffic Information Services (TIS), in which processed surveillance data will be reported automatically from ground stations to aircraft in flight.
- Terrestrial or satellite-based A/G transfer of voice and data traffic for CNS services.
- Potential future CNS applications to support Free Flight.

The FAA is also considering the retention of a subset of the nationwide VOR/DME network. Continued use of some of the 108-117.975 MHz band would be needed to sustain the VOR elements of such a network. A substantial portion of the 960-1215 MHz band would be required to support its DME elements.

3.2.6 TACAN

TACAN is a UHF radionavigation system which is the military counterpart of VOR/DME. 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. User Community

There are presently approximately 14,500 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. Additionally, allied and third world military aircraft use TACAN extensively.

Because of propagation characteristics and radiated power, TACAN is limited to line-of-sight and is limited to approximately 180 miles at higher altitudes. 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.

B. Operating Plan

DOD presently operates 173 TACAN beacons and the FAA operates 640 TACAN beacons for DOD. Present TACAN coverage ashore will be maintained until phased out in favor of GPS. However, GPS without enhancement cannot replace the TACAN function afloat (moving platforms). Civil DME and the distance-measuring functions of TACAN will continue to be the same.

The DOD requirement for and use of land-based TACAN will terminate when aircraft are properly integrated with GPS and when GPS is approved for all operations in national and international controlled airspace. Proper integration requires hardware and software modifications to GPS user equipment to meet navigation accuracy, integrity, availability, and continuity of service requirements. These modifications as well as development of operational procedures and navigation databases will require a transition period where TACAN must be retained. The target date to begin TACAN phaseout is 2005.

C. Spectrum

TACAN operates in the 960-1027, 1033-1087, and 1093-1215 MHz subbands of the 960-1215 MHz aeronautical radionavigation frequency band. It shares those bands with DME. The FAA and the rest of the civil aviation community are investigating potential aeronautical applications of those subbands, for implementation after TACAN and DME have been partially or completely decommissioned. Possible future applications are noted in Section 3.2.5.

3.2.7 ILS

ILS provides aircraft with precision vertical and lateral 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. User Community

Federal regulations require U.S. part 121 air carrier aircraft to be equipped with ILS avionics. It is also extensively used by general aviation aircraft. A slight increase in the number of users equipped with ILS is expected over the next several years due to an increase in the aircraft population operating in the U.S. ILS equipage rates are then expected to rapidly decrease once the WAAS is approved for Category I approaches.

Because ILS is an ICAO standard landing system, it is extensively used by air carrier and general aviation aircraft of other countries.

B. Operating Plan

The FAA operates nearly 900 ILS systems in the NAS, of which 81 are Category II or Category III systems. In addition, the DOD operates 165 ILS facilities in the U.S. New ILS sites may be installed prior to the availability of precision approaches using the WAAS if they are cost-beneficial.

ILS is a standard civil landing system in the U.S. and abroad, and is protected by ICAO agreement to January 1, 2010. ICAO has endorsed the Global Navigation Satellite System (GNSS) as the core system for international use. The U.S. will continue to promote the international acceptance and implementation of GPS as part of the GNSS for navigation in all phases of flight.

The WAAS is expected to provide a limited Category I precision approach service beginning in late 1998, and the system is anticipated to become fully operational in 2001. ILS will remain in service together with WAAS precision approaches to allow users an opportunity to equip with WAAS receivers and to become comfortable with its service. The phaseout of Category I ILS is expected to begin in 2005 and to be complete by 2010.

The date when LAAS Category II/III approaches will become available is less certain. Extensive testing has demonstrated the ability of LAAS to meet Category II/III accuracy requirements. Analyses and field tests are currently in progress to demonstrate that the integrity requirements can also be achieved. Following this, several years will be required to select among the available techniques and develop and certify an operational LAAS system.

Until LAAS systems are available, the FAA plans to meet upgrade and new Category II/III requirements with ILS. Upgrades and new system establishments will be done only if cost beneficial, given the expected availability of LAAS Category II/III approaches by 2005. The FAA does not anticipate phasing out any Category II/III ILS systems prior to 2005. The phaseout is expected to be complete by 2010.

ILS limitations manifest themselves in four major areas. First, performance of individual systems can be affected by terrain and man-made obstacles, e.g., buildings and surface objects such as taxiing aircraft and snowbanks. These items may impose permanent use constraints on individual systems or limit their use at certain times. Second, the straight-line approach path inherent in ILS constrains airport operations to a single approach ground track for each runway. In contrast, both augmented GPS and MLS will allow multiple ground track paths for approaches to the active runway as well as provide a steeper glide slope capability for Short Take-Off and Landing (STOL) aircraft. Third, even though the new 50 kHz frequency spacing has doubled 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. Fourth, interference from commercial FM broadcast stations in the adjacent frequency band limits ILS frequency assignments in many congested locations; however, this is more of a concern in other countries than in the U.S.

C. Spectrum

ILS marker beacons operate in the 74.8-75.2 MHz frequency band. Since all ILS marker beacons operate on a single frequency (75 MHz), the aeronautical requirements for this band will remain unchanged until ILS has been completely phased out. No future aeronautical uses are envisioned for this band after ILS has been fully decommissioned.

ILS localizers share the 108-111.975 MHz portion of the 108-117.965 MHz band with VOR. As noted in Section 3.2.5, the FAA and the rest of the civil aviation community are investigating several potential aeronautical applications of this band for possible implementation after VOR and ILS have been partially or completely decommissioned. One of those future applications is LAAS. Another is the expansion of the present 117.925-137 MHz A/G communications band to support the transition to, and future growth of, the next-generation VHF A/G communications system for air traffic services. Substantial amounts of spectrum in the 108-111.975 MHz subband will continue to be needed to operate Category II and III localizers even after Category I ILS has been decommissioned.

ILS glideslope subsystems operate in the 328-335.4 MHz band. The FAA and the rest of the civil aviation community are investigating several potential aeronautical applications of this band for possible implementation after ILS has been partially or completely decommissioned. The inherent physical characteristics of this band, like those of the 108-111.975 MHz band, are quite favorable to long-range terrestrial line-of-sight A/G communications and data-link applications like LAAS, ADS-B and TIS. Consequently, this band is well suited to provide multiband diversity to such services or to serve as an overflow band for them if they cannot be accommodated entirely in other bands. Substantial amounts of spectrum in this band will continue to be needed to operate Category II and III ILS glideslope subsystems even after Category I ILS has been decommissioned.

3.2.8 MLS

MLS applications are limited to aviation. MLS does not have the siting problems of ILS and offers higher accuracy and greater flexibility, permitting precision approaches at more airports. MLS provides DOD tactical flexibility due to its ease in siting and adaptability to mobile operations. However, there is limited user support for MLS in the U.S.

A. User Community

A limited procurement of Category I MLS equipment was initiated in 1992. However, the FAA has determined that augmented GPS is feasible for Category I precision approach operations and is progressing toward implementation and certification. Only 29 Category I MLS systems are currently planned to be installed, and the FAA has terminated the development of Category II and III MLS equipment.

The termination of the Category II and III development contracts was primarily a budget decision, supported by initial results of R&D efforts that have demonstrated the potential for using augmented GPS technology for this application. The FAA retains the option to purchase MLS for Category II and III operations on the open market should the decision be made to implement MLS in the future.

B. Operating Plan

The FAA has terminated the development of MLS based on favorable GPS test results and budgetary constraints. The U.S. does not anticipate additional MLS development, but could purchase systems on the open market for Category II/III operations if the need should arise in the future. The phaseout of Category I MLS is expected to begin in 2005 and to be complete in 2010.

C. Spectrum

MLS operates in the 5000-5250 MHz frequency band. The FAA and the rest of the civil aviation community are investigating potential aeronautical applications of this band for implementation after MLS has been partially or completely decommissioned. These include:

- An extension of the tuning range of the Terminal Doppler Weather Radar (TDWR) in order to relieve spectral congestion within its present limited operating band.
- Weather functions of the planned multipurpose primary terminal radar that will become operational around the year 2013.

The possible use of this band for LAAS is also being considered by the international community.

3.2.9 Aeronautical Nondirectional Beacons (NDBs)

Aeronautical nondirectional beacons are used for transition from en route to precision terminal approach facilities and as nonprecision approach aids at many airports. In addition, some state and locally owned NDBs are used to provide weather information to pilots. However, GPS and the FAA's automated weather observing system (AWOS) and automated surface observing system (ASOS) have begun to satisfy the requirement currently met by NDBs. In Alaska and in some remote areas, NDBs are also used as en route facilities.

A. User Community

All air carrier, most military, and many general aviation aircraft carry automatic direction finders (ADF). However, the importance of ADF is expected to decline with the increasing popularity of GPS.

Aircraft use radiobeacons as compass locators to aid in finding the initial approach point of an instrument landing system, for nonprecision approaches at low traffic airports without convenient VOR approaches, and for en route operations in some remote areas.

The large number of general aviation aircraft that are equipped with radio direction finders attests 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. However, now that GPS-based nonprecision approaches are available, transition from the NDB network can begin.

B. Operating Plan

The FAA operates over 700 NDBs. This number is expected to decline steadily over the next decade due to the increasing popularity of GPS. In addition, there are about 200 military NDBs and 800 non-Federally operated NDBs. 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.

The FAA expects to decommision NDB facilities where essentially equivalent capability is provided by VOR beginning in 2000. The remaining stand-alone NDBs will be rapidly phased out after 2005. However, in each case, through consultation with the user community, aircraft operator desires for continued NDB service will be weighed against the cost of continuing to provide that service. There may be cases where operation and maintenance of an NDB will be taken over by an individual operator or community desiring to delay its phaseout.

NDBs used as compass locators for ILS approaches, where no equivalent ground-based means for transition to the ILS course exists, will be maintained until the underlying ILS is itself phased out. A separate transition timeline will be developed for NDBs that define low frequency airways in Alaska.

C. Spectrum

Aeronautical NDBs operate in the 190-435 and 510-535 kHz frequency bands, portions of which it shares with maritime NDBs. Except in Alaskan airspace, no future civil aeronautical uses are envisioned for these bands after the aeronautical NBD system has been decommissioned throughout the rest of the NAS.

3.2.10 Maritime Radiobeacons

Maritime radiobeacons have remained as a backup to more sophisticated radionavigation systems and as a low-cost, medium accuracy system for vessels equipped with only minimal radionavigation equipment. Use and number of these beacons is dwindling very rapidly.

A. User Community

Radiobeacons are primarily used as homing devices for recreational boaters, but they also act as a backup for those users having more sophisticated radionavigation capability. As selected radiobeacons are modified to broadcast DGPS corrections, those radiobeacons will become a primary element in the harbor entrance and approach and coastal phases of navigation, used by all vessels, and required for certain classes of vessels. Due to single carrier operations, which eliminates the Morse tone identifier, USCG DGPS beacons do not conform to traditional radiobeacon standards.

Maritime radiobeacons have been an acceptable radionavigation tool for pleasure boaters using them for homing purposes, largely due to the adequate service with low-cost user equipment.

Marine radiobeacons provide a bearing accuracy relative to vehicle heading on the order of +-3 to +-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.

B. Operating Plan

Four maritime radiobeacons continue to be operated by the USCG. Many of the previously-configured maritime radiobeacons have been modified to broadcast DGPS corrections for the USCG DGPS service; therefore, they no longer provide service as traditional homing devices.

With the availability of low-cost Loran-C and GPS receivers that provide far more flexible use to the boater, the use of radiobeacons has been continually declining. As the USCG conducts evaluation of the need for beacons, those with no identifiable user base will be discontinued. Maritime radiobeacons not modified to carry DGPS correction signals are expected to be phased out by the year 2000.

Although some aviation users have benefited from maritime radiobeacons, modulation of maritime radiobeacons with DGPS corrections will make these beacons unusable by digital aviation ADFs and may make their use by analog ADFs difficult.

Radar Transponder Beacons: Radar transponder beacons (RACONs) are short-range radio devices used to provide fixed radar reference points in areas where it is important to identify a special location. Currently, they are only used in the marine environment. 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 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; and 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. In 1986, the Code of Federal Regulations was changed (33 CFR 66.01-1 (d)) to allow private operation of RACONs with USCG approval. The USCG now has about 104 frequency agile RACONs.

3.3 Interoperability of Radionavigation Systems

3.3.1 Overview

Radionavigation 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.

3.3.2 GPS/GLONASS

Manufacturers of navigation and positioning equipment are beginning to develop and manufacture combined GPS/GLONASS receivers to take advantage of these benefits. Some receivers are on the market with others in the planning stage. The RTCA SC 159 is developing a MOPS for a combined GPS and GLONASS system. The Airlines Electronic Engineering Committee (AEEC) is developing specifications for a multimode receiver which includes GLONASS. The satellite communications MOPS and SARPS provide for both GPS and GLONASS protection.

A combination of GPS and GLONASS has several potential benefits over either system alone. Combining the capability in one receiver to navigate using satellites from the GPS and GLONASS constellations results in a receiver with improved navigation and positioning availability worldwide, improved polar coverage, improved resistance to interference and jamming and improved RAIM and FDE. The FAA has entered into a bilateral agreement with the Russian Federation to investigate a combined GPS/GLONASS avionics receiver which could take advantage of all 48 satellites of the two constellations.

4

Radionavigation System Research and Development Summary

4.1 Overview

This section describes Federal Government research and development (R&D) activities relating to Federally provided radionavigation systems and their worldwide use by the U.S. Armed Forces and the civilian community. It is organized in two segments: (1) civil R&D efforts to be conducted by DOT and other Government organizations for civil purposes, and (2) DOD R&D.

The DOT R&D activities emphasize applications for and enhancement of GPS for civil uses. GPS has broad multimodal civil and military applications; consequently, there is 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. DOT's participation in the evaluation and development of GPS ensures that benefits can be derived from DOD's advances in systems technology.

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 of ensuring safety and economy of transportation. These factors involve an evaluation of the overall performance and 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 a complex evaluation of accuracy and equipment performance characteristics. As a first step in the comparison of system capabilities, ten parameters, discussed in Appendix A, can be identified as follows:

- Signal characteristics
- Accuracy
- Availability
- Coverage
- Reliability
- Fix rate
- Fix dimensions
- System capacity
- Ambiguity
- Integrity

User equipment costs are a major consideration if universal civil participation is to be achieved. DOT R&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&D activities mainly address evaluations by Armed Forces user groups which are identified by military mission requirements and national security considerations. For this reason, DOD R&D 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-C, TACAN, VOR, ILS, and Omega is that these systems are already developed and, therefore, do not require R&D.

Although there are some similarities between the DOD and DOT analyses of the system 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&D programs, the major cost issues will be evaluated. These evaluations and R&D programs will be used to support joint positions related to system mix, phase-in and phase-out, and transition strategies for common-use systems.

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

- DOT will evaluate the costs of all radionavigation systems which meet identified civil user requirements.
- DOT will provide DOD with the most current information on civil user requirements which may have a significant impact on DOD-operated radionavigation systems.
- Consistent with existing DOD policy, DOD will provide information to DOT on GPS receiver designs that may be applicable to civil receiver development.
- DOT will conduct studies of GPS performance capabilities of receivers in order to provide an assessment of their applicability to the civil sector.
- DOD/DOT will not constrain the use of SPS-based differential GPS service as long as applicable U.S. statutes and international agreements are adhered to.
- DOT will cooperate in the development of differential correction reference stations for the best possible differential/integrity network.
- DOT will continue to evaluate satellite radionavigation technologies (such as dual capacity receivers) for potential use in an international Global Navigation Satellite System (GNSS).

The specific civil R&D activities are discussed in the following sections. These activities have been coordinated to achieve efficient use of the limited funds available for R&D and to avoid duplication of effort. R&D tasks for the individual DOT agencies (FAA, USCG, MARAD, etc.) and related tasks by other government agencies are addressed and schedules have been specified if possible so that the results of the efforts will be of maximum usefulness to all participants in the program.

4.2 DOT R&D

DOT R&D activities have been conducted primarily by the USCG, the FAA, the FHWA, and ITS/JPO. Efforts initially were directed primarily toward determining the capability of GPS to meet civil user needs in the air, marine, 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, R&D efforts focused on ways of enhancing GPS to meet these civil needs. Many new efforts are focusing on the development of new and innovative applications of GPS.

