Federal Radionavigation Plan

1999

1.

Letter of Promulgation

This letter promulgates the tenth edition of the Federal Radionavigation Plan (FRP), which was prepared jointly by the Departments of Defense and Transportation. It supersedes the 1996 Federal Radionavigation Plan. The FRP 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 FRP is revised biennially.

This issue of the FRP is the last issue of the 20th Century. As we look to radionavigation in the 21st century, we do so with the confidence that satellite systems will predominate as the new worldwide standard for positioning, navigation and time dissemination. The past decade has confirmed the capability of the technology to provide benefits, far exceeding initial expectations, to users throughout the world on land, at sea and in the air. The United States is proud to have pioneered and implemented this powerful technology. Hand in hand with bringing a major and revolutionary new capability on line come many challenges, the greatest of which is managing change. Transition from current systems and the determination of what part of the current radionavigation infrastructure to retain is a complex matter involving government, industry and users.

This edition covers planning completed as of the date of this Letter of Promulgation plus policies and plans until publication of the eleventh edition, the 2001 FRP. Of necessity, the FRP can be no more than a snap shot in time but nevertheless it remains the official radionavigation plan and policy of the United States. Policies and plans formulated in this edition may be subject to change during formulation of the next edition of the FRP. Your suggestions for the improvement of future editions are welcomed.

Rodney E. Slater
Secretary of Transportation

Date: 1-28-2000

William S. Cohen
Secretary of Defense

Date: FEB 8 2000

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13. ABSTRACT (Maximum 200 words)

The Federal Radionavigation Plan (FRP) is published in accordance with 10 U.S.C. 2281(c) and 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 tenth 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.

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Preface

The Department of Defense (DOD) and the Department of Transportation (DOT) have developed the tenth edition of the Federal Radionavigation Plan (FRP) as required by 10 U.S.C. 2281(c). 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. It also describes uses of such systems for purposes other than navigation. The policies in the FRP often involve a balancing of the interests of public safety and economic growth.

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 are planned to be held before the preparation of the next FRP.

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Executive Summary

The Federal Radionavigation Plan (FRP) is prepared as required by 10 U.S.C. 2281(c) and 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 the authorities and responsibilities of Federal agencies and describes the management structure established to guide individual operating agencies in defining and meeting 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 1996 FRP and covers common-use radionavigation systems (i.e., systems used by both civil and military sectors) that are covered in the Department of Defense (DOD) Chairman, Joint Chiefs of Staff (CJCS) Master Positioning, Navigation, and Timing Plan (MPNTP). The FRP does not cover radionavigation systems used exclusively by the military.

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 included in order to provide a complete picture of U.S. radionavigation. The plan does not include systems which mainly perform surveillance and communication functions.

The Federally provided systems covered in this plan are:

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

Major goals of DOD and the Department of Transportation (DOT) are to ensure that a mix of common-use (civil and military) systems is available to meet user requirements for accuracy, reliability, availability, integrity, coverage, operational utility, and cost; to provide adequate capability for future growth; and to eliminate 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, the military has more stringent requirements including performance under intentional interference, operations in high-performance vehicles, worldwide coverage, and operational capability in severe environmental conditions. Cost is always 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 document is composed of the following sections:

Section 1 - Introduction to the Federal Radionavigation Plan: Delineates the purpose, scope and objectives of the plan 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 and military 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 – U.S. Government Agency Radionavigation Roles and Responsibilities: Presents the DOD, DOT, and other Federal agency roles and responsibilities for providing radionavigation services.

Appendix B – Radionavigation Systems Selection Considerations: Describes the radionavigation system mix in terms of five parameters: operational, technical, economic, institutional, and international.

Appendix C - 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 D – Datums and Reference Systems: Discusses geodetic datums and the reference systems based upon them.

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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.

A Federal Radionavigation Plan is required by 10 U.S.C. 2281(c) (Ref. 1). A Memorandum of Agreement (MOA) between DOD and DOT provides for radionavigation planning as well as for the development and publication of the FRP. This agreement recognizes the need to coordinate all Federal radionavigation system planning and to attempt, wherever consistent with operational requirements, to utilize common systems. In addition, a memorandum of agreement between the DOD and DOT on the civil use of the Global Positioning System (GPS) establishes 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) (Ref. 2) 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, manages the dual civil/military use GPS and U.S. Government augmentations and supports the implementation of GPS national policy in accordance with the provisions of the PDD. The IGEB ensures 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 consults 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 currently includes the Department of State (DOS), Chairman, Joint Chiefs of Staff (CJCS), Department of Commerce (DOC), Department of Interior (DOI), Department of Agriculture (DOA), Department of Justice (DOJ), and the National Aeronautics and Space Administration (NASA). The IGEB management structure is shown in Figure 1-1. A detailed discussion of U.S. Government agency roles and responsibilities is contained in Appendix A.

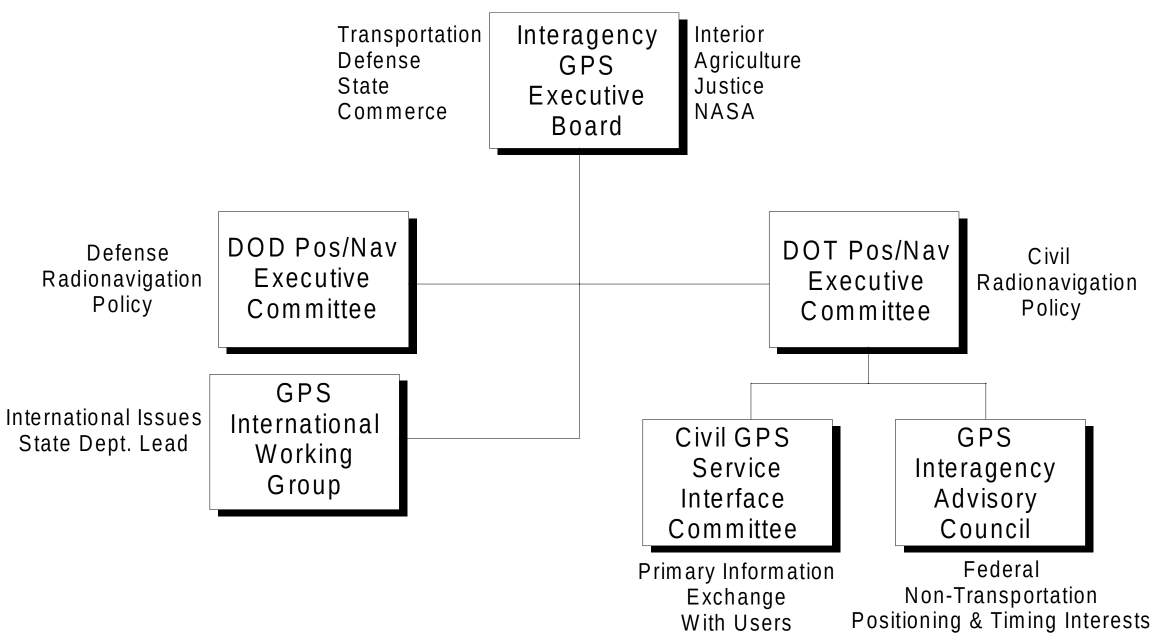


Figure 1-1. Interagency GPS Executive Board Management Structure

The 1990 FRP included, for the first time, discussions of land uses of radionavigation systems. This 1999 FRP includes expanded 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 1998, user meetings were held in Long Beach, CA and Washington, DC. 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. Comments focused on support for use of GPS; concerns with relying on a single radionavigation system (i.e., GPS) without backup or complementary systems and support from the general aviation community for continuing Loran-C beyond the current phaseout date.

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 1.7.

1.2 Purpose

The purpose of the FRP is to:

- Present the current Federal policy and plan for common-use civil and military radionavigation systems.
- Document radionavigation requirements and address common-use systems and applications.
- Outline the Government's approach for implementing new and consolidating existing 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. The plan does not include systems that mainly perform surveillance and communication functions.

The systems addressed in this FRP are:

- GPS

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

1.4 Objectives

The radionavigation policy of the United States is a product of the balancing of a myriad of national interests.

The objectives of U.S. Government radionavigation system policy are to:

- Strengthen and maintain national security.
- Provide safety of travel.
- Promote efficient transportation.
- Help protect the environment.
- Support peaceful civil, commercial, and scientific applications of radionavigation systems.

1.5 Practices and Procedures

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

a. Provide and operate radio aids to navigation which contribute to safe, expeditious, and economic air, land and maritime commerce and which support United States national security interests in accordance with international agreements.

b. Avoid 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.

c. Consider electromagnetic spectrum requirements in the planning and management of radionavigation systems.

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

e. Evaluate domestic and foreign radio aids to navigation, with support for the development of those systems having the potential to meet unfulfilled operational requirements or those offering major economic advantages over existing systems.

f. Establish suitable system transition periods for systems being phased out based on user equipage and acceptance, spectrum transition issues, budgetary considerations, and the public interest.

g. Promote international exchange of scientific and technical information concerning radionavigation aids.

h. Guide and assist siting, testing, evaluating, and operating non-Federal and private radio aids to meet unique aviation and land transportation requirements.

i. Promote national and international standardization of civil and military radionavigation aids.

j. Publish system and signal standards and specifications.

k. Provide the minimum number of special radionavigation aids and services for military operations.

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

m. Equip 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.

n. Establish 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.

o. Consider, in accordance with the national policy contained in OMB Circular A-76 (Ref. 3), the extent to which the private sector can participate in the design, development, installation, operation, and maintenance of all equipment and systems required to provide common-use radionavigation aids (within the constraints of national security).

1.6 Radionavigation Systems Selection Considerations

Many factors are considered in determining the optimum mix of Federally provided radionavigation systems. These factors include 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 also must be considered. 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 that 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. This process resulted in the proliferation 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 1999 recommendation reflects policy direction from the PDD (Ref. 2), advances in 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 solicit and consider inputs from users of radionavigation systems in the decision-making process on radionavigation systems. Developments in GPS augmentations and the changing user needs 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.

When the need or economic justification for a particular system appears to be diminishing, the Department operating the system will notify the appropriate Federal agencies and the public, by publishing the proposed discontinuance of service in the Federal Register.

In the final analysis, 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. A more detailed discussion of selection considerations is contained in Appendix B.

1.7 Federal Policy on the Radionavigation System Mix

This section contains the current U.S. Federal radionavigation policy and plans.

Federal Radionavigation System Policy and Plans (1999 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 dual-use (civil and military) satellite-based radionavigation system, the Global Positioning System (GPS). The services provided by this system and its civil augmentations meet or exceed the services provided by many existing radionavigation systems. Additional improvements in GPS are planned to improve the service provided to both the civil and military users of the system. As the full civil potential of GPS and its augmentations are realized, the service provided by other Federally provided radionavigation systems is expected to decrease to match the reduction in demand for those services.

One of the objectives of this plan is to reflect anticipated changes in radionavigation services provided by the Federal Government. This plan will continuously evolve to reflect the needs of users of Federal radionavigation services. When the benefits derived by the users of a service drop below the cost of providing that service, the Federal Government can no longer continue to provide that service. A number of factors go into anticipating these benefits. Navigation standards establish which service or combination of services is sufficient to conduct an operation. A suitable transition period will be established based on user equipment availability, radio spectrum transition issues, cost and acceptance, budgetary considerations, and the public interest. Operational or safety considerations may dictate the need for a complementary service to support navigation to conduct certain operations. International commitments dictate certain levels and types of navigation services to ensure interoperability with international users.

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 the needs of these users.

Radionavigation systems operated by the U.S. Government are available as directed by the National Command Authority (NCA) in the event of war or threat 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 SPS accuracy is currently degraded globally through the use of a technique called selective availability (SA). U.S. Government policy is to discontinue the use of SA by the year 2006.

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. In recognition that GPS receivers utilize the entire transmitted bandwidth of the GPS signal at L1, the first sentence of paragraph 2.3.1.1 of the SPS Signal Specification was recently amended to read, "The L-band SPS ranging signal is a 2.046 MHz null-to-null bandwidth signal centered about L1. The transmitted ranging signal that comprises the GPS-SPS is not limited to the null-to-null signal and extends through the band 1563.42 to 1587.42 MHz."

Although the L2 is currently not part of the Standard Positioning Service, many civil users currently employ dual frequency receiver technologies to support their requirements. Consequently, the U.S. Government has determined that availability of not one, but two additional C/A coded signals is essential for many critical uses of GPS. The additional signals are planned to enhance the ability of GPS to support all civil users. A second non-safety-of life coded signal will be added at the GPS L2 Frequency (1227.60 MHz) on the satellites scheduled for launch beginning in 2005. A third civil signal that can meet the needs of critical safety-of-life applications such as civil aviation will be added at 1176.45 MHz. The third

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

signal will be implemented on the satellites scheduled for launch beginning in 2007. It is planned that both the second and third civil signals may become part of a civil GPS service. Until the 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 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.

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 foreseeable future.

Augmentations to GPS are enhancements to the GPS SPS 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 that are consistent with U.S. and international agreements.

Maritime DGPS Service: The USCG declared Full Operational Capability (FOC) of the Maritime DGPS Service on March 15, 1999. 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 that broadcast pseudo-range corrections using radionavigation radiobeacons. The Maritime DGPS Service 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.

Nationwide DGPS: Seven Federal agencies are expanding the Maritime DGPS Service to cover all surface areas of the United States to meet the requirements of surface users. A seven agency Memorandum of Agreement has been jointly signed by the Federal Railroad Administration (FRA), the Federal Highway Administration (FHWA), the USCG, the U.S. Air Force, the Office of the Secretary (DOT), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Army Corps of Engineers (USACE). The predictable accuracy of the NDGPS Service within all established coverage areas is better than 10 meters. Fielded operations are achieving accuracies of better than 3 meters.

Wide Area Augmentation System (WAAS): The Federal Aviation Administration (FAA), in cooperation with other DOT organizations and DOD, is augmenting the GPS/SPS with a satellite-based augmentation system, the Wide Area Augmentation System. The initial operational capability of WAAS will begin by the end of 2000, and will provide en route through nonprecision approach service as well as a limited precision approach capability. After achieving initial operational capability, the WAAS will then be incrementally improved over the next six years to expand the area of coverage, increase the availability of precision approaches, increase signal redundancy, and reduce operational restrictions. The result of these incremental improvements will enable aircraft equipped exclusively with WAAS avionics to execute all phases of flight in the NAS except Category II and Category III precision approaches.

Local Area Augmentation System (LAAS): The LAAS, a ground-based augmentation system, 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 services where WAAS will not meet CAT I service performance requirements. LAAS may be used to support runway incursion warnings, high-speed turnoffs, missed approaches, departures, vertical takeoffs and surface operations.

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 an en route supplemental air navigation system for both Instrument Flight Rule (IFR) and Visual Flight Rule (VFR) operations. The Loran-C system serves the 48 conterminous states, their coastal areas, and parts of Alaska. While the Administration continues to evaluate the long-term need for continuation of the Loran-C radionavigation system, the Government will operate the Loran-C system in the short term. The U.S. Government will give users reasonable notice if it concludes that Loran-C is not needed or is not cost effective, so that users will have the opportunity to transition to alternative navigation aids.

Omega: Omega ceased operation as a navigation, positioning, and timing system on September 30, 1997.

VOR/DME: VOR/DME provides users with a means of air navigation in the National Airspace System (NAS). VOR/DME will continue to provide navigation services for en route through nonprecision approach phases of flight throughout the transition to satellite-based navigation. The FAA plans to reduce VOR/DME services provided in the NAS based on the anticipated decrease in use for en route navigation and instrument approaches. The phase-down of VOR/DME is expected to begin in 2008.

TACAN: TACAN is the military counterpart of VOR/DME. The azimuth service of TACAN primarily serves military users only while the DME service serves both military and civil users. The DOD requirements for land-based TACAN will terminate when aircraft are equipped with GPS and are approved by the individual DOD Services for operations in national and international controlled airspace. The requirement for sea-based TACAN will continue until a suitable replacement is operational. The phase-down of TACAN will be based on its decreased utility as an en route navigation and nonprecision approach aid by DOD. Target date to begin the phase-down is 2008.

Precision Approach Systems:

The Instrument Landing System (ILS) is the predominant system supporting civil precision approaches in the U.S. With the advent of GPS-based precision approach systems, the role of ILS will be reduced. Factors in planning the phase-down of ILS service will include assessment of progress with GPS-based precision approaches and the economic utility of continued ILS service on a per-approach basis. ILS may continue to be used to provide precision approach service at major terminals. The phase-down of Category I ILS is expected to begin in 2008.

Limited WAAS Category I precision approach service is expected to be available beginning in 2000. ILS service will be provided for a transition period to allow users to equip with WAAS receivers and to gain confidence in its service.

The FAA expects LAAS Category II/III precision approach systems to be available for public use by 2003 at a few selected airports. Based on current plans for implementing Category II/III LAAS and the anticipated service life of Category II/III ILS equipment, the FAA does not anticipate phasing out any Category II/III ILS systems prior to 2015.

The DOD has established the Joint Precision Approach and Landing System (JPALS) program to provide its next generation precision approach and landing capability. JPALS will provide U.S. forces a global precision landing capability in a variety of mission environments and under a wide range of meteorological conditions. Assuming a successful risk reduction effort, JPALS plans to begin phasing in new capabilities as early as 2004.