4.2.1 Civil Aviation

The FAA's basic R&D activities for the introduction of GPS into the NAS are currently focused on the GPS WAAS to satisfy accuracy, coverage, reliability, and integrity for all phases of flight down through Category I precision approach.

Additional R&D activities to exploit the full capabilities of GPS for civil aviation are continuing.

The FAA, through its GPS R&D program, is developing the requirements for use of GPS in the national airspace. This includes refining the appropriate standards for GPS airborne receivers and developing the air traffic control methodology for handling GPS area navigation aircraft operation in an environment with non-GPS equipped aircraft. The FAA has certified GPS as a supplemental means of navigation. The use of GPS as a primary means of navigation depends on the successful development, deployment, and operation of the WAAS, as well as the development of appropriate standards, operating procedures, and avionics. The objective of the FAA is to support the integration of GPS and DGPS into the NAS in an evolutionary manner. The evolving WAAS will be a key component of the NAS precision approach and landing architecture. The WAAS is projected to meet all requirements for Category I precision approach. Additional augmentation will be required to support Category II and III operations; the FAA has successfully determined the technical feasibility of using GPS LAAS for Category II and III operations. Other augmentations and auxiliary/hybrid sensors may also be employed, and are currently being examined. There is close cooperation between FAA, DOD, and industry in these efforts. A Memorandum of Agreement between FAA and DOD to implement GPS for civil aviation was signed on May 15, 1992.

The FAA is actively supporting the activities of the ICAO and RTCA, Inc. in the definition of the GNSS and associated implementation planning guidelines. The GNSS is intended to be a worldwide position, velocity and time determination system. ICAO has accepted the GPS and GLONASS as the constituent components of the GNSS and is actively developing SARPS. The GNSS will also require end-user receiver equipment, a system integrity monitoring function, and ground-based services augmented as necessary to support specific phases of flight. GPS will be the primary satellite constellation used for navigation during early GNSS implementation. The FAA’s activities in support of ICAO and RTCA will ensure that satellite navigation capabilities are implemented in a timely and evolutionary manner on a global basis.

The FAA is actively pursuing technology related to GPS augmentation in order to achieve a new primary means of navigation capability. While several methods are being analyzed and developed, WAAS is fully endorsed and is being developed by the FAA. This satellite-based augmentation concept has been operationally demonstrated for use in all phases of flight with a system prototype. The system is expected to be operational beginning in late 1998.

A. FAA R&D Accomplishments To Date

The FAA has:

- Allowed the use of GPS positioning data as input to multi-sensor navigation systems for selected IFR phases of flight using existing criteria for operating minima, flight inspection, obstacle clearance, and ATC separation standards.

- Approved the use of GPS as a supplemental civil aviation navigation system and as a primary system for oceanic and specified remote areas.
- Published a GPS National Aviation Standard.
- Participated in the development of a Minimum Aviation System Performance Standard (MASPS) for GPS private Special Use Category I precision approaches and has published an Order describing its use.
- Initiated an “overlay” project to quickly certify about 5,000 GPS nonprecision approaches.
- Supported the satellite navigation activities of the Air Transport Association, the National Business Aircraft Association, and the Aircraft Owners and Pilots Association user groups to develop customer capabilities.
- Developed a GPS/GLONASS common receiver test set to collect data and support developing avionics MOPS.
- Established cooperative research agreements with aviation community organizations such as NASA Ames, Ohio University, Stanford University, Honeywell, and Alaska Airlines to investigate the use of GPS for precision approaches.
- Established international cooperation for developing the GNSS through the ICAO Future Air Navigation System (FANS) IV research and development working group.
- Participated in the development of the WAAS MOPS.
- Identified the mechanisms contributing to RFI from on-board VHF air-ground radios and developed simple mitigation techniques to eliminate it.

B. Planned FAA R&D Activities

For primary means of navigation, the FAA is pursuing the development of the WAAS to enhance the availability and integrity of GPS. The FAA is also researching the development, deployment, and certification of the WAAS as a public-use system for Category I precision approaches. There is a continuing certification standards R&D effort to support Category I.

Emphasis is placed on the GPS-based navigational benefits and associated activities for the oceanic, domestic en route, nonprecision approach, and Category I precision approach phases of flight. This reflects that these benefits are near-term, while the capability of the GPS LAAS to provide navigation guidance for Category II and III precision approaches and airfield surface navigation remains relatively long-term and requires further research.

In parallel with the development of WAAS, the FAA is conducting several studies to address concerns related to the GPS/WAAS transition. Unintentional interference to

GPS receivers includes interference caused by such sources as excessive spurious or harmonics emissions from other systems and case penetration of strong undesired signals. This category of interference is being investigated, and effective mitigation techniques and procedures are being developed. Intentional interference, other than planned military electronic countermeasures exercises, is a result of illegal transmission of signals on or close to the GPS frequencies. Such transmission violates both national and international radio regulations, and appropriate law enforcement authorities will take necessary action to terminate such transmission; this will be done with the cooperation of DOD and DOT. The FAA is developing the capability to quickly and effectively identify and locate sources of RFI to the GPS L1 frequency be it intentional or unintentional.

A study is also underway to determine the effect of ionospheric disturbances on the accuracy of GPS and WAAS, especially during the peaks of the 11-year sunspot cycle. The next peak, which is expected to occur about the year 2001, will be important in determining whether the number of references stations in place is sufficient to maintain the required systems accuracy.

Various studies have successfully demonstrated the technical feasibility of using GPS LAAS for conducting Category I, II, and III approaches. The studies include FAA-funded demonstrations and studies by industry and academia worldwide. Presently, the ILS ground-based system is the only system used to support CAT II/III operations. GPS without proper LAAS augmentation cannot support CAT II/III operations. Until the LAAS system is declared fully operational, Category II/III requirements will be met by ILS.

Other activities are to:

- Develop CAT II/III standards. This activity contains multiple elements such as development of TSOs, FAA Orders and ACs, and configuration management updates of NAS documentation.
- Track the GPS signal RF carrier phase during high dynamic movements to obtain sub-meter navigation accuracies.
- Obtain GPS real-time (1 second or less) integrity.
- Provide GPS navigation continuity of service which can meet requirements for landing and rollout under very low visibility weather conditions.

Figure 4-1 shows the FAA schedule for the development of GPS performance standards for civil avionics.

Possibilities exist to develop receiver avionics which combine two radionavigation signals, such as GPS/GLONASS, and thereby significantly improve user navigation performance. FAA, in cooperation with industry, is developing standards under which a specific system or combination of systems may be certified in aircraft conducting IFR, en route, and terminal area operations, including nonprecision approach.

Phase of Flight	CALENDAR YEARS								
	1992	1993	1994	1995	1996	1997	1998	1999	2000
GPS as Input to Multi-Sensor Nav									
En Route Oceanic	Complete								
En Route Domestic	Complete								
Terminal	Complete								
Nonprecision Approach	Complete								
GPS Supplemental Navigation									
En Route Oceanic		Complete							
En Route Domestic		Complete							
Terminal		Complete							
Nonprecision		Complete							
GPS Augmented for Primary Means									
En Route Oceanic (FMS/IRS/ADC)				Complete					
En Route Oceanic				Complete					
En Route Domestic				Complete					
Terminal				Complete					
Nonprecision Approach				Complete					
Precision Approach Cat I						MOPS	TSO		
Precision Approach Cat II & III					Feasibility Study Complete		MOPS	TSO	

Figure 4-1. Development of GPS Performance Standards for Civil Avionics

In the long term, communications, navigation, and surveillance (CNS) may be combined into an integrated communications and navigation system (ICNS) providing a seamless system for civil users. 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. This will also enhance the utilization efficiency of the NAS, allowing increased capacity without a proportional increase in infrastructure expenditures.

Automatic dependent surveillance (ADS) is defined as a function in which aircraft automatically transmit navigation data derived from onboard navigation systems via a datalink for use by air traffic control. Automatic dependent surveillance R&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.

GPS-based navigation offers new opportunities for vertical-flight aircraft to operate more efficiently in the NAS. As prime examples, significant benefits have been derived through virtually uninterrupted emergency medical services to hospitals and trauma centers in all weather operations, undelayed passenger carrying operations and optimized low-altitude air routes.

Emergency medical services have long recognized the importance of delivering prompt medical attention and expeditiously transporting patients to and between medical facilities. GPS-based navigation enhances this potential by enabling instrument approaches to every hospital with sufficient obstacle-free airspace. The FAA is investigating how best to maximize this new capability through reduced Terminal Instrument Procedures (TERPS) obstacle clearance areas, steeper glide slopes, and curved approaches for vertical-flight aircraft. The first stage of this testing focuses on nonprecision approaches. Tests of vertical-flight aircraft performance during nonprecision approaches are being conducted at four heliport sites. Data collection will focus on system-use accuracy and pilot workload over various combinations of glide slopes and curved approaches. Follow on testing will examine precision approach and en route navigation requirements. The results gained during these tests can also be applied to a wide variety of other vertical-flight aircraft missions.

Passenger-carrying operations using vertical-flight aircraft is one method of reducing congestion and delays at high activity airports and on highways. In terminal areas, however, this will work most efficiently if vertical-flight aircraft can operate independently of the regular fixed-wing traffic flow. The high accuracy of GPS-based navigation together with the unique flight capabilities of vertical-flight aircraft can enable undelayed approaches. The FAA is examining methods to optimize these traffic patterns and approaches into high activity airports to eliminate delays regardless of the weather.

The vertical-flight community has identified the need to have low altitude IFR routes that are nearly direct and separate from high traffic fixed-wing routes. Flying IFR at low altitudes is also important in many areas of the United States, most notably the northeast United States, to avoid the frequent icing conditions. Due to the limitations of VOR, only one such IFR route had been feasible. GPS-based navigation can enable these types of routes to be developed wherever a need exists. The FAA has begun analyzing these requirements and the best methods to integrate this route structure into the NAS.

4.2.2 Civil Marine

USCG activities focus on verifying and improving the performance of GPS for maritime navigation. There is particular emphasis upon the harbor entrance and approach phase of marine navigation, where augmentation of visual piloting and positioning of other aids to navigation using radio aids to navigation is needed. Major efforts are to verify the differential GPS concept and techniques developed by the RTCM/SC-104 on differential GPS, and to initiate action to publish a standard for a marine differential GPS system after the RTCM/SC-104 concepts and techniques have been verified.

The R&D activities of the USCG have historically been: (1) user field tests for comparative assessment of GPS versus alternative aids to navigation; (2) assessment of SPS performance potential; and (3) assessment of using differential GPS for various applications including harbor entrance and approach navigation. The purpose of the marine program is to acquire a sufficient base of knowledge to determine those missions of the marine fleet for which GPS and its augmentations can satisfy the navigation performance requirements. Issues important to the use of GPS for marine navigation include:

- Accuracy: Non-augmented GPS cannot provide the accuracies needed by marine users in some applications, including commercial fishing, where repeatable accuracies of 50 meters using Loran-C are commonplace; the offshore industry, which requires 1 meter accuracy; harbor entrance and approach, which requires 8-20 meter accuracy; and inland waterway navigation, which requires 3-10 meter accuracy depending on application.

- Technical and Economic Factors: Technology, and a rapidly-developing satellite constellation, have driven the costs of GPS equipment dramatically downward over the past two years. This trend is also expected over the next two years with DGPS receiver costs. Government activity in this area will be limited to participation with industry in the development of performance standards and functional requirements for receivers to support carriage requirements for vessels.

- Use with ECDIS: DGPS receivers are most effective when used with some form of automated chart display. The extreme accuracy of DGPS-derived positions (small fractions of a minute of latitude and longitude) is difficult to plot manually, and its capability of outputting position data at intervals of one second or less is far beyond the human ability to plot the information in real time. Research into the integration of highly accurate position sensors such as DGPS is ongoing.

The USCG has completed its proof-of-concept for DGPS use in harbor entrance and approach navigation and IOC has been declared for this system. The system greatly exceeded the required levels of accuracy and integrity. Future R&D will focus on jamming and spoofing of the GPS signal. The USCG is working with the RTCM to develop correction messages for geostationary satellites that will provide ranging signals. Working with the RTCM, the USCG has participated in developing a message to broadcast ionospheric measurements which will be thoroughly characterized through field testing. This message, the Type 15, will extend the high accuracy achieved in the vicinity of the reference station out to several hundred miles.

Other USCG R&D projects focus on system enhancements and techniques for improving navigation safety in the harbor entrance and approach phase of marine navigation, principally involving shipboard displays as well as enhanced VTS equipment designs to prevent vessel casualties, loss of life, or pollution of the marine environment. A project is also under way to evaluate the requirements for harbor entrance and approach navigation system performance.

MARAD, in cooperative research with the private sector and the USCG, has developed a computerized decision support system for safe navigation which combines artificial intelligence technology, digital chart data bases, vessel maneuvering data, and precise positioning information to enhance piloting performance in the harbor entrance and approach and coastal phases of navigation. The system is undergoing an operational evaluation aboard ship which should prove its contribution to safe navigation.

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: inland waterway, harbor entrance and approach, coastal, and ocean.

No efforts are being expended by the USCG to develop any radionavigation systems for inland waterways. However, the USCG is cooperating to expand DGPS service through a joint effort with the USACE to meet navigation requirements of certain inland waterways.

Ship simulator studies were conducted to evaluate the minimum radionavigation sensor accuracy and display requirements for piloting in restricted waterways. These studies helped to provide a basis for establishing requirements for harbor entrance and approach navigation system performance.

For the coastal phase of marine navigation, Loran-C and GPS meet the radionavigation requirements. As it is implemented, DGPS will also be usable in much of this navigation phase. No R&D activities are ongoing or planned.

For oceanic navigation, the primary system is GPS. No R&D activities are ongoing or planned.

4.2.3 Civil Land

Land radionavigation users, unlike air and marine users, do not come under the legislative jurisdiction of any single agency. Several DOT organizations are conducting studies and analyses to determine requirements and applications of GPS.

In 1994, DOT conducted a study to evaluate the capabilities of augmented GPS technologies for meeting the requirements of aviation, land and marine users. As part of this task, the current requirements of these users were examined, and the augmented GPS options were evaluated to determine which, if any, could satisfy user requirements. The study concluded that no single augmentation system could meet all user requirements. It recommended an integrated approach that included the FAA'S WAAS and LAAS for aviation users, an expanded USCG local area DGPS system for land and marine users, and that all reference stations associated with these systems be compliant with the Continuously Operating Reference Station (CORS) standards developed by the National Geodetic Survey (NGS) for post processing applications. Additionally, while a high level technical analysis was completed of the feasibility of expanding the USCG system inland, an in-depth analysis was needed to determine the technical feasibility of expanding the USCG system nationwide to meet the needs and requirements of Federal Government land-based users. The technical feasibility study, initiated in 1995 and concluded in April 1996, found that there were no major technical barriers to expanding the system nationwide. Further studies on implementing this system are planned by FHWA and ITS/JPO in cooperation with other government agencies and departments.

RSPA, as the DOT focal point for hazardous materials transportation and pipeline safety, will also study GPS tracking technologies.

Several departments and agencies of the Federal Government are sponsoring R&D activities that use existing radionavigation systems for various land uses. Federal and state governments and private industry are conducting research, as part of the ITS program, to assess the feasibility of using in-vehicle navigation and automatic vehicle location to satisfy the needs of ITS user services. Table 4-1 lists operational tests using GPS that are wholly or partially funded by FHWA, FTA, and NHTSA. A complete listing of R&D studies and operational tests wholly or partially funded by FHWA, FTA and NHTSA can be found in DOT's *Intelligent Vehicle Highway Systems Projects, January 1996* (Ref. 10). These tests are focused on the development of ITS user services to achieve improvements in safety, mobility, and productivity, and reduce harmful environmental impacts, particularly those caused by traffic congestion. The following paragraphs describe some of these tests.

The Onboard Automated Mileage Test in Iowa, Minnesota, and Wisconsin is a three state project that tested and evaluated the effectiveness of using GPS and first-generation onboard computers to record the miles driven within a state for fuel tax allocation purposes in a manner acceptable to state auditors. The system will automatically record mileage by specific roadway as well as state border crossings using GPS and vehicle location technology with a map-matching algorithm.