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 except when operationally required and economically justified. ICAO also extended the ILS protection date to January 1, 2010. This date is not to be confused with Europe's requirement for aircraft to be equipped with FM immune ILS and VHF communication transceivers by January 1, 2001. 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 phase-down of Category I MLS is expected to begin in 2008.

Radiobeacons:

Maritime and aeronautical nondirectional radiobeacons (NDBs) serve the civil 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.

Aeronautical NDBs serve two principal functions in the NAS: first, as a stand-alone nonprecision approach (NPA) aid at small airports; and second, as a compass locator, generally collocated with the outer marker of an ILS to assist pilots in getting on the ILS course in a non-radar environment. Stand-alone NDBs will be phased out beginning in 2008. NDBs needed as compass locators will be phased out when the underlying ILSs are withdrawn. Due to the wide use of NDBs in Alaska for en route navigation, a separate transition plan will be developed for this operating environment.

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 navigation problem as the mobile craft passes through different regions in its voyage. For example, ship navigation becomes progressively more complex and risky as the 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. 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 upon what the user intends to do, the type of transportation system used, and the user location within that particular transportation system.

Unique military missions and national security needs impose a different set of requirements that 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. All users require that systems used for safety service must be adequately protected.

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.

2.1 Civil Radionavigation System Requirements

The radionavigation requirements of civil users are determined by a DOT process that 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.

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.

The provision of Government radionavigation services 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 that 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. Three subphases may be classified as nonprecision approach (NPA), precision approach and landing, and missed approach.

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

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

3. Missed Approach: Missed approach procedure is conducted when a landing cannot be completed safely as determined by the pilot or Air Traffic Controller.

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 navigation 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 navigation service available and, in some airspace, the Air Traffic Control (ATC) surveillance service. Aircraft separation criteria are influenced by the quality of navigation 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.

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. No single set of navigation 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 that may require the service without unduly limiting the performance characteristics or utility of those aircraft types; e.g., maneuverability, fuel economy, and combat capability.

* Horizontal accuracy is usually expressed as cross track and/or along track.

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 system must be free from unresolved ambiguities of operational significance.

h. Any source-referenced element of the total navigation system shall be capable of providing operationally acceptable navigation information simultaneously and instantaneously to all aircraft that 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 provide for efficient transition through all phases of flight, for which it is designed, 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 for 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.

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. 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.

Some evolving systems, such as WAAS, may have specified requirements that do not reconcile with Table 2-1. The numbers in Table 2-1 are expected to evolve to accommodate new systems. It is anticipated that the WAAS numbers will reflect the Standards and Recommended Practices (SARPs) for Global Navigation Satellite Systems (GNSS) once the SARPs are approved.

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.

2.2.4.1.1 Oceanic En Route

The system must provide navigation 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 lateral separation standard has been reduced to 50 nm in parts of the Pacific Ocean.

2.2.4.1.2 Domestic En Route

Two types of domestic air navigation are allowed under operational procedures. Fixed domestic air routes are based on the locations of VOR/DME or VORTAC facilities relative to fixed obstacles like mountains. Airspace is protected at FL 600 and below to ±4 nm on each side of the route to a point no greater than 51 nm from the navaid facility.

Area navigation is not restricted to fixed air routes. Under VFR, area navigation is allowed to be direct between the origin and destination. Under IFR, area navigation is usually restricted to FL 290 and above with separation maintained by the controller. Onboard collision avoidance with Traffic Alert and Collision Avoidance System (TCAS) is required for revenue carrier operations. VFR and IFR area navigation can be supported by GPS or Loran-C services. More commonly, air carrier operations support area navigation with flight management systems (FMS) that integrate a number of navigation sources used within the constraints of their operational service volumes to define a

Table 2-1. Controlled Airspace Navigation Accuracy Requirements

PHASE	SUBPHASE		ALTITUDE FL/FT	TRAFFIC DENSITY	ROUTE WIDTH (nm)	SOURCE ACCURACY[1] CROSS –TRACK (95%, nm)		SYSTEM USE ACCURACY[2] CROSS -TRACK (95%, nm)
EN ROUTE/ TERMINAL	Oceanic		FL 275 to 400	Normal	50*	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	+/-17.1 **	+/-4.1 ***	N/A
						CAT I Decision Height Point ****		
		CAT II	N/A	Normal	N/A	+/-5.2 **	+/-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 ****		

1 The requirements of the navigation sensor.
2 The combination of Source Accuracy and Flight Technical Error.
* *Lateral separation requirements in the Pacific.*
** *Lateral position accuracy in meters.*
*** *Vertical position accuracy in meters.*
**** *Assumes a 3° glide slope and 8,000 ft. distance between runway threshold and localizer antenna. It may be possible to meet CAT III touchdown requirements down to the runway.*

navigation solution. Basic RNAV performance can be sustained with scanning DME systems that interrogate the distance to multiple DME facilities and use barometric altimeter input for vertical height. VOR can be combined into this solution. ILS is added when present in a precision approach terminal. Inertial reference, airspeed, and attitude are often incorporated to stabilize the aircraft when it is flown by the FMS.

Loran-C and, more recently GPS, inputs have been added to increase area navigation accuracy.

2.2.4.1.3 Terminal Area

Terminal procedures provide transition from the en route to the approach phase of flight. Terminal VOR/DME facilities can be used to support such a procedure. Terminal surveillance facilities support controller vectoring of aircraft to intercept precision approach services in higher density terminal areas. As RNAV-equipped aircraft support more precise navigation, new terminal procedures have been developed to support these operations.

2.2.4.1.4 Remote Areas

Remote areas are defined as regions that 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. 4).

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 navigation 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 navigation accuracy available and other factors. The unique features of RNAV for nonprecision approaches are specified in Reference 5.

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

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.

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 accuracy requirements for the various landing categories are shown in Table 2-1. A range of values is provided for Category I precision approach. The 95 percent accuracy requirement depends upon the error characteristics of the system, such as the frequency and correlation of errors. ILS has an angular error characteristic and has both low-frequency and high-frequency components. The 95 percent accuracy for ILS at a 200-foot decision height is 4.1 meters. The Category II/III accuracy of 2 meters is equal to the accuracy of ILS at 100 feet above the runway. Aircraft use a combination of the landing system and a radar altimeter to accomplish a Category III approach.

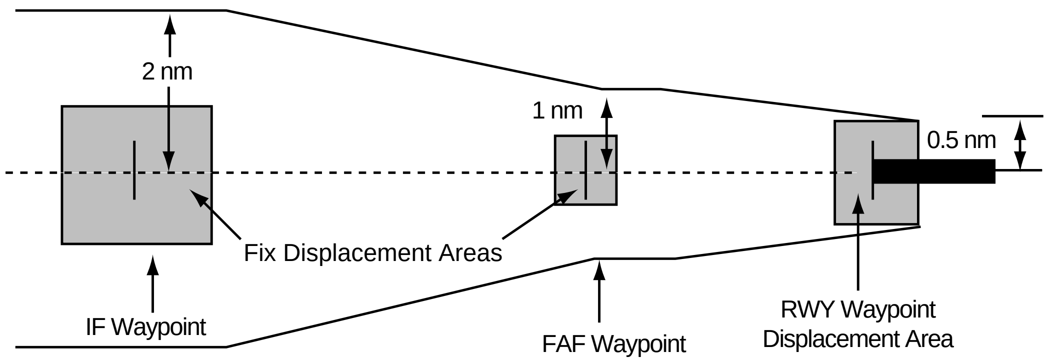


Figure 2-1. RNAV Nonprecision Approach Protected Areas

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

Aviation navigation requirements are evolving toward the concept of Required Navigation Performance (RNP). The RNP concept establishes criteria 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. Some route separations in the Pacific area have been reduced to 50 nm.

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 navigation 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 navigation 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), and privately owned facilities such as TACAN are being used in combination to meet the user navigation needs in these areas. GPS 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 non-seagoing ships and their requirements on long voyages in restricted waterways, typified by tows and barges in the U.S. Western Rivers System and the U.S. Intracoastal Waterway System.

In some areas, seagoing craft in the harbor phase of navigation and inland craft in the inland waterway phase share the use of the same restricted waterway. The distinction between the two phases depends primarily on the type of craft. It is made because seagoing ships and typical craft used in inland commerce have differences in physical characteristics, 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 navigation 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 nm 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 navigation 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 navigation 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 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 that 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 that 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 that 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.

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 (seconds)	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	2	Unlimited	Resolvable with 99.9% confidence
Safety of Navigation (Recreational Boats & Smaller Vessels)	5-10	5-10	US Inland Waterway Systems	99.9%	*	5-10	2	Unlimited	Resolvable with 99.9% confidence
River Engineering & Construction Vessels	0.1**-5	0.1**-5	US Inland Waterway Systems	99%	*	1-2	2 or 3	Unlimited	Resolvable with 99.9% confidence

* Dependent 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 (seconds)	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY
	PREDICTABLE	REPEATABLE							
Safety of Navigation (Large Ships & Tows)	8-20***	-	US harbor entrance and approach	99.7%	**	6-10	2	Unlimited	Resolvable with 99.9% confidence
Safety of Navigation (Smaller Ships)	8-20	8-20	US harbor entrance and approach	99.9%	**	***	2	Unlimited	Resolvable with 99.9% confidence
Resource Exploration	1-5*	1-5*	US harbor entrance and approach	99%	**	1	2	Unlimited	Resolvable with 99.9% confidence
Engineering & Construction Vessels Harbor Phase	0.1****-5	0.1****-5	Entrance channel & jetties, etc.	99%	**	1-2	2 and 3	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%	**	***	2	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	2	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	2	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	2	Unlimited	
Resource Exploration	1.0-100m*	1.0-100m*	US coastal areas	99%	**	1 second	2	Unlimited	
Search Operations, Law Enforcement	0.25nm (460m)	300-600 ft (90-180m)	US coastal/ Fisheries areas	99.7%	**	1 minute	2	Unlimited	
Recreational Sports Fishing	0.25nm (460m)	100-600 ft (30-180m)	US coastal areas	99%	**	5 minutes	2	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	2	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	2	Unlimited	Resolvable with 99.9% confidence
Resource Exploration	10-100m*	10-100m*	-	Worldwide	99%	**	1 minute	2	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	2	Unlimited	Resolvable with 99.9% confidence

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

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 navigation 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.

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 navigation service in the coastal area must provide service of useful quality and be within the economic reach of all classes of mariners.

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 that 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.

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 navigation 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 navigation 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 that 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, the ability to operate at increased speed, 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 navigation performance is needed.

2.3.3.1.3 Greater Need for Traffic Management/Navigation 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 and Automated Identification Systems (AIS) are expected to play an increasingly important role in areas such as Vessel Traffic Services (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 impact maritime operations. Future 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, fishing is expected to continue in the U.S. Exclusive Economic Zone. In summary, both sets of activities may generate demands for navigation 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 Space User Community

NASA is currently using GPS to support earth orbiting satellites conducting space and earth science missions and plans to extend the use of GPS in the future to human space exploration missions as well. In addition, other government agencies may use GPS on satellites in the future. There are also numerous examples of GPS use by the U.S. commercial space community for Low Earth Orbiting (LEO) communication satellite constellations and aboard commercial earth sensing satellites.

2.4.2 *Space User Community Application of GPS*

The U.S. space community uses GPS in a number of spacecraft and science instrument applications. Onboard satellites, GPS is being used to determine satellite position as an input to navigation software that calculates and propagates the satellite's orbit. GPS also can provide accurate time synchronization for satellites as well as spacecraft attitude determination.

NASA is also experimenting with the use of dual frequency GPS receivers aboard science satellites to conduct atmospheric occultation experiments. In this application, the GPS receiver actually becomes an instrument for measuring atmospheric temperature and moisture content. The NPOESS is currently planning to use GPS atmospheric occultation for routine atmospheric measurements aboard its satellites beginning in the next decade.

The U.S. space community also plans to use GPS for various launch vehicle applications in the future. DOD is currently planning to convert the national spacelift ranges to use GPS for range safety. This is an important aspect of DOD's Range Standardization and Automation (RSA) program. In addition, NASA is planning to use GPS for launch vehicle navigation and control functions on the Reusable Launch Vehicle (RLV) now under development. The RLV will use GPS in all three phases of its flight: launch; orbital operations; re-entry and landing. NASA will also begin using GPS for the re-entry and landing phases for the Space Shuttle in 1999.

2.4.3 *Current Space Radionavigation Requirements*

The use of GPS for space applications falls into three different categories:

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

   - Three-dimensional position error not to exceed 1 m (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) as maintained at the U.S. Naval Observatory (USNO) and the GPS time scale not to exceed 1 microsecond (1 sigma).

It should be noted that the required accuracies above result from filtered GPS data and do not represent instantaneous solution requirements.

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 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.

3. Use of GPS receivers aboard satellites as scientific instruments for atmospheric research. These receivers require dual frequency GPS signals in order to measure the occultation of the GPS signals as they pass through the atmosphere. This application has been demonstrated in the GPSMET experiment and is the basis behind planned instruments for the future NPOESS.

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

- The Space Shuttle will implement GPS for re-entry and landing phases beginning in 2000, and will evolve to on-orbit operations in the near future. Space Shuttle experiments in the use of GPS in the ascent phase of flight will also continue.

- The International Space Station (ISS) will use GPS for position and navigation, attitude determination, and as a precise time source. Present planning is for the ISS GPS system to become active on ISS assembly flight 8A.

- Crew Return Vehicle (CRV) is the emergency return vehicle that would be used in the event of a crew emergency aboard the ISS and it will depend upon GPS for critical navigation and attitude determination functions. It will use GPS to initially align its avionics systems after separation from the ISS, use GPS for orbit phase navigation and attitude determination, for navigation during descent, and for navigation to its recovery area.

- 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 of space flight 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, post-pass processing of orbit data will be used. NASA has developed post pass-process techniques using GPS on the TOPEX/POSEIDON satellite that routinely provides satellite positioning accuracy at the 5 cm level. However, in order to obtain this level of precise, accurate GPS satellite position data must be obtained. This accurate GPS satellite tracking data is developed using an extensive global network of ground monitoring stations.

- The use of GPS out to geosynchronous orbit altitudes is being explored by NASA and may prove to be useful to the commercial space industry in the future. However, it is essential that future GPS satellite power levels and beam coverage patterns remain consistent with the current signal characteristics in order to meet the needs of future space users in the geosynchronous orbital region.

- Both of NASA's RLV development efforts, the X-33 and X-34, will depend upon GPS for navigation data throughout their flight regime. This includes the use of GPS during the launch, orbit, and re-entry and landing phases. Initial flights of these vehicles will occur in 1999 - 2000 time frame.

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, FRA, 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 Architecture documentation (Ref. 6).

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

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

operations will benefit from route guidance in rural and low density areas. Also, services such as automated transit stop annunciation are being implemented. 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

Nationwide DGPS can significantly aid the development of positive train control (PTC) systems by providing an affordable and reliable location determination system that is available to surface and marine transportation throughout the contiguous United States and Alaska.

New PTC systems will be communication-based; they will depend upon use of data communication over a variety of paths, including radio, to gather information for integration by microprocessors. One of the principal issues related to PTC is affordability. If systems are highly affordable, they will be widely deployed for both safety and business purposes. Wide deployment will mean that collision avoidance and other safety features will be available over a larger portion of the national rail system. Universal equipping of trains with on-board systems will be necessary to realize maximum safety benefits.

Railroads and their suppliers have evaluated their requirements for train location in relation to NDGPS as follows:

- The single most stressing requirement for the location determination system to support the PTC system is the ability to determine which of two tracks a given train is occupying with a very high degree of assurance* (an assurance that must be greater than 0.99999 or (0.9_5)). The minimum center-to-center spacing of parallel tracks is 11.5 feet. Direct GPS *will not* satisfy this requirement.

- Train location is a *one*-dimensional issue, with well-defined discrete points (switches) where the potential for diverging paths exists. NDGPS narrows the location to less than 5 meters (16 feet). The most frequent interval at which successive turnouts can be located (locations at which a train may diverge from its current route over a switch) is 48 feet. Since the train is constrained to be *located on a track*, as opposed to somewhere within an area, this collapses the problem from a two- or three-dimensional problem into a *one*-dimensional problem.

- The *detailed* track geometry data for a specific route are stored on-board the locomotive (needed for calculating the safe braking distance algorithm). Which of two parallel tracks a train is occupying can then be determined by maintaining a continuous record of which direction the train took over each diverging switch point (normal or reversed). There are several heading reference system techniques available to make this determination.

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

* The assurance of a navigation system is the probability over both time and area, that the services will be sufficiently robust to meet the requirements of the user. This differs from availability in that it goes beyond time and beyond a single navigation system. An example is the system envisioned for PTC. This system, as currently envisoned, will use NDGPS, inertial sensors, transponders at critical junctions, map matching, and other techniques to form an integrated navigation solution.

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. 7, 8). Examples of land transportation positioning and navigation system accuracy needs and requirements are shown in Table 2-7.

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 since the mid-1980s 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. 9) 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. The availability requirement for highways and transit is estimated as 99.7 percent. The availability requirement for rail is estimated as 99.9 percent.