The Baltimore Mass Transit Administration (MTA) is implementing an automatic vehicle location system that will provide bus status information to the public while simultaneously improving bus schedule adherence and labor productivity. A prototype system involving 50 buses is being tested with Loran-C receivers and 800-MHz radios. The buses' location is determined by the receiver and the information is transmitted to a central dispatch center. Off-schedule buses are identified so corrective action can be taken. The system has been expanded to include all 900 Baltimore transit buses and GPS inputs will replace Loran-C for vehicle location.

Dallas Area Rapid Transit (DART) has installed an Integrated Radio System that includes automatic vehicle location. When completely installed, 832 transit buses, 200 mobility impaired vans and 142 supervisory and support vehicles will be equipped. GPS will generate vehicle location information for fleet management and data collection purposes.

The Colorado Mayday System operational test calls for the installation of in-vehicle devices which are capable of capturing a snapshot of available GPS location data, and other vehicle related emergency information, and a communications system primarily based on cellular telephones and specialized mobile radio units. A control center will be established to receive and process emergency assistance requests from the in-vehicle units and determine vehicle location from the GPS data that was included in the emergency assistance request. The control center will determine the nature of the request and forward it to the appropriate response agency for action. The motorist will then be notified by the control center on the actions taken and the expected response time. The in-vehicle unit will be capable of automatically activating the emergency assistance request under some conditions where the driver may be incapacitated. In addition, there will be a button box that will allow the driver to initiate a specialized call for assistance ranging from vehicle service or repair to medical emergencies. The Denver, Colorado Rapid Transit District (RTD) Passenger Information Display System will use data gathered from the AVL system,

Table 4-1. Examples of ITS Operational Tests Using GPS

Test Name			
ADVANCE (Chicago) DIRECT	GPS GPS	Geolocation for map-matching Vehicle location	1994-7 1993-7
TRAVTEK (Orlando)	GPS	Geolocation for map-matching	1992

FY 93 Operational Tests Using GPS

Test Name			
Travlink	GPS	Automatic Vehicle Location for mass transit scheduling	1993-1996
Colorado Advanced Public Transportation	GPS	Automatic Vehicle Location for mass transit scheduling	1995
Iowa, Minnesota, Wisconsin Border Crossings	GPS	Mileage determination	1994-5
New York City Mass Transit Authority Travel Information Test	GPS	Automatic Vehicle Location for mass transit scheduling	1994-5

FY 94 Operational Tests using GPS

Test Name			
Atlanta En Route Traveler Advisory	DGPS	Geolocation for radio tuning information	1994-1997
Idaho Motor Carrier Safety Assistance Program Out-of-Service Verification	GPS	Automatic Vehicle Location	1995-6
Seattle Wide Area Communications System/Bellevue Smart Traveler	GPS	Geolocation for map-matching	1995-6
PUSH ME	GPS/DGPS	Geolocation for mayday	1995-6
Trilogy In-vehicle ATIS	GPS	Geolocation for graphic map display	1995-1997
Advanced Rural Transportation Information and Coordination (Minnesota)	GPS	Geolocation for routing and mayday	1995-6
Colorado Mayday	GPS	Geolocation for mayday	1995

Table 4-1. Examples of ITS Operational Tests Using GPS (cont.)

FY 95 Operational Tests using GPS

Test Name			
IBEX	GPS	Vehicle tracking	1996-1998

FY 96 Operational Tests using GPS

Test Name			
TRANZIT Express	GPS	Vehicle location	1996
Automated Collision Verification	GPS	Geolocation for collision	1996-1998

currently being installed on all RTD buses, to provide information to video monitors at selected locations regarding estimated bus departures for waiting bus passengers.

The DOT is currently working to develop the Intelligent Transportation Infrastructure through the Model Deployment Program, gradually moving away from operational tests as new technologies are becoming commercially viable.

A number of services are evolving that use GPS-based AVL systems. In mass transit systems, they are being proposed for use in computer-aided dispatch, traffic signal preemption and bus stop annunciation. Within the trucking industry, companies have equipped vehicles with GPS receivers to aid in fleet management. Knowing the location of every vehicle across the nation at any instant in time will allow more efficient planning and operations. Urgent pick-up and delivery services to customers will be possible and rapid and optimal rescheduling of each vehicle's itinerary is expected to result in improved productivity.

FRA is participating in and supporting several positive train control projects that incorporate the use of GPS for position and speed determination. Shown in Table 4-2, these projects are being carried out under FRA's Next Generation High-Speed Rail Program, and are aimed at the development of safer, lower cost train control systems for high-speed passenger train operations.

As navigation benefits to land users become more 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. Typical applications include site registration for remote site location, highway records, land management, and resource exploration; AVM/AVL for truck fleets, railroad transportation management, buses, and police and emergency vehicles; driver information systems for highway vehicles; and navigation applications for highways and remote areas.

Table 4-2. Positive Train Control Projects Using GPS

Project	Sponsors	Location
Positive Train Separation System	Union Pacific Railroad Burlington Northern Santa Fe Railway Washington DOT Oregon DOT	Seattle - Portland
Incremental Train Control System	Michigan DOT Amtrak	Detroit - Chicago
Advanced Train Control System	Illinois DOT Amtrak Union Pacific Railroad	Chicago - St. Louis

4.3 NASA R&D

NASA is conducting R&D in a number if GPS application areas in the space, aeronautics, and terrestrial environments. These efforts include:

Space Applications: The emphasis in the space applications R&D of GPS is primarily on development of off-the-shelf GPS receivers that can be installed in satellites. These receivers will be capable of providing onboard navigation products, providing GPS time signals for distribution to spacecraft systems and instruments, providing necessary data for post-pass processing in support of science data collection, and determining spacecraft attitude. Some receivers will send GPS observables to the ground for processing of position information; however, the more advanced receivers will provide onboard autonomous position and navigation.

In addition to the direct use of GPS satellite information, NASA will be conducting research into the use of global GPS WAAS and the evolving GNSS. Initial work in this area indicates that significant improvements will be achieved in real time determination of satellite position at the submeter level.

GPS will be installed on the Space Shuttle and the ISSA. The ISSA will employ GPS receivers for acquiring precise time and determining satellite position and altitude. The Shuttle applications will include use of GPS for on-orbit position determination as well as a source of position data during Shuttle descent and landing. Although critical missions will have alternate, backup means for position determination, it is envisioned that some NASA satellites will be totally reliant on GPS for navigation, time, and altitude functions. This group of satellites will be mainly small, low-cost, single mission satellites. The use of GPS for time, onboard navigation, and altitude determination will enable further automation of earth-orbiting satellites and will become a significant factor in reduction of satellite construction and operations costs in the future.

During the next few years, NASA, in conjunction with DOD and the international community, will be exploring the use of GPS at satellite altitudes extending to geosynchronous orbit.

NASA is also continuing to refine the post-pass processing techniques used to support precise analysis of scientific data requiring precise knowledge of spacecraft position at data collection time.

Aeronautics Applications: NASA will continue to use GPS receivers aboard NASA aircraft for both aeronautics research and in support of airborne scientific observations. There are numerous projects throughout NASA where GPS technology is being developed for these purposes. Airborne GPS receivers have been used to support NASA scientific research in areas such as Airborne Synthetic Aperture Radar (AIRSAR) and in Greenland ice sheet thickness measurements, and it is anticipated that these uses of GPS will continue and expand.

Terrestrial Applications: NASA is supporting the continued development of the IGS. Areas of research include continued enhancement of the software used to determine orbit ephemerides and techniques for improving measurement accuracy to the 1 mm level.

4.4 NOAA R&D

NOAA performs GPS research and development aimed at (1) improved orbit determination, (2) improved determination of the vertical coordinate using GPS, and (3) development of models of error sources that can improve the accuracy attainable using data from the CORS network of GPS reference stations. Some of the specific studies being undertaken are: improved modeling of tidal deformations of the Earth; development of models of antenna phase center variation as a function of elevation angle of a satellite; development of models of station specific multipath errors; development of improved models of geoid height required to convert GPS derived ellipsoid heights to orthometric heights; and development of improved computational models for determination of the vertical coordinate.

NOAA is also developing operational methods of using GPS derived total precipitable water vapor determinations in weather prediction and climate models and is investigating methods of improving the accuracy of the precipitable water vapor determinations. Finally, studies are underway to improve the methods used to position and orient aircraft performing photogrammetry in support of nautical and aeronautical charting.

4.5 DOD R&D

GPS Security Program

The PDD announced that it was the U.S. intention to discontinue the use of GPS Selective Availability (SA) within a decade (2006) in a manner that allows adequate time and resources for military forces to prepare for operations without SA.

The DOD has initiated a Navigation Warfare (NAVWAR) program that provides the warfighter with the tools to effectively employ GPS as a force multiplier on the 21st

Century battlefield. The effort provides for the incorporation of advanced technologies to meet emerging mission requirements while countering theater threats. There are three elements to the NAVWAR effort: protection, prevention, and sustainment of civil use. Protection is the ability of U.S., Allied, and Coalition forces to operate in a challenged electronic warfare environment. Prevention is the ability to prevent an adversary's use of GPS technologies against us. There must be an integration of protection and prevention technologies to ensure optimal use of GPS on the battlefield. In addition, civil use of GPS outside a theater of operations or area of responsibility must not be adversely impacted by the military's exploitation of the electromagnetic spectrum. NAVWAR is designed to preserve civil user service by providing a regional or local protection and prevention capability, thus satisfying the U.S. commitment to provide SPS service on a worldwide basis.

This R&D effort will require periodic testing which may impact the civil use of GPS. DOD and DOT are developing mechanisms to coordinate times and places for testing, and to notify users in advance.

Multimode Receivers

Based on a continuing worldwide mission and a need to replace existing systems (particularly precision approach radars), the DOD has initiated a joint service precision approach and landing system program. The portion of this program that has common user application is the development of a multimode receiver for precision landings.

Several contractors are developing multimode receivers for the DOD. To reduce aircraft integration cost, the prototype receivers are form, fit, and function replacements for current ILS receivers. The pilot sees the same display whether using MLS, ILS, or GPS (all generated from the same ILS-sized box).

The Air Force, at Hanscom AFB, MA, and the FAA, at their Tech Center near Atlantic City, NJ, have proved the feasibility of such a multifunction, precision landing system receiver. The 113 approaches flown at Hanscom and the Tech Center proved that the multimode receiver works with existing ground stations (ILS, MLS, and DGPS), and that the three landing systems are compatible on the same aircraft. These tests also showed that the prototype multimode receiver has the accuracy for Category I performance, and provided operational insights for both civil certification and military qualification. A production quality receiver with a 12 channel C/A-P/Y GPS card could replace the standard ARN-108 military ILS receiver.

Improvements in Precise Time and Time Interval (PTTI)

Over the past several decades, developments in technology for all military electronic systems have led to greater requirements for PTTI. Interoperability of systems throughout all the Services, as well as with NATO, requires accurate common time. Within the next decade, it is anticipated that requirements for PTTI at the 1 part in 10 to the 15th per day (1ps) will exist. In order to prepare for this stringent requirement, the U. S. Naval Observatory, as the provider of the DOD precise reference for time, has begun research and development efforts in advanced clock design and in clock analysis algorithms. In order to better disseminate the time reference, the USNO is developing a Distributed Master Clock System as well as investigating new techniques for time transfer. The Two-Way Time and Frequency Satellite Time Transfer System is currently under tests for very high precision users.

Recently, the importance of PTTI technology throughout DOD was recognized in the Special Technology Area Review on Frequency Control Devices (STAR), February 1, 1996. It reported that frequency control device technology is of vital importance to the DOD since the accuracy and stability of frequency sources and clocks are key determinants of the performance of radar, C3I, navigation, surveillance, EW, missile guidance, and IFF systems.

The report continues with some R&D opportunities with potential for meeting future DOD needs. These opportunities include development in high perfection quartz; new piezoelectric materials; resonator theory, modeling and computer-aided design of resonators and oscillators; processing and packaging of high stability resonators; microresonators and thin film resonators; low power, high, accuracy quartz clocks; low noise resonators and oscillators; smart clocks; miniature and high-performance optically pumped atomic clocks; and resonator based chemical, biological and uncooled infrared sensors.

Appendix A

System Descriptions

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

- GPS
- GPS Augmentations
- Loran-C
- Omega
- VOR, VOR/DME, and TACAN
- ILS
- MLS
- Aeronautical Nondirectional Beacons
- Maritime Radiobeacons

A.1 System Parameters

All of the systems described are defined in terms of system parameters which determine the use and limitations of the individual navigation system's signal-in-space. These parameters are:

- Signal Characteristics
- Accuracy
- Availability
- Coverage
- Reliability
- Fix Rate

- Fix Dimensions
- System Capacity
- Ambiguity
- Integrity

A.1.1 Signal Characteristics

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

A.1.2 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 squared) uncertainty estimate will be used. Two drms is twice the radial error drms. 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, the conversion of CEP to 2 drms has been 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:

- Predictable accuracy: The accuracy of a radionavigation system's position solution with respect to the charted solution. Both the position solution and the chart must be based upon the same geodetic datum. (Note: Appendix B discusses reference systems and the risks inherent in using charts in conjunction with radionavigation systems).

- 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.

- 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.

A.1.3 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.1.4 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.1.5 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.1.6 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.1.7 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 (e.g., time) from the navigational signals is also included.

A.1.8 System Capacity

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

A.1.9 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 resolve them.

A.1.10 Integrity

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

A.2 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.1. 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 CJCS MNP.

A.2.1 GPS

GPS is a space-based radionavigation system which is operated for the Government of the United States by the U.S. Air Force. GPS was originally developed as a military force enhancement system and will continue to play this role; however, GPS also has significant potential to benefit the civil community in an increasingly large number and variety of applications. In an effort to make GPS service available to the greatest number of users while ensuring that national security interests of the United States are protected, two GPS services are provided. The Precise Positioning Service (PPS) provides full system accuracy to authorized users. The Standard Positioning Service (SPS) is designed to provide accurate positioning to all users throughout the world. The GPS has three major segments: space, control, and user.

The GPS Space Segment is composed of 24 satellites in six orbital planes. The satellites operate in circular 20,200 km (10,900 nm) orbits at an inclination angle of 55 degrees and with a 12-hour period. The spacing of satellites in orbit are arranged so that a minimum of 5 satellites are in view to users worldwide, with a Position Dilution of Precision (PDOP) of six or less.

The GPS Control Segment has five monitor stations and three ground antennas with uplink capabilities. The monitor stations use a GPS receiver to passively track all satellites in view and accumulate ranging data from the satellite signals. The information from the monitor stations is processed at the Master Control Station (MCS) to determine satellite clock and orbit states and to update the navigation message of each satellite. This updated information is transmitted to the satellites via the ground antennas, which are also used for transmitting and receiving health and control information.

The GPS User Segment consists of a variety of configurations and integration architectures that include an antenna and receiver-processor to receive and compute navigation solutions to provide positioning, velocity, and precise timing to the user.

The characteristics of GPS are summarized in Table A-1.

A. Signal Characteristics

Each satellite transmits three separate spectrum signals on two L-band frequencies, L1 (1575.42 MHz) and L2 (1227.6 MHz). L1 carries a Precise P (Y) Pseudo-Random Noise (PRN) code and a Coarse/Acquisition (C/A) PRN code; L2 carries the P(Y) PRN code. (The Precise code is denoted as P(Y) to identify that this PRN code can be operated in either a clear unencrypted “P” or an encrypted “Y” code configuration.) Both PRN codes carried on the L1 and L2 frequencies are phase-synchronized to the satellite clock and modulated (using modulo two addition) with a common 50 Hz navigation data message.