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	< 1
Rail:	
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.*

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 144 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 (e.g., NDGPS) 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 are 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 three quarters of a million to a million weather radiosondes and dropwindsondes each year worldwide to measure such atmospheric parameters as pressure, temperature, humidity, and wind speed and direction. Currently Loran-C, Radio Direction Finding and recently GPS are methods used for weather instrument tracking. With the loss of the Omega system, which had been widely used by the international community for tracking weather radiosondes, and the projected phaseout of Loran-C, there has been a concerted effort to use GPS technology for tracking and wind speed and direction determination. GPS-based upper-air systems will be in wide use early in the next millennium. 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 and Loran-C are 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 the 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 are 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 than 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 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

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

Surveying

TASK	MINIMUM PERFORMANCE CRITERIA: ACCURACY - 1 SIGMA, POSITION, ABSOLUTE (m)		RELATIVE (cm)		COVERAGE %	AVAILABILITY %	INTERVAL: MEASUREMENT RECORDING (seconds)	SOLUTION FIX	REMARKS
	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 hr	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.

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 deception (e.g., spoofing), interference, intrusion or jamming.
- 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 navigation 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).

DOD must invest in reliable, accurate, self-contained systems that are uniquely tailored to match platform mission requirements. Therefore, the DOD Positioning, Navigation, and Timing (PNT) 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

Service and Defense agencies' PNT requirements are validated in accordance with a Joint Chiefs of Staff instruction. Validated requirements are reflected in the Chairman of the Joint Chiefs of Staff Master Positioning, Navigation, and Timing Plan (CJCS MPNTP). The CJCS MPNTP provides the policy and planning bases for all military PNT requirements, compares requirements to existing technology, identifies performance shortfalls, highlights needed research and development, and provides long-term projection of anticipated capabilities.

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 that 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 C. Estimates of the current numbers of users of Federally provided radionavigation systems are provided in Figure 3-1.

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 navigation 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 for those systems being phased out after augmented GPS SPS is approved as a primary navigation system for domestic en route, terminal, nonprecision approach, and precision approach phases of flight.

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 airspace. Incremental improvements to WAAS will allow the 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), 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 services are presently being provided, 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. Loran-C 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 services are presently provided using VOR, VOR/DME, VORTAC, TACAN, NDB, GPS, or Loran-C. Loran-C and GPS are approved as supplemental systems.

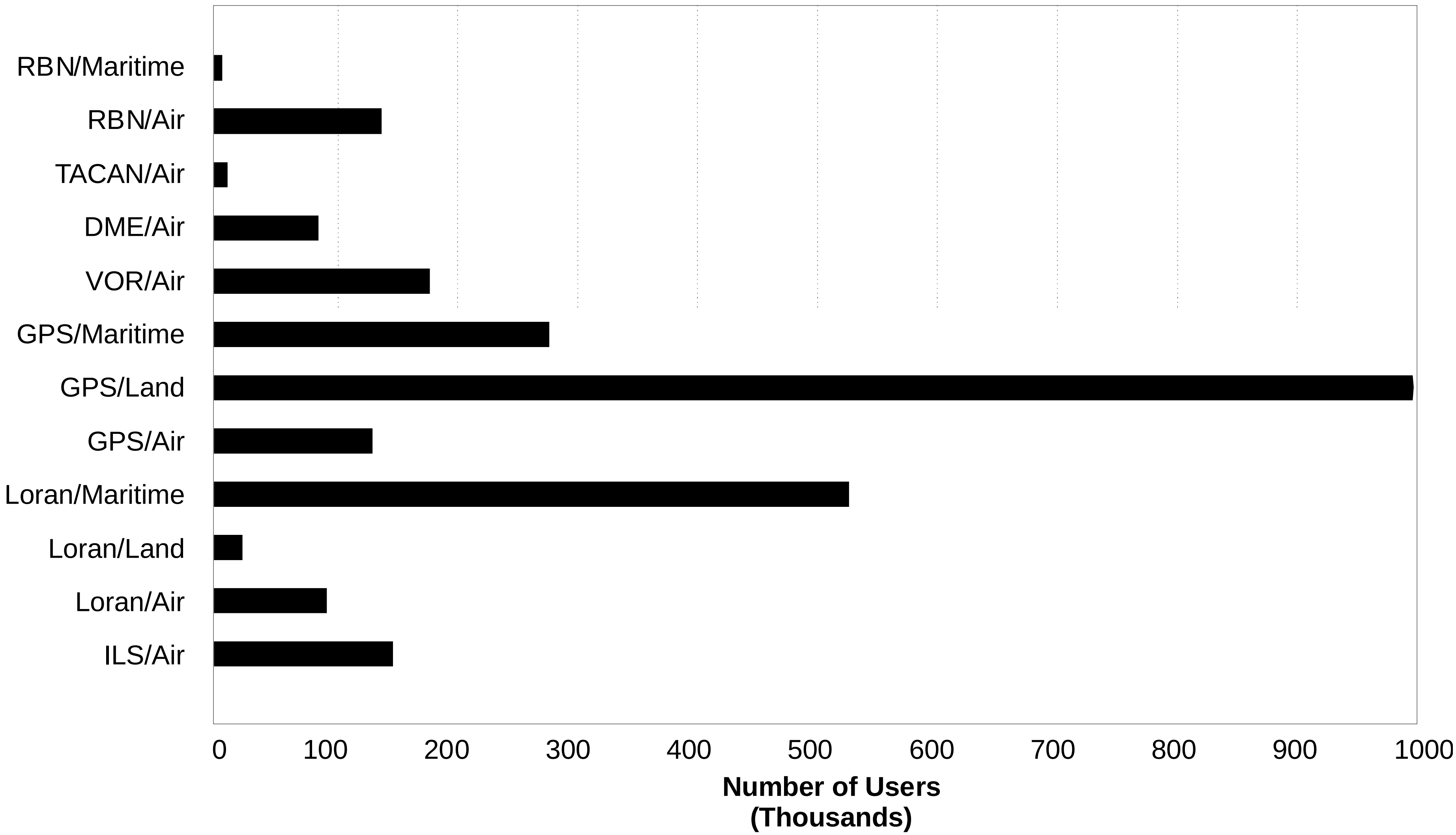


Figure 3-1. Estimated Current U.S. Radionavigation System User Population

Approach and Landing: Nonprecision approach navigation services are presently being provided using ILS localizer, VOR, VOR/DME, VORTAC, TACAN, GPS, or NDB. GPS is approved as a supplemental system. Presently, precision approach and landing requirements are 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 navigation 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 that 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 VTS along with AIS in certain port areas and investigation of the use of radio aids to navigation. DGPS coverage includes all coasts of the continental U.S. and parts of Alaska, Hawaii, and the Great Lakes. The system provides better than 10 meter accuracy.

Coastal Phase: Navigation service for operation within the coastal area is provided by Loran-C, GPS and DGPS. 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 and GPS. GPS is now the system of choice. Worldwide coverage by most ground-based systems such as Loran-C is not practicable.

3.1.3 Space Applications

There are numerous uses of GPS for space navigation; many are discussed in Section 2. Several spacecraft including the ISS, the Space Shuttle, and numerous small satellites 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 Space Shuttle and Reusable Launch Vehicles, for re-entry and landing as well as during orbital operations. The private sector is also implementing the use of GPS in space applications such as low Earth orbiting communication satellites and Earth sensing satellites.

3.1.4 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 is 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 and DGPS as a part of positive train control systems for freight as well as high-speed passenger train operations. GPS 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.

3.1.5 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 determination position, 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 USCG to position floating aids as well as fixed aids to navigation. Additionally, the USACE 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.

3.2 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.