The SPS signal received by the user is a spread spectrum signal centered on L1 with a 2.046 MHz bandwidth. Minimum SPS received power is specified as -160.0 dBW. The navigation data contained in the signal is composed of satellite clock and

Table A-1. GPS/SPS Characteristics (Signal-In-Space)

ACCURACY (METERS) - 95%*									
PREDICTABLE	REPEATABLE	RELATIVE **	AVAILABILITY*	COVERAGE*	RELIABILITY*	FIX RATE	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
Horz ≤ 100 Vert ≤ 156 Time ≤ 340ns	Horz ≤ 141 Vert ≤ 221	Horz ≤ 1.0 Vert ≤ 1.5	99.85%	99.90% (PDOP ≤ 6)	99.97%***	1-20 per second	3D + Time	Unlimited	None

* Global averages.
** Receivers using the same satellites with position solutions computed at approximately the same time.
*** 500 meter not to exceed predictable horizontal error reliability threshold (measurement interval - one year)

SYSTEM DESCRIPTION: GPS is a space-based radio positioning navigation system that provides three-dimensional position and time information to suitably equipped users anywhere on or near the surface of the Earth. The space segment consists of 24 satellites in 6 orbital planes of 12-hour periods. Each satellite transmits navigation data and time signals on 1575.42 and 1227.6 MHz. 1227.6 MHz is reserved for authorized users; therefore, data is encrypted and not available for private civil use. For more detail, refer to Ref. 8.

ephemeris data for the transmitting satellite plus GPS constellation almanac data, GPS to UTC time offset information, and ionospheric propagation delay correction parameters for single frequency users. The entire navigation message repeats every 12.5 minutes. Within this 12.5-minute repeat cycle, satellite clock and ephemeris data for the transmitting satellite is sent 25 separate times so it repeats every 30 seconds. As long as a satellite indicates a healthy status, a receiver can continue to operate using this data for the validity period of the data (up to 4 or 6 hours). The receiver will update this data whenever the satellite and ephemeris information is updated - nominally once every 2 hours.

The concept of GPS position determination is based on the intersection of four separate vectors each with a known origin and a known magnitude. Vector origins for each satellite are computed based on satellite ephemeris. Vector magnitudes are calculated based on signal propagation time delay as measured from the transmitting satellite's PRN code phase delay. Given that the satellite signal travels at nearly the speed of light and taking into account delays and adjustment factors such as ionospheric propagation delays and earth rotation factors, the receiver performs ranging measurements between the individual satellite and the user by dividing the satellite signal propagation time by the speed of light.

B. Accuracy

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

1. Standard Positioning Service (SPS)

SPS is the standard specified level of positioning and timing accuracy that is available, without restrictions, to any user on a continuous worldwide basis. SPS provides a predictable positioning accuracy of 100 meters (95 percent) horizontally and 156 meters (95 percent) vertically and time transfer accuracy to UTC within 340 nanoseconds (95 percent). Decisions to change operational modes of GPS to include degrading GPS accuracy to civil users will be made by the NCA.

2. Precise Positioning Service (PPS)

PPS is the most accurate direct positioning, velocity, and timing information continuously available, worldwide, from the basic GPS. This service is limited by the DOD to users who are specifically authorized access. P(Y) code capable user equipment provides a predictable positioning accuracy of at least 22 meters (95 percent) horizontally and 27.7 meters vertically and time transfer accuracy to UTC within 200 nanoseconds (95 percent).

C. Availability

Provided there is coverage as defined below, SPS will be available at least 99.85 percent of the time.

D. Coverage

GPS coverage is worldwide. The probability that 4 or more GPS satellites are in view anywhere on or near the earth (over any 24-hour period) with a PDOP of 6 or less, and with at least a 5 deg mask angle, is at least 99.9 percent.

E. Reliability

If the conditions on coverage and service availability are met, the probability that the horizontal positioning error will not exceed 500 meters at any time is at least 99.7 percent.

F. Fix Rate

The fix rate is essentially continuous, but the need for receiver processing to retrieve the spread-spectrum signal from the noise results in an actual users fix rate of 1-20 per second. 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 time when four or more satellites are available and two-dimensional positioning when only three satellites are available.

H. System Capacity

The capacity is unlimited.

I. Ambiguity

There is no ambiguity.

J. Integrity

DOD GPS receivers use the information contained in the navigation and health messages, as well as self-contained satellite geometry software programs 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. The figure of merit does not satisfy civil aviation requirements.

A.2.2 Augmentations to GPS

GPS 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.

The basic GPS must be augmented to meet current civil aviation and marine integrity requirements. Receiver Autonomous Integrity Monitoring (RAIM), a receiver algorithm, and DGPS are two methods of satisfying integrity requirements.

DGPS enhances GPS through the use of differential corrections to the basic satellite measurements. DGPS is based upon accurate knowledge of the geographic location of one or more reference stations, which is used to compute corrections to GPS parameters, error sources, and/or resultant positions. These differential corrections are then transmitted to GPS users, who apply the corrections to their received GPS signals or computed position. For a civil user of SPS, differential corrections can improve navigational accuracy from 100 meters (2 drms) to better than 7 meters (2 drms). A DGPS reference station is fixed at a geodetically surveyed position. From this position, the reference station typically tracks all satellites in view, downloads ephemeris data from them, and computes corrections based on its measurements and geodetic position. These corrections are then broadcast to GPS users to improve their navigation solution. There are two well-developed methods of handling this:

- Computing and transmitting a position correction in x-y-z coordinates, which is then applied to the user's GPS solution for a more accurate position.
- Computing pseudorange corrections for each satellite, which are then broadcast to the user and applied to the user's pseudorange measurements before the GPS position is calculated by the receiver, resulting in a highly accurate navigation solution.

The first method, in which the correction terms for the x-y-z coordinates are broadcast, requires less data in the broadcast than the second method, but the validity of those correction terms decreases rapidly as the distance from the reference station to the user increases. Both the reference station and the user receiver must use the same set of satellites for the corrections to be valid. This condition is often difficult to achieve, and limits operational flexibility.

Using the second method, an all-in-view receiver at the reference site receives signals from all visible satellites and measures the pseudorange to each. Since the satellite signal contains information on the satellite orbits and the reference receiver knows its position, the true range to each satellite can be calculated. By comparing the calculated range and the measured pseudorange, a correction term can be determined for each satellite. The corrections are broadcast and applied to the satellite measurements at each user's location. This method provides the best navigation solution for the user and is the preferred method. It is the method being employed by the U.S. Coast Guard DGPS Service and the FAA LAAS.

An elaboration of the second method is being incorporated in the FAA's WAAS for GPS. In this system, a network of GPS reference/measurement stations at surveyed locations collects dual-frequency measurements of GPS pseudorange and pseudorange rate for all spacecraft in view, along with local meteorological conditions. These data can be processed to yield highly accurate ephemeris, ionospheric and tropospheric calibration maps, and DGPS corrections for the broadcast spacecraft ephemeris and clock offsets (including the effects of Selective Availability (SA). In the WAAS, these GPS corrections and system integrity messages will be relayed to civil users via a dedicated package on geostationary satellites. This relay technique will also support the delivery of an additional ranging signal, thereby increasing overall navigation system availability.

Non-navigation users of GPS who require few-centimeter accuracy or employ post processing to achieve few-decimeter to few-meter accuracy often employ augmentation somewhat differently from navigation users. For post processing applications using C/A code range, the actual observations from a reference station (rather than correctors) are provided to users. The users then compute correctors in their reduction software. Surveyors and other users who need subcentimeter to few-centimeter accuracy in positioning from post-processing use two-frequency (L1 and L2) carrier phase observations from reference stations, rather than range data. The CORS system is designed to meet the needs of both of the above types of these users.

Real time carrier phase differential positioning is increasingly employed by non-navigation users. Currently, this requires a GPS reference station within a few tens of kilometers of a user. In many cases, users are implementing their own reference stations, which they operate only for the duration of a specific project. Permanent reference stations to support real time carrier phase positioning by multiple users is currently provided in the U.S. primarily by private industry. Some state and local government groups are moving toward providing such reference stations. Other countries are establishing nationwide, real time, carrier phase reference station networks at the national government level.

With the advent of commercially available combined GPS/GLONASS receivers, non-navigation users will begin to augment GPS with reference stations that provide differential GPS and GLONASS. This will occur most rapidly where users operate in locations such as urban canyons and heavily forested areas where sufficient GPS satellites are not always in view to adequately support positioning.

A worldwide network of GPS reference stations is needed for geodetic reference frame, geophysical, and meteorological applications which require carrier phase data to achieve centimeter level accuracy on a regional to global basis. Such a network is currently operated by the IGS and provides the required centimeter-accuracy reference frame and subdecimeter orbits. At present, this worldwide IGS reference network supports only post-processing applications. However, the IGS is moving toward near-real time to real time provision of information to support such applications as seismic monitoring and inclusion of water vapor information into short term weather prediction. Because this near-real-time and real-time information would be used by fixed facilities rather than moving platforms, it may be provided to users by telephone or similar communications links rather than by broadcast.

A.2.2.1 Maritime DGPS

Figure A-1 shows the USCG DGPS architecture using pseudorange corrections. The reference station's and the mariner's pseudorange calculations are strongly correlated. Pseudorange corrections computed by the reference station, when transmitted to the mariner in a timely manner, can be directly applied to the mariner's pseudorange computation to dramatically increase the resultant accuracy of the pseudorange measurement before it is applied within the mariner's navigation solution. The USCG DGPS fielded sites are achieving accuracies on the order of 1 meter. Figure A-1 and the following discussion describe the characteristics of the maritime DGPS system.

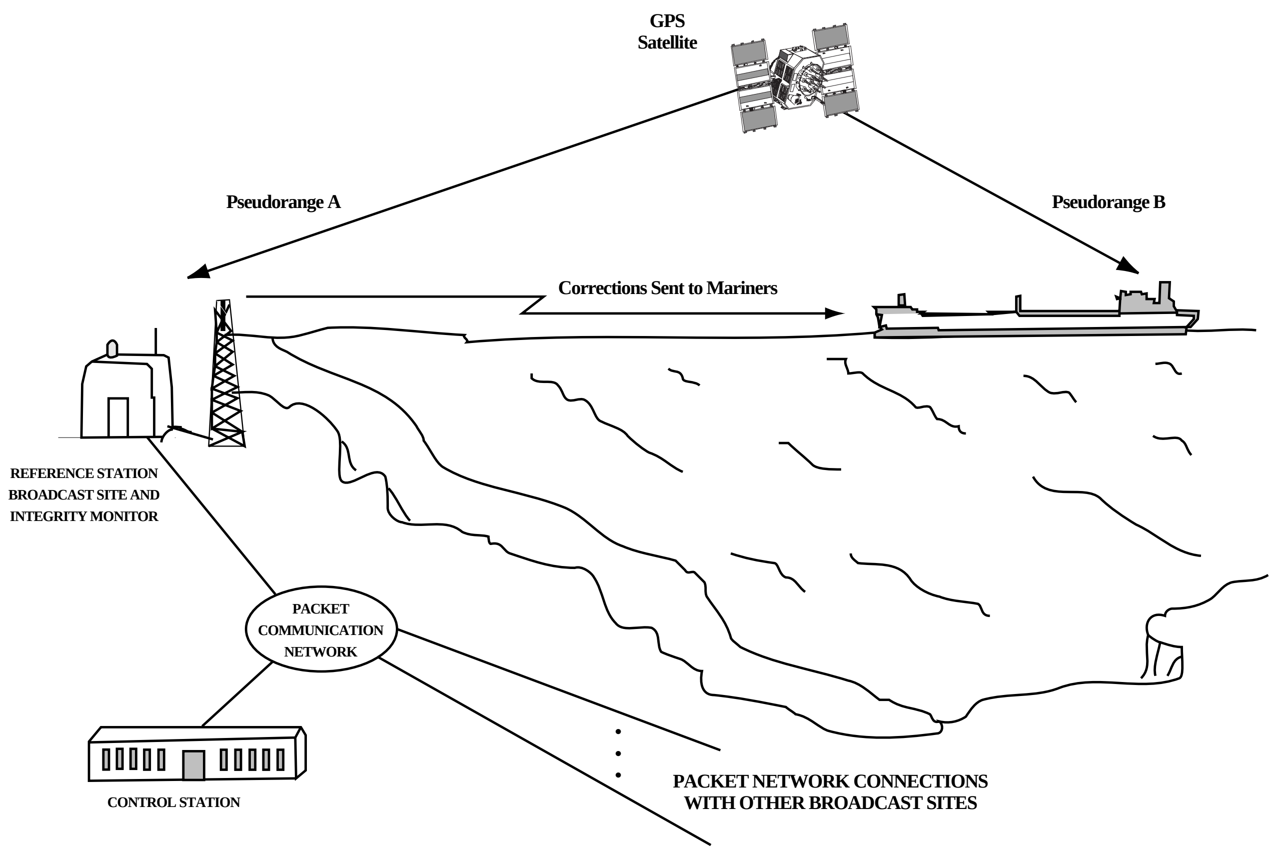


Figure A-1. USCG DGPS Navigation Service Architecture

A. Signal Characteristics

The datalinks for DGPS corrections are radiobeacons which have been converted to accept MSK modulation. This conversion to single-carrier operation removes the Morse tone identifier, thus removing compliance with IMO standards for marine radiobeacons. Real time differential GPS corrections are provided in the Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC-

104) format and broadcast to all users capable of receiving the signals. The USCG does not use data encryption. Radiobeacons were chosen because of existing infrastructure, compatibility with the useful range of DGPS corrections, international radio conventions, international acceptance, commercial availability of equipment, and highly successful field tests.

The USCG's DGPS system will broadcast corrections to the user in the RTCM SC-104 format. The RTCM has defined data messages and an interface between the DGPS receiver and the data link receiver. The USCG DGPS Broadcast Standard (Commandant Instruction M16577.1) should be consulted for detailed information on DGPS broadcasts.

B. Accuracy

The accuracy of the USCG's DGPS service is expected to be better than 10 meters (2 drms) in all approaches to major U.S. harbors. Fielded operations are now achieving accuracies on the order of 1 meter.

C. Availability

Availability will be 99.9 percent in selected waterways with more stringent VTS requirements and at least 99.7 percent in other parts of the coverage area.

D. Coverage

Figure A-2 shows the approximate coverage of the USCG's maritime DGPS system. Per the USCG's DGPS Broadcast Standard (COMDTINST M16577.1), the USCG system is designed to provide complete coastal DGPS coverage of the continental U.S. to a minimum range of 20 nm from shore and to selected portions of Hawaii, coastal Alaska, Puerto Rico, and major inland rivers.

E. Reliability

The number of outages per site will be less than 500 in one million hours of operation with a time to alarm of less than five seconds.

F. Fix Rate

The DGPS reference station computes corrections at least once per second. Due to the transmission time, users will receive updated corrections on an average of every five seconds for beacons transmitting at 100 bps and every 2.5 seconds for beacons transmitting at 200 bps.

G. Fix Dimensions

Through the application of pseudorange corrections, maritime differential GPS provides three-dimensional positioning and velocity fixes.

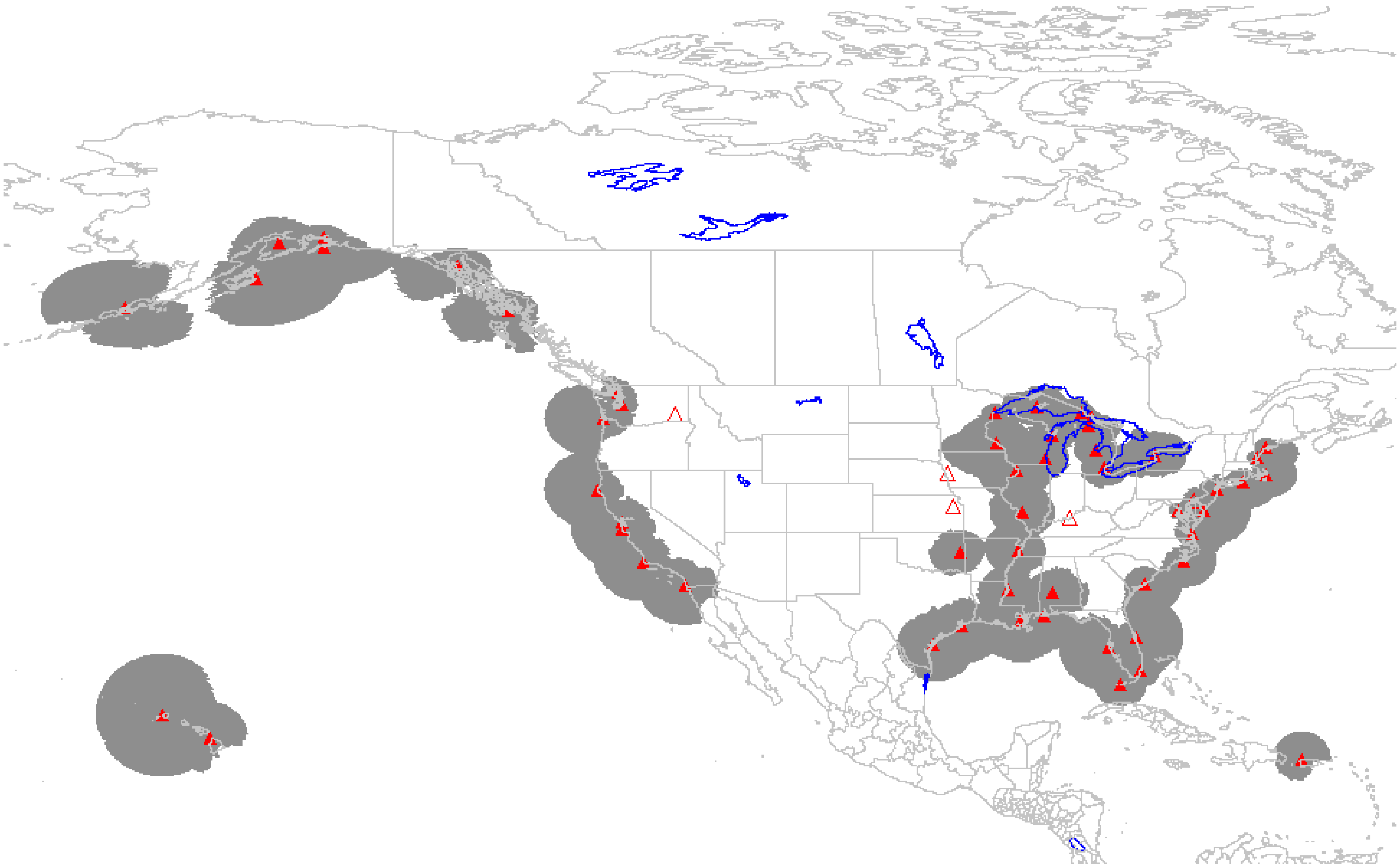


Figure A-2. Proposed Conus, Alaska and Hawaii Maritime DGPS Coverage

H. System Capacity

Unlimited.