A. User Community

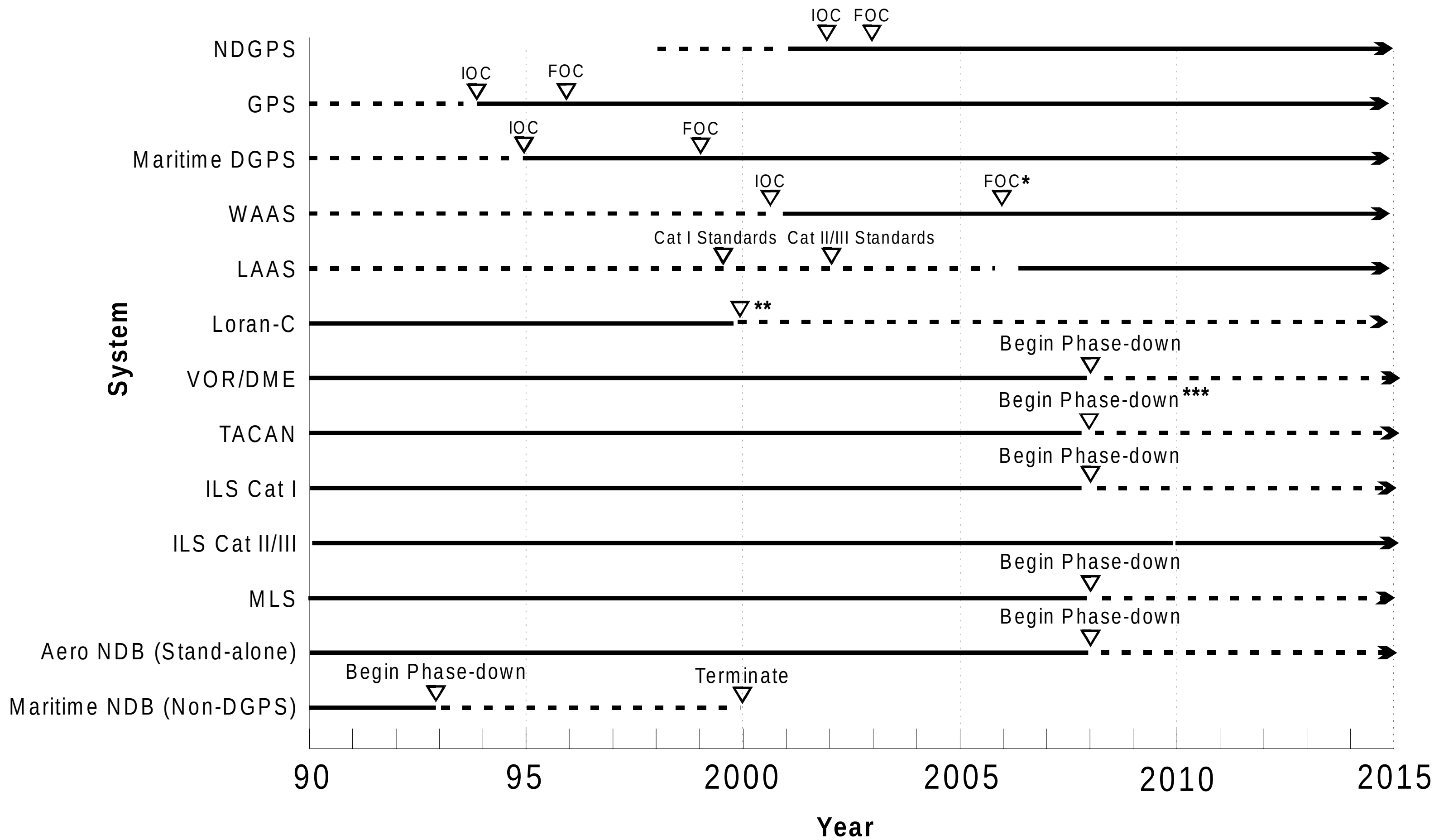
The GPS user community has grown exponentially in the past two years and that growth is expected to continue. Rapid growth has occurred in all modes of transportation. Non-transportation use is also growing at a rapid rate and includes users employed in surveying, farming, resource exploration, and law enforcement. The GPS signal, as defined in the Standard Positioning Service Signal Specification (Ref. 10), is designed to support civil GPS applications. The GPS 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 provided radionavigation system for the foreseeable future. In certain regions of the world, GPS will be augmented to satisfy additional civil requirements for accuracy, coverage, availability, and integrity. The GPS constellation is configured and operated to provide the SPS signals to civil users in accordance with the GPS Standard Positioning Service Signal Specification (Ref. 10). 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 (MCS) 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, other than planned GPS interference testing as described in Section 3.2.3, 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. 10). Unplanned system outages resulting from system malfunctions or unscheduled maintenance will be announced by the NIS and NOTAM systems (see Appendix C) as they become known.



* Projected date based upon achieved system performance.
** Loran-C will continue to operate in the short-term while the Administration continues to evaluate the long-term need for continuation of the system.
*** Unless determined to be necessary for long-term navigation services.
Note: Phase-down dates are targets and may be changed in subsequent editions of the FRP.

Figure 3-2. Radionavigation Systems Operating Plan

The FAA's GPS overlay initiative, which permits use of GPS to fly most existing NPA procedures, was of particular significance in achieving early operational benefits from GPS. The convenience of GPS for executing the thousands of existing VOR-and NDB-based NPAs was made immediately available to suitable equipped aircraft. In addition to "overlay" NPAs, the FAA moved 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. More than 2200 stand-alone GPS approaches have been published. Initial WAAS-based precision approach procedures are due to be published coincident with WAAS achieving its initial operational capability in the year 2000. 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 principal elements of the ICAO GNSS, operate in the 1559-1610 MHz aeronautical radionavigation/satellite navigation service frequency band. This is the sole band that is identified worldwide for the satellite-based aeronautical radionavigation requirements of civil aviation. The GPS L1 SPS ranging signal is a 2.046 MHz null-to-null bandwidth signal centered about 1575.42 MHz. The transmitted ranging signal that compromises the GPS-SPS is not limited to the null-to-null signal and extends through the band 1563.42 to 1587.42 MHz. WAAS, when it becomes operational, will utilize the same band and carrier frequency as GPS L1. Additionally, systems of pseudolites that may share the GPS L1 frequency or operate on an offset frequency have been proposed as an availability 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 1227.60 MHz.

Additional signals are planned to enhance the ability of GPS to support civil users. These signals will assist in the mitigation of ionospheric-delay estimation errors and serve as backups for the GPS L1 link. A second non-safety-of-life civil signal will be added at the GPS L2 frequency (1227.60 MHz), and a third safety-of-life civil signal will be added at 1176.45 MHz.

3.2.2 GPS Modernization

The utility of GPS to support civil and military positioning and timing applications has grown tremendously during the 1990s. From hikers to automotive direction finding, aviation to spacecraft applications, GPS has become an integral part of our information infrastructure. Despite its revolutionary impact on navigation and timing applications, some improvements can make it significantly more useful and reduce the cost of augmentation systems and receiver equipment being designed to enhance and extend the current position and timing service provided by the GPS.

In 1997, the Air Force initiated a review of the capabilities of GPS. In an unprecedented teaming of the Departments of Defense, Transportation, Commerce, Interior, and Agriculture, plus NASA, both military and civil user requirements were collected. Current system shortcomings relative to those requirements were identified, and changes were recommended to improve the GPS service.

The first element of GPS Modernization was the decision to provide a civil signal at the L2 frequency. Civil users will be able to correct for ionospheric errors using a second frequency in addition to the current signal on L1. These corrections, when combined with setting Selective Availability (SA) to zero, will enable user equipment that meets benchmark standards to achieve horizontal accuracies in the 4 meter range. Vice President Gore announced the second civil signal decision on March 30, 1998. In addition, the Vice President announced that there would be a third civil signal for safety-of-life applications implemented on the Block II F satellites. In January 1999, it was announced that the second civil signal would be located at the L2 frequency (1227.60 MHz) and the third civil signal would be located at 1176.45 MHz, which is in an aeronautical radionavigation service protected band.

The GPS Modernization effort focuses on improving position and timing accuracy, availability, integrity monitoring support capability and enhancement to the control system to ensure a robust, highly dependable navigation and timing source for all users. As these system enhancements are introduced, users will be able to continue to use existing receivers, as signal backward compatibility is an absolute requirement for both the military and civil user community. Although current GPS users will be able to operate at the same, or better, levels of performance that they enjoy today, users will need to modify or procure new user equipment in order to take full advantage of any new signal structure enhancements.

GPS modernization will apply the principles of electronic and information warfare to ensure uninterrupted access to the PPS signal by U.S., Allied, and coalition forces. In addition, SA will be replaced with other means to deny hostile exploitation of the GPS service.

3.2.3 Interference Testing Coordination

In order to minimize service disruptions and prevent situations threatening safety or efficient use of GPS, any government agency or activity with a need to perform interference testing (i.e., transmit) in the GPS spectrum must coordinate with the FAA Spectrum Policy and Management Office. The FAA Spectrum Policy and Management Office acts as coordinator for any and all GPS interference testing. Due to guidance in the GPS Presidential Decision Directive (Ref. 2) that requires DOD to “develop measures to prevent hostile use of GPS and its augmentations to ensure that the United States retains a military advantage without unduly disrupting or degrading civilian uses,” the DOD has frequent need to perform interference testing. However, any and all other agencies with interference testing requirements must also coordinate through the FAA.

3.2.4 Augmentations to GPS

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.

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, accidental perturbations of signal timing, and the implementation of 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 corrections) are provided to users. The users then compute corrections in their reduction software. Surveyors and other users who need sub-centimeter to few-centimeter accuracy in positioning from post-processing use two-frequency carrier phase observations from reference stations, rather than range data. The Continuously Operating Reference Stations (CORS) system is designed to meet the needs of both of the above types of these users.

3.2.4.1 Maritime Differential GPS

The USCG Maritime DGPS Service 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 that broadcast pseudo-range corrections using radionavigation radiobeacons. The Maritime DGPS Service 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 USACE has partnered with the USCG 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.