I. Ambiguity

None.

J. Integrity

DGPS system integrity is provided through an on-site integrity monitor and 24-hour operations at a DGPS control center. Users will be notified of an out-of-tolerance condition within five seconds.

In addition to providing a highly accurate navigational signal, DGPS also provides a continuous integrity check on satellite health. System integrity is a real concern with GPS. With the design of the ground segment of GPS, a satellite can be transmitting an unhealthy signal for 2 to 6 hours before it can be detected and corrected by the Master Control Station or before users can be warned not to use the signal. Through its use of continuous, real time messages, the DGPS system can often extend the use of unhealthy GPS satellites by providing accurate corrections, or will direct the navigator to ignore an erroneous GPS signal.

A.2.2.2 Aeronautical GPS Wide Area Augmentation System (WAAS)

The WAAS will be a safety-critical system consisting of the equipment and software which augments the DOD-provided GPS Standard Positioning Service (see Figure A-3). It will provide a signal-in-space to WAAS users with the specific goal of supporting aviation navigation for the en route through Category I precision approach phases of flight. The signal-in-space will provide three services: (1) integrity data on GPS and GEO satellites, (2) wide area differential corrections for GPS satellites, and (3) an additional ranging capability.

The GPS satellites' data is to be received and processed at widely dispersed sites, referred to as Wide-area Reference Stations (WRS). These data are forwarded to data processing sites, referred to as Wide-area Master Stations (WMS), which process the data to determine the integrity, differential corrections, residual errors, and ionospheric information for each monitored satellite and generate GEO satellite navigation parameters. This information is to be sent to a Ground Earth Station (GES) and uplinked along with the GEO navigation message to GEO satellites. These GEO satellites will then downlink this data on the GPS Link I (LI) frequency with a modulation similar to that used by GPS.

In addition to providing GPS integrity, the WAAS will verify its own integrity and take any necessary action to ensure that the system meets the WAAS performance requirements. The WAAS also has a system operations and maintenance function that provides information to FAA Airway Facilities NAS personnel.

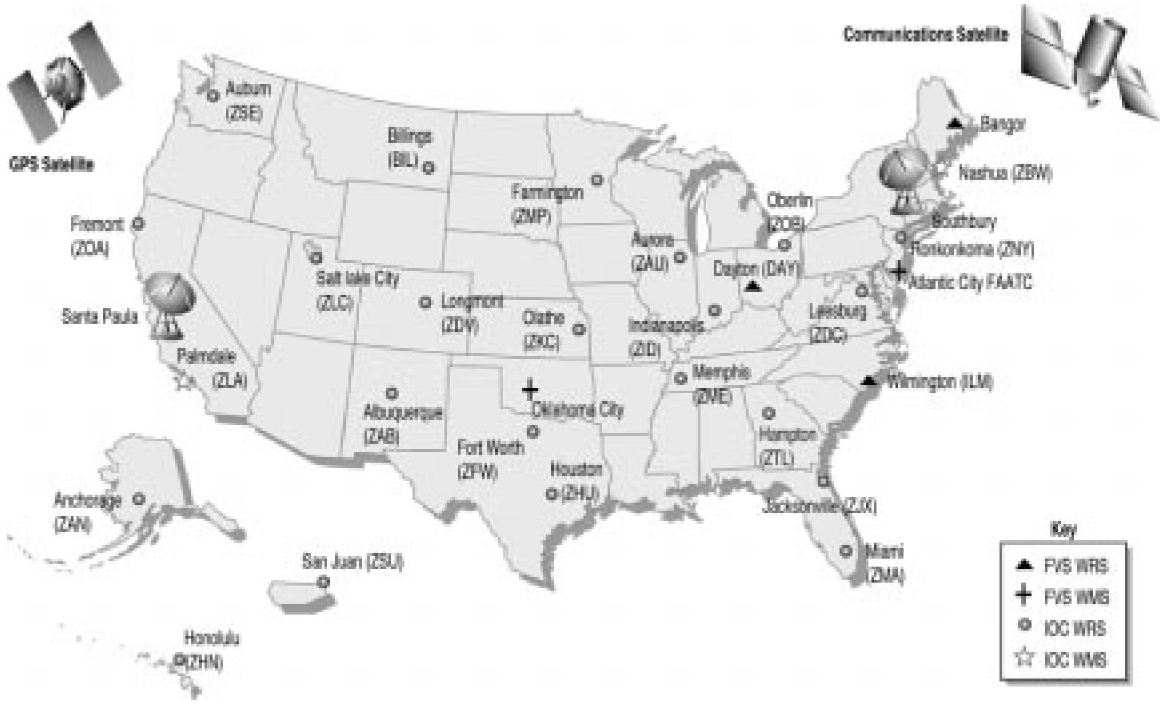


Figure A-3. WAAS Architecture

The WAAS user receiver will process: (1) the integrity data to ensure that the satellites being used are providing in-tolerance navigation data, (2) the differential correction and ionospheric information data to improve the accuracy of the user’s position solution, and (3) the ranging data from one or more of the GEO satellites for position determination to improve availability and continuity. The WAAS user receivers are not considered part of the WAAS.

A. Signal Characteristics

The WAAS will collect raw WAAS GEO and GPS data from all GPS and WAAS GEO satellites that support the navigation service.

WAAS ground equipment will develop messages on ranging signals and signal quality parameters of the GPS and GEO satellites. GEO satellites will broadcast the WAAS messages to the users and provide ranging sources. The signals broadcast via the WAAS GEOs to the WAAS users are designed to require minimal standard GPS receiver hardware modifications.

The GPS LI frequency and GPS-type modulation, including a C/A PRN code, will be used for WAAS data transmission. In addition, the code phase timing will be synchronized to GPS time to provide a ranging capability.

B. Accuracy

Accuracies for the WAAS are currently based on aviation requirements. For the en route through nonprecision approach phases of flight, a horizontal accuracy of 100 meters 95 percent of the time is guaranteed with the requisite availability and integrity levels to support operations in the NAS. For the Category I precision approach phase of flight, horizontal and vertical accuracies are guaranteed at 7.6 meters 95 percent of the time.

C. Availability

The WAAS availability for the en route through nonprecision approach phases of flight is at least 0.99999. For the precision approach phase of flight, the availability is at least 0.999.

D. Coverage

The WAAS full service volume is defined from the Category I decision height up to 100,000 feet for the airspace of the 48 contiguous states, Hawaii, Puerto Rico, and Alaska (except for the Alaskan peninsula west of longitude 160 degrees West or outside of the GEO satellite broadcast area).

E. Reliability

The WAAS will provide sufficient reliability and redundancy to meet the overall NAS requirements with no single point of failure. The overall reliability of the WAAS signal-in-space will approach 100 percent.

F. Fix Rate

This system provides a virtually continuous position update.

G. Fix Dimensions

The WAAS provides three-dimensional position fixing and highly-accurate timing information.

H. System Capacity

The user capacity is unlimited.

I. Ambiguity

The system provides no ambiguity of position fixing information.

J. Integrity

Integrity augmentation of the GPS SPS by the WAAS is a required capability that is both an operational characteristic and a technical characteristic. The required system performance levels for the integrity augmentation are the levels necessary so that GPS/WAAS can be used for all phases of flight.

Integrity for the WAAS is specified by three parameters: probability of hazardously misleading information (PHMI), time to alarm, and the alarm limit. For the en route through nonprecision approach phases of flight, the performance values are:

PHMI	10-7 per hour
Time to Alarm	8 seconds
Alarm Limit	Protection limits specified for each phase of flight

For the precision approach phase of flight, integrity performance values are:

PHMI	4 x 10-8 per approach
Time to Alarm	5.2 seconds
Alarm Limit	As required for Category I operation

The WAAS will provide the information such that the user equipment can determine the integrity to these levels.

A.2.3 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.

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 radio frequency (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 signal comparison early in the ground wave pulse assures that the measurement is made before the arrival of the corresponding sky waves. Precise control over the pulse shape ensures that the proper comparison point can be identified by the receiver. To aid in preventing sky waves 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-2.

Table A-2. Loran-C System Characteristics (Signal-In-Space)

ACCURACY (2 drms)								
PREDICTABLE	REPEATABLE	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
0.25nm (460m) 1:3 SNR	60-300 ft. (18-90m)	99.7%	U.S. coastal areas, continental U.S., selected overseas areas	99.7%*	1 fix/sec.	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.

B. Accuracy

Within the published coverage area, Loran-C provides the user who employs an adequate receiver with predictable accuracy of 0.25 nm (2 drms) or better. The repeatable accuracy of Loran-C is usually between 18 and 90 meters. Accuracy is dependent upon the Geometric Dilution of Precision (GDOP) factors at the user's location within the coverage area.

Loran-C navigation is predominantly accomplished using the ground wave signal. Sky wave navigation is feasible, but with considerable loss in accuracy. Ground waves and to some degree sky waves 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. Because the position solution of GPS provides precise time, the interpretable use of rho-rho Loran-C with GPS appears to have merit.

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. Although this can improve Loran-C's absolute accuracy features, no investment in this approach to enhancing Loran-C's performance is anticipated by the Federal Government.

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, providing 99.7 percent triad availability.

D. Coverage

The Loran-C system has been expanded over the years to meet the requirements for coverage of the U.S. coastal waters and the conterminous 48 states, the Great Lakes, the Gulf of Alaska, the Aleutians, and into the Bering Sea. Current Loran-C coverage is shown in Figure A-4.

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

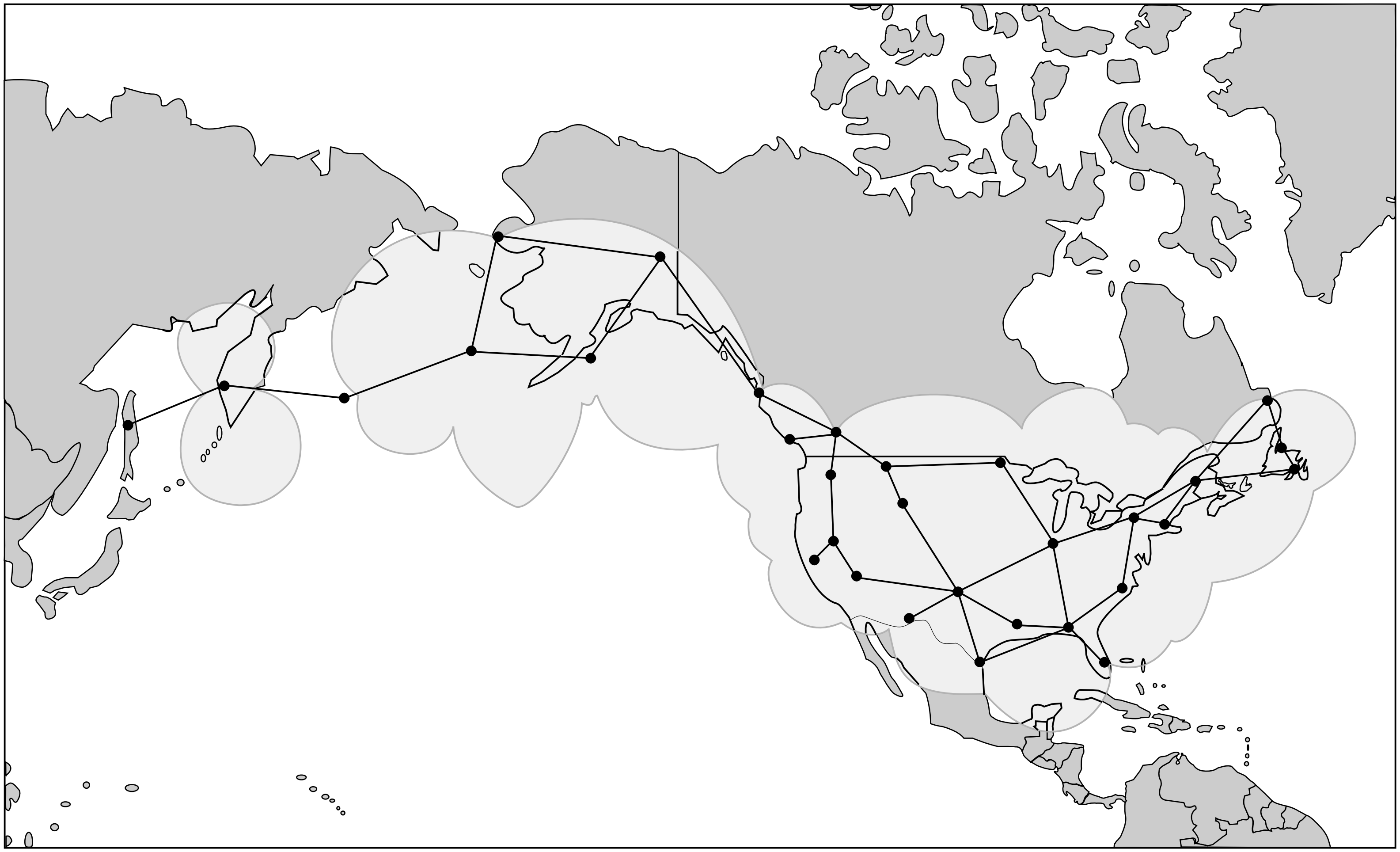


Figure A-4. Coverage Provided by U.S. Operated or Supported Loran-C Stations

benefit/cost ratio was insufficient to justify expansion of Loran-C into any of these areas.

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. System tolerance within the U.S. is +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 second, based on the Group Repetition Interval. Receiver processing in noise results in typically 1 fix per second.

G. Fix Dimensions

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

H. System 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 unusable for navigation purposes. The secondary stations “blink” to notify the user that a master-secondary pair is unusable. Blink begins immediately upon detection of an abnormality. The USCG and the FAA are also developing automatic blink equipment and a concept of operations based on factors consistent with aviation use. If automatic blink equipment is installed in the NAS, secondary blink would be initiated within ten seconds of a timing abnormality and in the case of a Master station, the signal will be taken off-air until the problem is corrected and all secondaries are blinking.

A.2.4 Omega

The Omega system initially was proposed 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. Omega information can be obtained via the USCG Navigation Information Service. The characteristics of Omega are summarized on Table A-3.

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.

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.

Propagation correction tables and formulas are based on theoretical models calibrated to fit worldwide monitor data taken over long periods. A number of permanent monitors are maintained to assess the system accuracy 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 in some cases much better accuracy is reported. A validation program conducted by the USCG indicated that the Omega system meets its design goal of 2 to 4 nm accuracy.

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.