B. Operating Plan

The USCG declared Full Operational Capability (FOC) of the Maritime DGPS Service on March 15, 1999. Necessary steps to include DGPS as a system that meets the carriage requirements of the Navigation Safety Regulations (33 CFR 164), for vessels operating on the navigable waters of the U.S are being undertaken. In addition, the USCG on behalf of the U.S. Government intends to offer the Maritime DGPS Service to the IMO for recognition as a component of the worldwide radionavigation 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 special committee and is using the SC-104 standard for its Maritime DGPS Service.

C. Spectrum

The Maritime DGPS Service operated by the USCG uses fixed GPS reference stations that broadcast GPS pseudorange corrections in the 285-325 kHz maritime radiobeacon band.

3.2.4.2 Nationwide Differential GPS (NDGPS)

A Nationwide DGPS (NDGPS) Service is being established to provide coverage for all areas of the U.S. not currently covered by the USCG Maritime DGPS Service.

This service is being established under the authority of P.L. 105-66 (Ref. 11) and is being implemented under a Memorandum of Agreement among the FRA, FHWA, USCG, OSTDOT, USAF, NOAA, and USACE.

A. User Community

Positive Train Control, Intelligent Transportation Systems, and precision agriculture are expected to receive benefits from the NDGPS Service.

B. Operating Plan

The NDGPS Service is expected to achieve IOC for land applications on December 31, 2002. The IOC phase is identified by the system's ability to provide accuracy, integrity, and single station broadcast coverage of the continental U.S.

The NDGPS Service will achieve FOC when it is capable of meeting the maritime broadcast standards of DGPS (Appendix C, section C.2.2.2) and provides dual coverage of the continental U.S. and selected portions of Hawaii and Alaska with single coverage elsewhere. FOC is expected December 31, 2003.

The service uses RTCM SC-104 standards.

C. Spectrum

NDGPS uses fixed GPS reference stations that broadcast pseudorange corrections in the 285-325 kHz maritime radiobeacon band.

3.2.4.3 Aeronautical GPS Wide Area Augmentation System (WAAS)

The WAAS is a safety-critical system designed primarily for aviation users consisting of the equipment and software that 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 are received and processed at widely dispersed sites, referred to as Wide-area Reference Stations (WRS). These data are 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 these 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 significant 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 that meets the basic requirements, and to enhance the system to meet the full WAAS requirements through a series of contract options.

WAAS is planned to achieve its initial operational capability by the end of 2000, and will provide en route through nonprecision approach service as well as a limited precision approach capability. After achieving initial operational capability, the WAAS will then be incrementally improved over the next six years to expand the area of coverage, increase the availability of precision approaches, increase signal redundancy, and reduce operational restrictions. The result of these incremental improvements will enable pilots equipped exclusively with WAAS avionics to execute all phases of flight in the NAS including Category I precision approach.

C. Spectrum

The WAAS will operate as an overlay on the GPS L1 link in the 1559-1610 MHz ARNS/RNSS frequency band. WAAS reference stations 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.

3.2.4.4 Aeronautical GPS Local Area Augmentation System (LAAS)

A. User Community

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 which require increased availability and at locations where WAAS is unable to provide Category I precision approach services. LAAS may be used to support runway incursion warnings, high-speed turnoffs, missed approaches, departures, vertical takeoffs and surface operations.

B. Operating Plan

The FAA completed the development of Category I LAAS specifications in 1999 and plans to develop prototype systems to validate the ground station specification. There will be a subsequent effort to specify and validate CAT II/III LAAS performance. The FAA is also conducting research on providing airport surface traffic surveillance and guidance based on LAAS-augmented GPS.

C. Spectrum

The international community has evaluated spectral alternatives and has agreed with the FAA that the 108-117.975 MHz ARNS frequency band, currently populated by VORs and ILSs, is the candidate of choice for LAAS. Pseudolites sharing the GPS L1 frequency in a low duty cycle pulsed mode have been proposed as an availability enhancement for CAT II/III LAAS ground facilities.

3.2.4.5 The Continuously Operating Reference Station (CORS) System

The CORS system is a GPS augmentation being established by the 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 November 1998, data were being provided from about 144 stations.

A. User Community

The observational data provided by the CORS system are being used by government, academia, and industry groups to support most of the applications described in section 2.6. Currently, users are downloading about 1.6 gigabytes of data per day. The largest user groups, in terms of number of bytes downloaded, are academic and government research groups involved in geophysical studies of Earth movement. However, the largest numbers 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.

National Geodetic Survey (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 Maritime DGPS Service described in section 3.2.4.1. Stations of the WAAS network (described in section 3.2.4.3 above) will be CORS compatible, as well as the NDGPS stations being established 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.

B. Operating Plan

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 50 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.

C. Spectrum

Not applicable.

3.2.4.6 Vulnerability of GPS in the National Transportation Infrastructure

Appendix G of the Final Report of the President's Commission on Critical Infrastructure Protection was entitled, "Vulnerabilities of the NAVSTAR Global Positioning System and its Augmentations." This report concluded that GPS services and applications are susceptible to various types of interference, and that the effects of these vulnerabilities on civilian applications should be studied in detail. As a result of the report, Presidential Decision Directive 63 gave the Department of Transportation the following directive:

> The Department of Transportation, in consultation with the Department of Defense, shall undertake a thorough evaluation of the vulnerability of the national transportation infrastructure that relies on the Global Positioning System. This evaluation shall include sponsoring an independent, integrated assessment of risks to civilian users of GPS-based systems, with a view to basing decisions on the ultimate architecture of the modernized NAS on these evaluations.

This evaluation will assist the DOT in developing a plan for protecting the national transportation infrastructure. The focus of the study will be on the civilian user of the national transportation infrastructure, although the scope will include other civilian users and applications with appropriate authorities being notified of vulnerabilities as necessary.

DOT is expected to produce a report of current studies, a recommended plan of action for additional studies, a report of vulnerabilities to the national transportation infrastructure relying on GPS, and a recommendation as to priorities of risks and potential mitigation actions. The report is expected in 2000.

Presidential Decision Directive 63 also issued the following directive to the Federal Aviation Administration (FAA):

> The Federal Aviation Administration shall develop and implement a comprehensive National Airspace System Security Program to protect the modernized NAS from information-based and other disruptions and attacks.

Although not mentioned specifically, the security of GPS-reliant systems in the NAS is included. The FAA worked with the Air Transport Association of America (ATA) and the Aircraft Owners and Pilots Association (AOPA) to perform an independent GPS risk assessment. This study assesses the risks associated with the use of GPS and GPS enhanced by the Wide Area Augmentation System (WAAS) and the Local Area Augmentation System (LAAS) as the only navigation system required in aircraft operating within the NAS. The final report was delivered in January 1999. The main conclusions of the study are as follows:

- GPS with appropriate WAAS/LAAS configurations can satisfy navigation performance requirements as the only navigation system installed in the aircraft and the only navigation service provided by the U.S. Federal Government for aviation.
- Risks to GPS signal reception can be managed, but steps must be taken to minimize the effects of intentional interference.
- A definitive national GPS plan and management commitment is needed to establish system improvements with civil aviation users and to provide greater informational access to the civil aviation community.

The final report's findings are being assessed.

3.2.5 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. Loran-C can also be used for precise time interval and highly accurate frequency applications.

A. User Community

Although there is a steady trend towards the use of GPS, there remains a significant number of both maritime and aviation users of the Loran-C system. In addition, telecommunications and weather services use Loran-C as an economical timing device and weather services use it to determine upper air wind speed and direction by determining the change of position of radiosonde flights with time.

B. Operating Plan

While the Administration continues to evaluate the long-term need for continuation of the Loran-C radionavigation system, the Government will operate the Loran-C system in the short term. The U.S. Government will give users reasonable notice if it concludes that Loran-C is not needed or is not cost effective, so that users will have the opportunity to transition to alternative navigation aids. With this continued sustainment of the Loran-C service, users will be able to realize additional benefits. Improvement of GPS time synchronization of the Loran-C chains and the use of digital receivers may support improved accuracy and coverage of the service. Loran-C will continue to provide a supplemental means of navigation. Current Loran-C receivers do not support nonprecision instrument approach operations.

C. Spectrum

Loran-C operates in the 90-110 kHz frequency band.

3.2.6 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 that 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

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. 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 2008. The DOD also operates stations in the U.S. and overseas which 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 2008 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 phase-down of the VOR/DME and TACAN network is expected to begin in 2008.

From today's full coverage network, the phase-down will transition through an interim network and then to a minimum operational network. This phased approach will allow for more efficient transition of airspace routings, encourage user equipage for area navigation, and maintain nonprecision approach alternatives. The minimum operational network will support IFR operations for the busiest airports in the NAS. A further reduction is then planned to the level of a basic backup network. Section 3.3 discusses the transition in more detail.