Table A-3. Omega System Characteristics (Signal-In-Space)

ACCURACY (2 drms)									
PREDICTABLE	REPEATABLE	RELATIVE*	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
2-4 nm (3.7-7.4km)	2-4nm (3.7-7.4km)	0.25-0.5nm (463-926m)	99+%	Worldwide continuous	97%*	1 fix to every 10 seconds	2D	Unlimited	Requires knowledge to ±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. Position information is obtained by measuring relative phase difference of received Omega signals. The system is multinational, operated by seven nations, with day-to-day operational control exercised by the U.S. Coast Guard.

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 position fixes once every ten seconds.

G. Fix Dimensions

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

H. System 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 baseline 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-airs, Polar Cap Absorption, etc.) are provided by the Navigation 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 through the Navigation Information Services, and recorded telephone messages. Scheduled off-air periods are announced up to 30 days before the off-air is to occur using the same distribution mechanisms as for unplanned status changes.

A.2.5 VOR, VOR/DME, and TACAN

The three systems that provide the basic guidance for en route air navigation in the United States 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 functionally the same.

I. VOR

A. Signal Characteristics

The signal characteristics of VOR are summarized in Table A-4. VORs are assigned frequencies in the 108 to 118 MHz frequency band, separated by 50 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 nondirectional (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.

B. Accuracy (2 sigma)

- Predictable - The ground station errors are approximately ±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 ±4.5 degrees.

Table A-4. VOR and VOR/DME System Characteristics (Signal-In-Space)

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

* *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.

- 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 ±4.3 degrees. The VOR ground station relative error is ±0.35 degrees.

- 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 ±2.3 degrees.

C. Availability

Because VOR coverage is 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 5,000 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.

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 an essentially continuous update of deviation from a selected course based on internal operations at a 30-update-per-second rate. Initialization is less than one minute after turn-on and will vary as to receiver design.

G. Fix Dimensions

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

H. System 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 signal characteristics of DME are summarized in Table A-4. 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 962 to 1,213 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.

B. Accuracy (2 sigma)

- Predictable - The ground station errors are less than ±0.1 nm. The overall system error (airborne and ground RSS) is not greater than ±0.5 nm or 3 percent of the distance, whichever is greater.
- Relative - Although some errors could be introduced by reflections, the major relative error emanates from the receiver and flight technical error.
- 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 1,000 watts. Terminal DMEs radiate 100 watts and are only intended for use in terminal areas. Because of facility placement, almost all of the airways have coverage and most of the CONUS has dual coverage, permitting DME/DME Area Navigation (RNAV).

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, with typical rates of 10 per second.

G. Fix Dimensions

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

H. System 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 (962 to 1,213 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-5.

B. Accuracy (2 sigma)

- Predictable - The ground station errors are less than ±1.0 degree for azimuth for the 135 Hz element and ±4.5 degrees for the 15 Hz element. Distance errors are the same as DME errors.
- Relative - The major relative errors emanate from course selection, receiver and flight technical error.
- 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

A TACAN station can be expected to be available 98.7 percent of the time.

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 200 nm. This coverage is based on a 5 kW station.

E. Reliability

A TACAN station can be expected to be reliable 99 percent of the time. Unreliable stations, as determined by remote monitors, are automatically removed from service.

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-5. TACAN System Characteristics (Signal-In-Space)

ACCURACY (2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE							
Azimuth ±1° (± 63m at 3.75km)	Azimuth ±1° (± 63m at 3.75km)	Azimuth ±1° (±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. Sight potential for ambiguity at multiples of 40°
DME: 185m (±0.1nm)	DME: 185m (±0.1nm)	DME: 185m (±0.1nm)							

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

G. Fix Dimensions

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

H. System 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 40 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.2.6 ILS

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

At present, ILS is one of the primary worldwide, ICAO-approved, precision landing system. This system is presently adequate, but has limitations in siting, frequency allocation, cost, and performance. The characteristics of ILS are summarized in Table A-6.

A. Signal Characteristics

The localizer facility and antenna are typically located 1,000 feet beyond the stop end of the runway and provides a VHF (108 to 112 MHz) signal. The glide slope facility is located approximately 1,000 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 final approach fix (typically four to seven miles from the approach end of the runway) and a middle marker located 3,500 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 1,000 feet from the threshold, is normally associated with Category II and III ILS approaches.

Table A-6. ILS Characteristics (Signal-In-Space)

ACCURACY AT DECISION HEIGHT (Meters - 2 Sigma)									
CATEGORY	AZIMUTH	ELEVATION	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE**	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
1	±9.1	±3.0	Approaches 99%	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 requirements	None
2	±4.6	±1.4							
3	±4.1	±0.4							

* *Signal availability in the coverage volume.*

SYSTEM DESCRIPTION: The Instrument Landing System (ILS) is a precision approach system consisting of a localizer facility, a glide scope 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 scope provides precise, single path, vertical guidance information to a landing aircraft.

B. Accuracy

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

C. Availability

To further improve the availability of service from ILS installations, vacuum tube equipment has been replaced with solid state equipment. Service availability is now approaching 99 percent.

D. Coverage

Coverage for individual systems is as follows:

Localizer: $\pm 2^{o}$centered about runway centerline.

Glide Slope: Nominally 3^{o}above the horizontal.

Marker Beacons: $\pm 40^{o}$ (approximately) on minor axis (along approach path) $\pm 85^{o}$ (approximately) on major axis.

E. Reliability

ILS reliability is 98.6 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.

In some cases, to resolve ILS siting problems, use has been made of localizers with aperture antenna arrays and two frequency systems. In the case of the glide slope, use has been made of wide aperture, capture effect image arrays and single-frequency infrared arrays to provide service at difficult sites.

F. Fix Rate

The glide slope and localizer provide continuous fix information, although the user will receive position updates at a rate determined by receiver/display design (typically more than 5 updates per second). 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

MARKER DESIGNATION	TYPICAL DISTANCE TO THRESHOLD	AUDIBLE SIGNAL	LIGHT COLOR
Outer	4-7nm	Continuous dashes (2/sec)	Blue
Middle	3,250-3,750 ft	Continuous alternating dot-dash	Amber
Inner	1,000 ft	Continuous dots (6/sec)	White

G. Fix Dimensions

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

H. System 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.2.6.E.

J. Integrity

ILS provides system integrity by removing a signal from use when an out-of-tolerance condition is detected by an integral monitor. The shutdown delay for each category is given below:

Shutdown Delay

	Localizer	**Glide Slope**
CAT I	<10 sec	<6 sec
CAT II	<5 sec	<2 sec
CAT III	<2 sec	<2 sec

A.2.7 MLS

MLS provides a common civil/military landing system to meet the full range of user operational requirements, as defined in the ICAO list of 38 operational requirements for precision approach and landing systems, to the year 2000 and beyond. It was originally intended to be a replacement for ILS, used by both civil and military aircraft, and the Ground Controlled Approach (GCA) system used primarily by military operators. However, augmented GPS systems are now envisioned to satisfy the majority of requirements originally earmarked for MLS. Accordingly, the FAA has terminated all R&D activity associated with MLS. The system characteristics of MLS are summarized in Table A-8.

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 962 to 1,213 MHz 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.

B. Accuracy (2 sigma)

The azimuth accuracy is ±13.0 feet (+4.0m) at the runway threshold approach reference datum and the elevation accuracy is ±2.0 feet (+0.6m). 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 ±1.2 feet throughout the touchdown zone and the DME accuracy is ±100 feet for the precision mode and ±1,600 feet for the nonprecision 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 ±40^{o}on either side of the runway centerline, elevation coverage from 0^{o} to a minimum of 15^{o}over the azimuthal coverage area, and out to 20 nm. A few systems will have ±60^{o}azimuthal coverage. MLS signal format has the capability of providing coverage to the entire 360^{o} area but with less accuracy in the area outside the primary coverage area of +60^{o} of runway centerline. There will be simultaneous operations of ILS and MLS during the transition period.

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.

Table A-8. MLS Characteristics (Signal-In-Space)

ACCURACY AT DECISION HEIGHT (Meters - 2 Sigma)										
CATEGORY	AZIMUTH	ELEVATION	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE**	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
1	±9.1	±3.0	Expected to approach 100%	±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 precision landing system that will operate in the 5-5.25 GHz band. Ranging is provided by precision DME operating in 962-1,213 MHz band.

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. System 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 monitor shuts down the MLS within one second of an out-of-tolerance condition.

A.2.8 Aeronautical Radiobeacons

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

The characteristics of aeronautical NDBs are summarized in Table A-9.

A. Signal Characteristics

Aeronautical NDBs operate in the 190 to 415 kHz and 510 to 535 kHz bands. (Note: NDBs is the 285-325 kHz band are secondary to maritime radiobeacons.) 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 1,020 Hz tone for Morse code identification. The MCW signal is generated by spacing two carriers either 400 Hz or 1,020 Hz apart and keying the upper carrier to give the Morse code identification.

Table A-9. Radiobeacon System Characteristics (Signal-In-Space)

ACCURACY (2 Sigma)									
PREDICTABLE	REPEATABLE	RELATIVE	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
Aeronautical ±3-10°	N/A	N/A	99%	Maximum service volume - 75nm	99%	Continuous	One LOP per beacon	Unlimited	Potential is high for reciprocal bearing without sense antenna
Marine ±3°	N/A	N/A	99%	Out to 50nm or 100 fathom curve					

SYSTEM DESCRIPTION: Aircraft nondirectional beacons are used to supplement VOR-DME for transition from en route to airport precision approach facilities and as a nonprecision 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 as homing beacons to identify the entrance to harbors. Selected marine beacons carry differential GPS data.

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 ±3 to ±10 degrees. Achievement of ±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. For FAA flight inspection, NDB system accuracy is stated in terms of permissible needle swing: ±5 degrees on approaches and ±10 degrees in the en route area.

C. Availability

Availability of aeronautical NDBs is in excess of 99 percent.

D. Coverage

Extensive NDB coverage is provided by 1,575 ground stations, of which the FAA operates 728.

E. Reliability

Reliability is in excess of 99 percent.

F. Fix Rate

The beacon provides continuous bearing information.

G. Fix Dimensions

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

H. System 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 navigational aid. For aviation radiobeacons, 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 nonprecision approaches are monitored and will shut down within 15 seconds of an out-of-tolerance condition.

A.2.9 Maritime Radiobeacons

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

There are 4 USCG-operated marine radiobeacons. These marine radiobeacons are expected to be phased out by the year 2000.

A. Signal Characteristics

Marine radiobeacons operate in the 285 to 325 kHz band. The signal characteristics for marine radiobeacons are summarized in Table A-9. Due to single carrier operations which eliminate the Morse tone identifier, USCG DGPS beacons do not conform to the traditional radiobeacon standards.

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 ±3 to ±10 degrees. Achievement of ±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.

C. Availability

Availability of marine radiobeacons is in excess of 99 percent.

D. Coverage

The coverage from marine radiobeacons has been steadily declining over the last four to six years. There is some evidence that privately maintained and operated beacons are still being used in the Gulf Coast region of the U.S. (e.g., homing beacons for oil rigs).

E. Reliability

Reliability is in excess of 99 percent. Radiobeacons used for DGPS broadcasts will have reliability in excess of 99.7 percent.

F. Fix Rate

The beacon signal is provided continuously.

G. Fix Dimensions

In general, one LOP is available from a single radiobeacon.

H. System 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 navigational aid. Notification of outages is provided by a broadcast Notice to Mariners. Outages of long duration will also be published in the Local Notice to Mariners.

A.3 Navigation Information Services

A.3.1 USCG Navigation Information Service

The U.S. Coast Guard's Navigation Information Service (NIS), formerly the GPS Information Center, is the operational entity of the Civil GPS Service (CGS) which provides GPS status information to civil users of GPS. Its input is based on data from the GPS Control Segment, Department of Defense, and other sources. The mission of the NIS is to gather, process and disseminate timely GPS, Loran-C, Omega, and DGPS radionavigation information as well as general maritime navigation information. Specifically, the functions performed by the NIS include the following:

- Act as the single focal point for civil users to report problems with GPS.
- Provide Operational Advisory Broadcast (OAB) Service.
- Answer questions by telephone, written correspondence, or electronic mail.

- Provide information to the public on the NIS services available.
- Provide instruction on the access and use of the information services available.
- Maintain tutorial, instructional, and other relevant handbooks and material for distribution to users.
- Maintain records of GPS broadcast information, GPS databases or relevant data for reference purposes.
- Maintain bibliography of GPS publications.
- Maintain and augment the computer and communications equipment as required.
- Develop new user services as required.

Information on GPS and USCG-operated radionavigation systems can be obtained from the USCG's Navigation Center (NAVCEN), 7327 Telegraph Road, Alexandria, VA 22315-3998. Table A-10 and Figure A-5 show the services through which the NIS provides Operational Advisory Broadcasts. NAVCEN's 24-hour hotline: (703) 313-5900. NAVCEN's E-mail address: nisws@smtp.navcen.uscg.mil. Internet WWW address: http://www.navcen.uscg.mil/.

A.3.2. GPS NOTAM/Aeronautical Information System

The Air Force Flight Standards Agency has established a fundamental GPS Notice to Airmen (NOTAM) requirement for flight planning purposes. This requirement has been coordinated with the FAA and the other Services to be consistent with established flying procedures and safety standards for all DOD requirements.

On October 28, 1993, DOD began providing notice of GPS satellite vehicle outages through the NOTAM system. These NOTAMs are reformatted Notice Advisories to NAVSTAR Users (NANUs) provided by the 2nd Space Operations Squadron (2SOPS) at the GPS Master Control Station (MCS). The outages are disseminated to the NOTAM Office at least 48 hours before they are scheduled to occur. Unexpected outages also are reported by the 2SOPS to the U.S. NOTAM Office (USNOF).

Example: !GPS 07/010 GPS PRN 14 OTS
EFF 07160300-07161500

This NOTAM shows PRN 14 scheduled out of service on July 16 from 0300 until 1500 UTC. Satellite NOTAMs are issued as both a domestic NOTAM under the KGPS identifier and as an international NOTAMs under the KNMH identifier. This makes the information accessible to both civilian and military aviators. Unfortunately, this information is meaningless to the pilot unless there is a method to interpret its effects on availability for the intended operation.

Table A-10. NIS Services

Service	Availability	Info Type	Contact Number
NIS Watchstander	24 hours	User Inquires	(703) 313-5900 FAX (703) 313-5920
NIS Computer Bulletin Board Service	24 hours	Status Fore/Hist/Outages NGS Data Omega/FRP Misc Info	BBS (703) 313 5910 (300-28800 bps) Sprintnet (x.25)31103501132800
Internet	24 hours	Status Fore/Hist/Outages/ NGS Data/Omega/FRP and Misc Info	http://www.navcen.uscg.mil ftp://ftp.navcen.uscg.mil
Fax on Demand	24 hours	Status Fore/Hist/Outages/ NGS Data/Omega/FRP and Misc Info	(703) 313-5931/5932
NIS Voice Tape Recording	24 hours	Status Forecasts Historic	(703) 313-5906 - Omega (703) 313-5907 - GPS
WWV	Minutes 14 & 15	Status Forecasts	2.5, 5, 10, 15, and 20 MHz
WWVH	Minutes 43 & 44	Status Forecasts	2.5, 5, 10, and 15 MHz
USCG	When Broadcasted	Status Forecasts	VHF Radio marine band
DMA Broadcast Warnings	When Broadcast Received	Status Forecasts	
DMA Weekly Notice to Mariners	Published & Mailed Weekly	Status Forecast Outages	(301) 227-3126
DMA Navinfonet Automated Notice to Mariners System	24 hours	Status Forecast Historic Almanacs	(301) 227-3351 300 BAUD (301) 227-5925 1200 BAUD (301) 227-4360 2400 BAUD
NAVTEX Data Broadcast	All Stations Broadcast 6 times daily at alternating times	Status Forecast Outages	518 kHz

Use of GPS for instrument flight rule (IFR) supplemental air navigation requires that the system have the ability to detect when a satellite is out of tolerance and should not be used in the navigation solution. This capability is provided by Receiver Autonomous Integrity Monitoring (RAIM), an algorithm contained within the GPS receiver. All receivers certified for supplemental navigation must have RAIM or an equivalent capability.

In order for the receiver to perform RAIM, a minimum of five satellites with satisfactory geometry must be visible. Since the GPS constellation of 24 satellites was not designed to provide this level of coverage, RAIM is not always available even when all of the satellites are operational. Therefore, if a satellite fails or is taken out of service for maintenance, it is not intuitively known which areas of the country are affected, if any. The location and duration of these outage periods can be predicted with the aid of computer analysis, however, and reported to pilots during the pre-flight planning process.

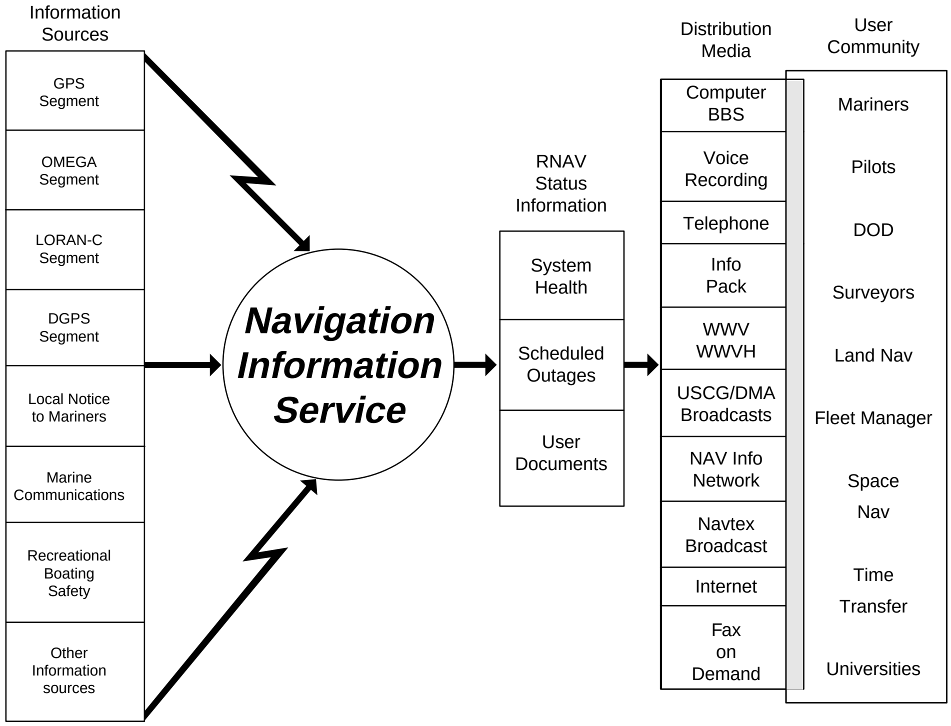


Figure A-5. NIS Information Flow

Notification of site specific outages provides the pilot with information regarding GPS RAIM availability for nonprecision approach at the filed destination.

Site specific GPS NOTAMs are computed based on criteria in the RTCA/DO-208, "Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)," dated July 1991, and FAA Technical Standard Order (TSO)-C129(a), "Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS)." The baseline RAIM algorithm, as specified in the MOPS and TSO, is used for computing the NOTAMs for GPS.

GPS almanac data is received via an antenna on the roof of the FAA or sent by modem from the GPS Master Control Station to a computer at the U.S. NOTAM Office. The almanac and satellite health status data are input into the RAIM algorithm and processed against a database of airfields to determine location specific outages. The outage information is then distributed in the form of a NOTAM to U.S. military aviators and as aeronautical information to U.S. Flight Service Stations for civilian aviators. This occurs daily for an advance 48 hour period or whenever a change occurs in a satellite’s health status.

The military GPS NOTAM system was officially declared operational on May 16, 1995. An example military NOTAM output from the system sent through NATCOM to the Aviation Weather Network (AWN) to the CONUS Meteorological Distribution

System (COMEDS) and the Automated Weather Distribution System (AWDS) is shown below:

a) KLAX
b) 11041700
c) 11041745
d) GPS ONLY NPA NOT AVBL

This NOTAM means that a GPS nonprecision approach at Los Angeles International airport is unavailable on Nov. 4 from 17:00 to 17:45.

The FAA provides similar GPS outage information in an aeronautical information format, but not as a NOTAM. The FAA uses the same GPS NOTAM generator as the DOD to compute their aeronautical information, but it is distributed through their two Automated Weather Processors (AWPs) to the 21 Flight Service Data Processing Systems (FSDPS) and then to the 61 Automated Flight Service Stations (AFSS), as shown in Figure A-6. The FAA's GPS aeronautical information became operational November 2, 1995. GPS availability for an NPA at the destination airfield is provided to a pilot upon request from the AFSS. The pilot can request information for the estimated time of arrival or ask for the GPS availability over a window of up to 48 hours.

NOTAM information applicable to additional phases of flight may be accommodated in the future. Since GPS is an area navigation system, GPS outage information may be provided using a graphical display, similar to that used to convey weather information.

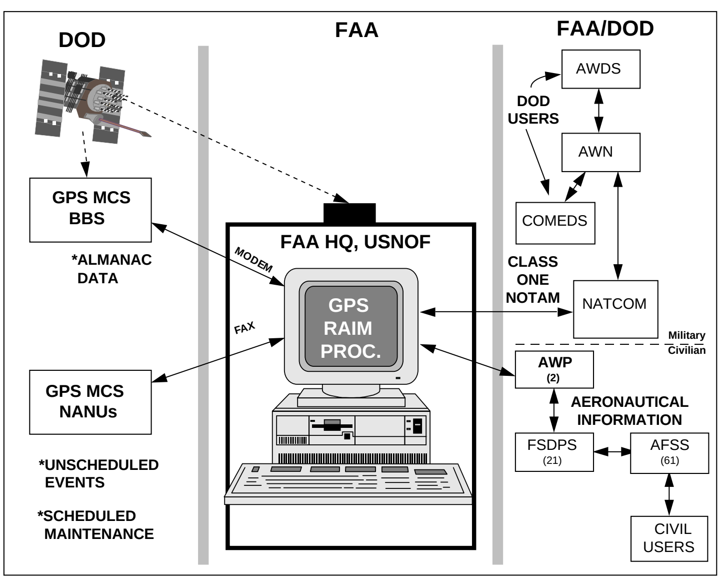


Figure A-6. GPS NOTAM/Aeronautical Information Distribution System

Appendix B

Reference Systems

B.1 Map and Chart Reference Systems

Geodetic datums are reference systems used as a basis for providing horizontal and vertical positions of features on the surface of the Earth. They can be established at all levels of government (international, national, and local) and form the legal basis for positioning and navigation. Historically, horizontal and vertical datums have been determined independent of one another. Older horizontal datums have usually been local or regional in nature and non-geocentric. Vertical positions (orthometric heights) have been referenced to an equipotential surface that approximated mean sea level.

With the advent of satellite positioning systems, especially GPS, it is possible to determine three dimensional coordinates related to a common geocentric reference system. Rather than orthometric heights, GPS provides geocentric radius vectors, expressed as ellipsoid heights above a geocentric reference ellipsoid with a specified semi-major axis and flattening. Orthometric heights and ellipsoid heights can differ by more than 100 meters and must not be confused. They can be related to one another using the gravimetrically determined separations between the ellipsoid to which ellipsoid heights are referred and the equipotential surface to which orthometric heights are referred. This separation is known as geoid height. Geoid height models (e.g., GEOID93, GEOID96, EGM96) have been developed to support conversions between orthometric and ellipsoid heights.

Within the U.S. the National Geodetic Survey (NGS) is the primary civil Federal agency responsible for establishment of datums. Until recently the horizontal datum used throughout most of the U.S. and Canada was the North American Datum of 1927 (NAD 27). NAD 27 is not Earth centered. In 1986 NGS completed a new horizontal datum known as the North American Datum of 1983 (NAD 83). NAD 83 is nominally geocentric. NAD 83 is now the legal horizontal datum for surveying, mapping and charting in the U.S. Until recently, the orthometric height datum for the U.S. was the National Geodetic Vertical Datum of 1929 (NGVD29). In 1991 the NGS completed a new vertical datum, the North American Vertical Datum of 1988 (NAVD 88). NAVD 88 is now the legal vertical datum for orthometric heights in the U.S.

With the advent of space technology, geodesy and navigation are increasingly being referenced to three dimensional, Earth centered reference systems. Three such systems are in common use at present. They are: NAD 83 (extended to be three dimensional), World Geodetic System of 1984 (WGS 84), and the International Terrestrial Reference Frame (ITRF) developed by the International Earth Rotation Service (IERS). New ITRF systems are produced every 1 to 2 years as more accurate information becomes available. Changes in station coordinates between ITRF systems are currently at the few centimeter level. WGS 84 was developed by the U.S. Department of Defense (DOD). The realization of WGS 84 has improved with time so that it is closely aligned with ITRF. Currently, WGS 84 and the most recent ITRF systems are in agreement to better than a decimeter. NAD 83 was extended to be three dimensional using space system stations included in the original NAD 83 adjustment supplemented by the introduction of a nationwide network of GPS stations. All versions of the three reference systems differ from one another by no more than about two meters. Therefore, for many mapping, charting and navigation purposes they can be considered equivalent.

By interagency agreements between NOAA and the USCG and FAA, NGS is providing NAD 83 positions for stations of the USCG DGPS stations which support marine navigation and the FAA WAAS stations which support air navigation.

B.2 Nautical Charts

Most nautical charts are based on regional horizontal datums which have been defined over the years independent of each other.

These include charts published by the National Imagery and Mapping Agency (NIMA) and NOS. 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 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 currently used for nautical charts. In addition to this difference, the plotted detail, such as soundings and navigational aids, contain a minimal plottable error that ranges between 0.5 mm and 1.0 mm on paper.

Virtually all radionavigation equipment incorporating coordinate converters (automatic computation of geodetic latitude and longitude from data received from a radionavigation system) were, until recently, programmed with the World Geodetic System of 1972 (WGS 72). Today, new radionavigation equipment coordinates, especially from differential GPS systems, are computed based on WGS 84, or, equivalently, in the U.S., NAD 83.

The large majority of the nautical charts published by NOS have been compiled based on a regional datum: NAD 27. The remaining NOS nautical charts were published on eight other local or regional datums. As stated, NOS has now adopted a geocentric datum: NAD 83. NOS has completed the conversion of most of its nautical charts to NAD 83. The charts of the Pacific islands, published by NOS, will be compiled based on WGS 84. As stated before, for charting purposes, NAD 83 is equivalent to WGS 84. As charts are converted to NAD 83, datum transformation notes will be added which report the amount of shifts from NAD 27 coordinates for each chart. These shifts can be in excess of 100 m and care must be taken not to mix NAD 83 and NAD 27 values while navigating.

Improvements in worldwide navigation accuracy, which are occurring with the implementation of GPS, will be significant. However, the ability to navigate safely 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 reference system.

B.3 Aeronautical Charts

The ultimate responsibility for the accuracy of air cartographic positional data rests with NOAA. 49 U.S.C Section 4472 authorizes the FAA, subject to available appropriations, to arrange for the publication of aeronautical maps and charts necessary for the safe and efficient movement of aircraft in air navigation utilizing the facilities and assistance of other Federal agencies. Through agreement between the FAA and NOAA the National Ocean Service (NOS) of NOAA provides many of the services necessary to provide the required maps and charts. Within the National Airspace System (NAS), the NGS, a component of NOS, establishes the basic U.S. datums that are the basis for aeronautical charting. NGS conducts the Airport Obstruction Chart Surveys (AOC Surveys) which provide the basis for positioning of navigation aids, obstructions, etc. needed to produce obstruction charts at about 930 major U.S. civil airports. The results of these extensive ground based and aerial photographic surveys are delivered to users in both digital and paper chart format.

NGS also conducts two other types of surveys in support of the FAA: Area Navigation Approach (ANA) surveys and Engine Out Departure (EOD) surveys. ANA surveys provide runway or vertical landing point positions, obstruction location, GPS antenna siting, and other positioning information for use in developing precision and nonprecision instrument approach procedures for aircraft using navigation systems such as GPS. In addition these surveys provide positions and elevations for selected navigational aids associated with the airport or heliport.

Surveys are expected to encompass on the order of 4,000 airports and perhaps as many as 2,000 heliports by the year 2000 to support conversion to GPS navigation. EOD surveys will also be performed to provide runway and obstruction information for use in determining the maximum allowable takeoff weights for civil aircraft assuming a complete failure of one engine at V1.

B.4 Electronic Chart Display Information System (ECDIS)

The Electronic Chart Display Information System (ECDIS) has emerged as a promising navigation aid that will result in significant improvements to maritime safety and commerce. More than simply a graphics display, ECDIS is a real-time geographic information system (GIS) that combines both spatial and textual data into a readily useful operational tool. As an automated decision aid that is capable of continuously determining a vessel's position in relation to land, charted objects, aids to navigation, and unseen hazards, ECDIS represents an entirely new approach to maritime navigation and piloting. It is expected that ECDIS will eventually replace the need to carry paper charts.

The development of an international performance standard for ECDIS was finalized by the International Maritime Organization (IMO) in May 1994. The IMO Performance Standards for ECDIS were formally adopted by the Nineteenth Assembly of IMO on November 23, 1995. To ensure early dissemination, IMO issued ECDIS Performance Standards as MCS/Circ. 637 on May 27, 1994.

As specified in the IMO Performance Standards, the primary function of ECDIS is to contribute to safe navigation. ECDIS must be capable of displaying all chart information necessary for safe and efficient navigation organized by, and distributed on the authority of, government-authorized hydrographic offices. With adequate backup arrangements, ECDIS may be accepted as complying with the up-to-date charts required by regulation V/20 of the Safety-of-Life-at-Sea (SOLAS) Convention of 1974. In operation, ECDIS should reduce the navigational workload compared to using the paper chart. It should enable the mariner to execute in a convenient and timely manner all route planning, route monitoring, and positioning currently performed on paper charts. ECDIS should also facilitate simple and reliable updating of the electronic navigational chart. Similar to the requirements for shipborne radio equipment forming a part of the global maritime distress and safety system (GMDSS), and for electronic navigational aids, ECDIS onboard a SOLAS vessel should be in compliance with the IMO Performance Standard.

For the electronic navigational positioning system to be used with an IMO-compliant ECDIS, it is specified that:

- The vessel's position be derived from a continuous positioning system of an accuracy consistent with the requirements of safe navigation.
- A second independent positioning method of a different type should be provided; and, ECDIS should be capable of detecting discrepancies between the primary and secondary positioning systems.

- ECDIS provide an indication when the input from a positioning system is lost or malfunctioning.

When ECDIS and radar/Automatic Radar Plotting Aid (ARPA) are superimposed on a single display, they provide a system that can be used both for navigation and collision avoidance. As specified in the IMO Performance Standards, radar information may be added to the ECDIS display, as long as it does not degrade the display and is clearly distinguishable from the electronic navigational chart. The IMO Performance Standard further stipulates that both the ECDIS and radar use a common reference system (e.g., GPS/DGPS), and that the chart and radar image match in scale and orientation.

Appendix C

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:

- Predictable - The accuracy of a radionavigation system's position solution with respect to the charted solution. Both the position solution and the chart must be based upon the same geodetic datum. (Note: Appendix B discusses chart reference systems and the risks inherent in using charts in conjunction with radionavigation systems.)
- Repeatable - 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.
- 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.

Air Traffic Control (ATC) - A service operated by appropriate authority to promote the safe, orderly, and expeditious flow of air traffic.

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

Area Navigation (RNAV) - Application of the navigation process providing the capability to establish and maintain a flight path on any arbitrarily chosen course that remains within the coverage area of navigation sources being used.

Automatic Dependent Surveillance (ADS) - A function in which aircraft automatically transmit navigation data derived from onboard navigation systems via a datalink for use by air traffic control.

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.

Block II/IIA - The satellites that form the initial GPS constellation at FOC.

Cellular Triangulation - A method of location determination using the cellular phone system where the control channel signals from a mobile phone are captured by two or more fixed base stations and processed according to an algorithm to determine the location of the mobile receiver.

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^{o}), circular error probable is the radius of the circle containing 50 percent of the individual measurements being made, or the radius of the circle inside of which there is a 50 percent probability of being located.

Coastal Confluence Zone (CCZ) - 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.

Continuity - The continuity of a system is the ability of the total system (comprising all elements necessary to maintain aircraft position within the defined airspace) to perform its function without interruption during the intended operation. More specifically, continuity is the probability that the specified system performance will be maintained for the duration of a phase of operation, presuming that the system was available at the beginning of that phase of operation.

Coordinate Conversion - The act of changing the coordinate values from one type of reference system to another; e.g., from geodetic coordinates (latitude and longitude) to Universal Transverse Mercator grid coordinates, or from one reference coordinate system to another, such as from ITRF to NAD 83.

Coordinated Universal Time (UTC) - UTC, an atomic time scale, is the basis for civil time. It is occasionally adjusted by one-second increments to ensure that the difference between the uniform time scale, defined by atomic clocks, does not differ from the earth’s rotation by more than 0.9 seconds.

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 United States.

En Route Oceanic - The phase of flight between the departure and arrival terminal phases, with an extended flight path over an ocean.

Fault Detection and Exclusion (FDE) - Fault detection and exclusion is a receiver processing scheme that autonomously provides integrity monitoring for the position solution, using redundant range measurements. The FDE consists of two distinct parts: fault detection and fault exclusion. The fault detection part detects the presence of an unacceptably large position error for a given mode of flight. Upon the detection, fault exclusion follows and excludes the source of the unacceptably large position error, thereby allowing navigation to return to normal performance without an interruption in service.

Flight Technical Error (FTE) - The contribution of the pilot in using the presented information to control aircraft position.

Free Flight - A safe and efficient flight operating capability under instrument flight rules in which the operators have the freedom to select their path and speed in real time. Air traffic restrictions are only imposed to ensure separation, to preclude exceeding airport capacity, to prevent unauthorized flight through special use airspace, and to ensure safety of flight. Restrictions are limited in extent and duration to correct the identified problem.

Full Operational Capability (FOC) - For GPS, this is defined as the capability that will occur when 24 operational (Block II/IIA) satellites are operating in their assigned orbits and have been tested for military functionality and meet military requirements.

Geocentric - Relative to the Earth as a center, measured from the center of mass of the Earth.

Geodesy - The science related to the determination of the size and shape of the Earth by such direct measurements as triangulation, GPS positioning, leveling, and gravimetric observations.

Geometric Dilution Of Precision (GDOP) - All geometric factors that degrade the accuracy of position fixes derived from externally-referenced navigation systems.

Global Navigation Satellite System (GNSS) - The GNSS is a world-wide position and time determination system, that includes one or more satellite constellations, aircraft receivers, and system integrity monitoring, augmented as necessary to support the required navigation performance for the actual phase of operation.

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.

Initial Operational Capability (IOC) - For GPS, this is defined as the capability that will occur when 24 GPS satellites (Block I/II/IIA) are operating in their assigned orbits and are available for navigation use.

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

Multipath - The propagation phenomenon that results in signals reaching the receiving antenna by two or more paths. When two or more signals arrive simultaneously, wave interference results. The received signal fades if the wave interference is time varying or if one of the terminals is in motion.

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

Nanosecond (ns) - One billionth of a second.

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.

National Command Authority (NCA) - The NCA is the President or the Secretary of Defense, with the approval of the President. The term NCA is used to signify constitutional authority to direct the Armed Forces in their execution of military action. Both movement of troops and execution of military action must be directed by the NCA; by law, no one else in the chain of command has the authority to take such action.

Nautical Mile (nm) - A unit of distance used principally in navigation. The International Nautical Mile is 1,852 meters long.

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

Nonprecision Approach - A standard instrument approach procedure in which no electronic glide slope is provided (e.g., VOR, TACAN, Loran-C, or NDB).

Precise Time - A time requirement accurate to within 10 milliseconds.

Precision Approach - A standard instrument approach procedure using a ground-based system in which an electronic glide slope is provided (e.g., ILS).

Primary Means Air Navigation System - A navigation system approved for a given operation or phase of flight that must meet accuracy and integrity requirements, but need not meet full availability and continuity requirements. Safety is achieved by limiting flights to specific time periods and through appropriate procedural restrictions. Note--There is no requirement to have a sole-means navigation system on board to support a primary-means system.

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.

Receiver Autonomous Integrity Monitoring (RAIM) - A technique whereby a civil GPS receiver/processor determines the integrity of the GPS navigation signals without reference to sensors or non-DOD integrity systems other than the receiver itself. This determination is achieved by a consistency check among redundant pseudorange measurements.

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

Required Navigation Performance - A statement of the navigation performance accuracy necessary for operation within a defined airspace, including the operating parameters of the navigation systems used within that airspace.

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).

Roadside Beacons - A system using infrared or radio waves to communicate between transceivers placed at roadsides and the in-vehicle transceivers for navigation and route guidance functions.

Sigma - See Standard Deviation.

Sole Means Air Navigation System - A sole-means navigation system approved for a given operation or phase of flight must allow the aircraft to meet, for that operation or phase of flight, all four navigation system performance requirements: accuracy, integrity, availability, and continuity of service. Note--This definition does not exclude the carriage of other navigation systems. Any sole-means navigation system could include one (stand-alone installation) or several sensors, possibly of different types (multi-sensor installation).

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 (sigma) - 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 - A navigation system that may only be used in conjunction with a primary- or sole-means navigation system. Approval for supplemental means for a given phase of flight requires that a primary-means navigation system for that phase of flight must also be on board. Amongst the navigation system performance requirements for a given operation or phase of flight, a supplemental-means navigation system must meet the accuracy and integrity requirements for that operation or phase of flight; there is no requirement to meet availability and continuity requirements. Note--Operationally, while accuracy and integrity requirements are being met, a supplemental-means system can be used without any cross-check with the primary-means system. Any navigation system approved for supplemental means could involve one (stand-alone installation) or several sensors, possibly of different types (multi-sensor installation).

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 at appropriate facilities. 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.

TOPEX/POSEIDON - TOPographic EXperiment/POSEIDON mission, a joint U.S./French oceanic mapping mission launched in August 1992.

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 84oN and 80^{o}S latitudes.

Vehicle Location Monitoring - 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).

Appendix D

Glossary

The following is a listing of abbreviations for organization names and technical terms used in this plan:

ADAM	Airport Datum Monument Program
ADC	Air Data Computer
ADF	Automatic Direction Finder
ADS	Automatic Dependent Surveillance
ADVANCE	Advanced Driver and Vehicle Advisory Navigation Concept
AEEC	Airlines Electronic Engineering Committee
AFSS	Automated Flight Service Stations
AGL	Above Ground Level
AIRSAR	Airborne Synthetic Aperture Radar
ANA	Area Navigation Approach
AOC	Airport Obstruction Chart
APTS	Advanced Public Transportation System
ARPA	Automatic Radar Plotting Aid
ARQ	Automatic Request/Reply
ARTS	Advanced Rural Transportation System
ASOS	Automated Surface Observing System

ATC	Air Traffic Control
ATIS	Advanced Traveler Information System
ATMS	Advanced Traffic Management System
ATON	Aids to Navigation
AVC	Automatic Vehicle Classification
AVCS	Advanced Vehicle Control System
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
AVM	Automatic Vehicle Monitoring
AWDS	Automated Weather Distribution System
AWN	Aviation Weather Network
AWOS	Automated Weather Observing System
AWP	Automated Weather Processor
BTS	Bureau of Transportation Statistics
C/A	Coarse/Acquisition
CCW	Coded Continuous Wave
CDI	Course Deviation Indicator
CEP	Circular Error Probable
CFR	Code of Federal Regulations
CGS	Civil GPS Service
CIS	Commonwealth of Independent States
CJCS	Chairman, Joint Chiefs of Staff
cm	centimeter
CNS	Communication, Navigation and Surveillance
COMEDS	CONUS Meterological Distribution System
CONUS	Continental United States
CORS	Continuously Operating Reference Stations
CSE	Course Selection Error

CVO	Commercial Vehicle Operations
CW	Continuous Wave
DART	Dallas Rapid Transit District
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
DIA	Defense Intelligence Agency
DME	Distance Measuring Equipment
DOA	Department of Agriculture
DOC	Department of Commerce
DOD	Department of Defense
DOI	Department of Interior
DOP	Dilution of Precision
DOS	Department of State
DOT	Department of Transportation
DR	Dead Reckoning
drms	distance root mean squared
DSN	Deep Space Network
ECDIS	Electronic Chart Display Information System
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
EOD	Engine Out Departure
EUVE	Extreme Ultraviolet Explorer
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FAR	Federal Aviation Regulation
FCC	Federal Communications Commission
FDE	Fault Detection and Exclusion
FDI	Fault Detection and Identification

FGDC	Federal Geographic Data Committee
FHWA	Federal Highway Administration
FL	Flight Level
FM	Frequency Modulation
FOC	Full Operational Capability
FRA	Federal Railroad Administration
FRP	Federal Radionavigation Plan
FSDPS	Flight Service Data Processing Systems
FTA	Federal Transit Administration
FTE	Flight Technical Error
GCA	Ground Controlled Approach
GDOP	Geometric Dilution of Precision
GEO	Geostationary Earth Orbit
GES	Ground Earth Station
GHz	Gigahertz
GIS	Geographic Information Systems
GLONASS	Global Navigation Satellite System (Russian Federation System)
GNSS	Global Navigation Satellite System (ICAO)
GPS	Global Positioning System
HF	High Frequency
Hz	Hertz (cycles per second)
IAG	International Association of Geodesy
IALA	International Association of Lighthouse Authorities
ICAO	International Civil Aviation Organization
ICNS	Integrated Communication, Navigation and Surveillance
IERS	International Earth Rotation Service
IFR	Instrument Flight Rules
IGEB	Interagency GPS Executive Board

IGS	International GPS Service
ILS	Instrument Landing System
IMO	International Maritime Organization
INMARSAT	International Maritime Satellite Organization
INS	Inertial Navigation System
IOC	Initial Operational Capability
IOTC	International Omega Technical Commission
IRAC	Interdepartmental Radio Advisory Committee
IRAC/SPS	IRAC Spectrum Planning Subcommittee
IRAC/SSG	IRAC Space Systems Group
IRS	Inertial Reference System
ISS	International Space Station
ITRF	IERS Terrestrial Reference Frame
ITS	Intelligent Transportation Systems
ITS-JPO	Intelligent Transportation Systems Joint Program Office
ITU	International Telecommunication Union
JCS	Joint Chiefs of Staff
JPO	Joint Program Office
kHz	kilohertz
km	kilometer
LAAS	Local Area Augmentation System
LADGPS	Local Area Differential GPS
LF	Low Frequency
LOP	Line of Position
Loran	Long-Range Navigation
MAP	Missed Approach Point
MARAD	Maritime Administration
MASPS	Minimum Aviation System Performance Standards

MCS	Master Control Station
MHz	Megahertz
MLS	Microwave Landing System
mm	millimeters
MNP	Master Navigation Plan
MOA	Memorandum of Agreement
MTA	Mass Transit Administration
NAD	North American Datum
NAG	Naval Astronautics Group
NANU	Notice Advisories to Navstar Users
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NAVCEN	U.S. Coast Guard Navigation Center
NAVD	North American Vertical Datum
NAVWAR	Navigation Warfare
NCA	National Command Authorities
NDB	Nondirectional Beacon
NGS	National Geodetic Survey
NGVD	National Geodetic Vertical Datum
NHTSA	National Highway Traffic Safety Administration
NIMA	National Imagery and Mapping Agency
NIS	Navigation Information Service
nm	nautical mile
NNSS	Navy Navigation Satellite System (Transit)
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NOTAM	Notice to Airmen

ns	nanosecond
NSA	National Security Agency
NSF	National Science Foundation
NSRS	National Spatial Reference System
NTIA	National Telecommunications and Information Administration
OAB	Operational Advisory Broadcast
OCST	Office of Commercial Space Transportation
Omega	Ground-based VLF navigation system (not an acronym)
OMB	Office of Management and Budget
OSD	Office of the Secretary of Defense
OST	Office of the Secretary of Transportation
OST/B	Assistant Secretary for Budget Programs
OST/C	General Counsel's Office
OST/M	Assistant Secretary for Administration
OST/P	Assistant Secretary for Transportation Policy
P-code	Pseudorandom Tracking Code
PDD	Presidential Decision Directive
PDOP	Position Dilution of Precision
PHMI	Probability of Hazardously Misleading Information
POS/NAV	Positioning and Navigation
PPS	Precise Positioning Service
PRN	Pseudo-Random Noise
ps	picosecond
PWSA	Ports and Waterways Safety Act
RACON	Radar Transponder Beacon
RAIM	Receiver Autonomous Integrity Monitoring
RBN	Radiobeacon
R&D	Research & Development

RDF	Radio Direction Finder
R&E	Research & Engineering
RF	Radio Frequency
RFI	Radio Frequency Interference
RNAV	Area Navigation
RNP	Required Navigation Performance
RSPA	Research and Special Programs Administration
RSS	Root Sum Square
RTCM	Radio Technical Commission for Maritime Services
RTD	Rapid Transit District
SA	Selective Availability
SAFI	Semi-Automatic Flight Inspection
SAR	Search and Rescue
SARPS	Standards and Recommended Practices
SCAT I	Special Category I
SLSDC	Saint Lawrence Seaway Development Corporation
SOFIA	Stratospheric Observatory For Infrared Astronomy
SOLAS	Safety-of-Life-at-Sea
SPS	Standard Positioning Service
STOL	Short Take-Off and Landing
TACAN	Tactical Air Navigation
TD	Time Difference
TERPS	Terminal Instrument Procedures
TRSB	Time Referenced Scanning Beam
TSO	Technical Standard Order
UHF	Ultra High Frequency
USACE	U.S. Army Corps of Engineers
USAF	United States Air Force

U.S.C.	United States Code
USCG	United States Coast Guard
USD/A&T	Under Secretary of Defense for Acquisition and Technology
USMC	United States Marine Corps
USNO	United States Naval Observatory
UTC	Coordinated Universal Time
VFR	Visual Flight Rules
VHF	Very High Frequency
VLBI	Very Long Baseline Interferometry
VLF	Very Low Frequency
VOR	Very High Frequency Omnidirectional Range
VORTAC	Collocated VOR and TACAN
VTS	Vessel Traffic Services
WAAS	Wide Area Augmentation System
WGS	World Geodetic System
WMS	Wide Area Master Stations
WRC	World Radio Conferences
WRS	Wide Area Reference Stations
WWW/WWVH	National Bureau of Standards Broadcast Notice to Airmen

References

1. OMB Circular A-76, *"Performance of Commercial Activities,"* August 4, 1983; Supplemental handbook, April 11, 1996; Transmittal memo #16, May 23, 1996.

2. FAA Advisory Circular No. 90-45A, *"Approval of Area Navigation Systems for Use in the U.S. National Airspace System,"* February 21, 1975.

3. United States Standard for Terminal Instrument Procedures (TERPS), FAA Handbook 8260.3B, July 1976.

4. FAA Advisory Circulars: No. 90-45A, *"Approval of Area Navigation Systems for Use in the U.S. National Airspace System,"* February 21, 1975; No. 20-130, *"Airworthiness Approval of Multi-Sensor Navigation Systems in the U.S. National Airspace System (NAS) and Alaska,"* September 12, 1988; No. 20-121A, *"Airworthiness Approval of the Loran-C Navigation System for Use in U.S. National Airspace (NAS) and Alaska,"* August 24, 1988; and TSO C129, *"Airborne Supplemental Navigation Equipment Using the Global Positioning System,"* December 12, 1992.

5. U.S. Department of Transportation, Federal Highway Administration, *ITS Architecture: Report of the Joint Architecture Team*, June 1996.

6. *A Technical Report to the Secretary of Transportation on a National Approach to Augmented GPS Services.* NTIA Special Publication 94-30, December l994.

7. *Report of the Joint DOD/DOT Task Force - The Global Positioning System: Management and Operation of a Dual System.* A Report to the Secretaries of Transportation and Defense, December 1993.

8. Federal Railroad Administration, *"Differential GPS: An Aid To Positive Train Control,"* Report to the Committees on Appropriations, June 1995.

9. U.S. Department of Defense, *Global Positioning System Standard Positioning Service Signal Specification.* 2nd Edition, June 2, 1995.

10. U.S. Department of Transportation - Intelligent Transportation Systems Joint Program Office, Federal Highway Administration, Federal Transit Administration, and National Highway Traffic Safety Administration, *Department of Transportation's Intelligent Transportation Systems (ITS) Projects,* January 1996.

1996
FRP Subject Index

A

C

D

E

F

G

I

L

M

N

O

P

R

S

T

V

W