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 sub-bands of the 960-1215 MHz ARNS band. It shares those sub-bands with TACAN. The frequency 1176.45 MHz has been selected as the third civil frequency (L5) for GPS. Location of GPS L5 in this protected ARNS band meets the needs of critical safety-of-life applications. The DOD's Joint Tactical Information Distribution System/Multi-function Information Distribution System (JTIDS/MIDS) also operates in this band on a non-interference basis. The civil aviation community is investigating potential aeronautical applications of those sub-bands for implementation after DME and TACAN have been partially or completely decommissioned. These potential future applications include:

- Automatic Dependent Surveillance, Broadcast (ADS-B), a function in which aircraft transmit position and altitude data derived from onboard navigation systems.
- Traffic Information Services (TIS), in which processed surveillance data will be reported automatically from ground stations to aircraft in flight.
- 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 ARNS band would be required to support its DME elements.

3.2.7 TACAN

TACAN is a UHF radionavigation system that 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 that are equipped to determine bearing and distance to TACAN. 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 TACANs and the FAA operates 609 TACANs for DOD. Present TACAN coverage ashore will be maintained until phased out in favor of GPS. However, the sea-based function of TACAN cannot be replaced by GPS unless combined with an appropriate data link function (ship to aircraft) with consideration for security, detection, classification, and exploitation threats. The potential to replace TACAN is being studied as a part of the Joint Precision Approach and Landing System (JPALS) program. The requirement for sea-based TACAN will continue until a suitable replacement is operational. 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 continue until 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 phase-down is 2008.

The FAA and DOD are conducting a NAS-wide prioritization review of FAA-operated TACAN facilities based on DOD mission requirements. The objective of the review is to identify and support critical facilities to ensure continued operation of these facilities to meet DOD needs. The prioritization assigns a class category to each facility.

- Class I - Critical, facilities essential for DOD operations. Class I facilities will continue to be maintained and operated with the support of a standby power source. Standby power may be provided by either an engine generator or a four-hour battery system.

- Class II - Non-Critical, facilities required, but not essential, for DOD operations. Class II facilities will continue to be maintained and operated but will not require a standby power source.
- Class III - Facility Not Required for DOD operations. Class III facilities will reduce service by eliminating TACAN azimuth service from operation.

C. Spectrum

TACAN operates in the 960-1027, 1033-1087, and 1093-1215 MHz sub-bands of the 960-1215 MHz ARNS frequency band. It shares those sub-bands with DME. The DOD's JTIDS/MIDS also operates in this band on a non-interference basis. The civil aviation community is investigating potential aeronautical applications of those sub-bands for implementation after DME and TACAN have been partially or completely decommissioned. Possible future applications are noted in Section 3.2.6.

3.2.8 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. ILS also is 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

ILS is a standard civil precision approach system in the U.S. and abroad, and is protected by ICAO agreement to January 1, 2010. The FAA operates 1062 ILS systems in the NAS, of which 99 are Category II or Category III systems. In addition, the DOD operates 165 ILS facilities in the U.S.

For Category I precision approaches, ILS will remain in service together with WAAS to allow users an opportunity to equip with WAAS receivers and to become comfortable with its service. The phase-down of Category I ILS is expected to begin in 2008. For Category II/III precision approaches, new and upgrade requirements will continue to be met with ILS until LAAS systems are available. The FAA does not anticipate phasing out any Category II/III ILS systems prior to 2015.

As the GPS-based precision approach systems (WAAS/LAAS) are integrated into the NAS, and user equipage and acceptance grows, the ILS systems will be phased down. From today's full coverage network the phase-down will transition through an interim network and then to a minimum operational network. This phased approach will encourage user changeover to GPS-based approaches and maintain precision approach alternatives. The minimum operational network will support IFR operations for the busiest airports in the NAS. A further reduction is then planned to the level of a basic backup network. Section 3.3 discusses the transition in more detail.

As the ILS phase-down occurs, non-Federal sponsors may wish to continue their operation of their non-Federal ILS systems. Additionally, non-Federal sponsors may wish to take over operations and maintenance of some systems planned for decommissioning by the FAA.

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 108-117.975 MHz ARNS band with VOR. As noted in Section 3.2.6, 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 sub-band will continue to be needed to operate Category II and III localizers even after Category I ILS has been decommissioned.

ILS glide slope 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 glide slope subsystems even after Category I ILS has been decommissioned.

3.2.9 MLS

MLS applications are limited to precision approach and landing. MLS is easier to cite than ILS and offers higher accuracy and greater flexibility, permitting precision approaches at more airports. MLS provides USAF tactical flexibility due to its ease in siting and adaptability to mobile operations. While there is limited user support for MLS in the U.S., it has continued to be a factor in other countries.

The USAF has implemented MLS capability on its fleet of C-130 aircraft for use with 37 Mobile MLS (MMLS) ground systems. The C-17 fleet is in the process of being equipped with a Multi-Mode Receiver (MMR) with enhanced ILS (radio interference protection), MLS, and GPS/JPALS/LAAS/WAAS growth capabilities. Additional fielding of MLS capability in the USAF will be driven by the extent of international civil and NATO Allied implementation. The U.S. Army and U.S. Navy currently have no plans to implement MLS.

A. User Community

FAA initiated a limited procurement of Category I MLS equipment in 1992. Twenty-nine Category I MLS systems have been installed. The FAA terminated the development of Category II and III MLS equipment based on favorable GPS test results.

B. Operating Plan

The U.S. does not anticipate additional MLS development. The phase-down of MLS is expected to begin in 2008.

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.

3.2.10 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) are providing the navigation and weather broadcast services currently met by NDBs.

A. User Community

All air carriers, 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 decommission stand-alone NDBs starting in 2008. However, 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.

3.2.11 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, that eliminate the Morse tone identifier, maritime 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 $\pm$3 to $\pm$10 degrees. This might be considered a systemic limitation but, in actual use, it is satisfactory for many navigation 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 Maritime 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.

3.3 Phase-Down of Ground-Based Aeronautical Navaids

3.3.1 Transition to Satellite-Based Navigation (Satnav)

The FAA is planning to transition into providing Satnav services based primarily on GPS augmented by the Wide Area Augmentation System (WAAS) and the Local Area Augmentation System (LAAS). As a result of this transition, the number of Federally provided ground-based navigation facilities will be reduced to coincide with a reduction in the need for ground-based navigation services. Transition to a totally new system represents a substantial undertaking—one that will require a major investment of resources by both the FAA and the aircraft owners and operators. Three essential prerequisites must be met for such a massive transition to take place:

- *System Performance:* Through analyses, flight tests, and substantial operational experience, aircraft operators and the FAA must be convinced that the new system meets their requirements for accuracy, integrity, availability, and continuity of service.
- *Operational Benefit:* The aircraft operator must perceive sufficient operational benefit to warrant an investment in the new technology.
- *Transition Period:* The aircraft operators must have sufficient time to recoup their investment in conventional avionics. Although many avionics systems have been used for 15 to 20 years or more, a reasonable compromise must be reached between the FAA's desire for a rapid transition (to avoid further investment in ground-based Navaids) and the aircraft operators' desire to use current avionics as long as possible.

The transition period begins when the capability is established for a pilot to perform navigation procedures throughout the NAS using Satnav as the only means of radionavigation aboard an aircraft. This will occur when WAAS achieves its full operational capability and procedures to use the new capability have been published (i.e., precision and nonprecision Satnav instrument approach procedures). Prior to this, even new aircraft must be equipped with avionics for the conventional ground-based Navaids. The transition period ends when the conventional Navaids have been reduced to the extent that they are unnecessary for routine NAS operations.

The reduction in Federally provided Navaid services can be performed in several distinct steps. This approach would allow the FAA to begin the phaseout gradually, providing users sufficient time to equip with Satnav avionics. A more abrupt transition would be too disruptive to NAS operations and would place too great a burden on the users. The proposed phase-down strategy is depicted in Figure 3-3. The FAA is evaluating alternatives for the future navigation architecture and will update the transition plans as Satnav program milestones are achieved; as the actual performance of Satnav systems is documented; and as users equip with Satnav avionics.

The proposed transition strategy involves a two-step phase-down from the current full coverage network of Navaids to a reduced network that supports a substantial number of currently certified airways, jet routes, and instrument approach procedures. This network, termed the Minimum Operational Network, is a scaled-down version of the current infrastructure of VORs, ILSs, MLSs, and NDBs. The phase-down strategy would provide the FAA and the airspace users with a safe recovery and sustained operations capability in the event of a disruption in Satnav service. A follow-on step to a basic backup network is also depicted in Figure 3-3.

The Navaid phase-down can be initiated after the following conditions have been met:

- WAAS has achieved FOC and has been approved as an only means of radionavigation for a given flight operation (at FOC, WAAS will comply with its end-state requirements, providing a level of availability sufficient to replace existing VOR/DME and NDB facilities, and many Category I ILS facilities).
- Procedures to use the new WAAS capability have been published.
- A majority of the airspace users have equipped with appropriate WAAS avionics.

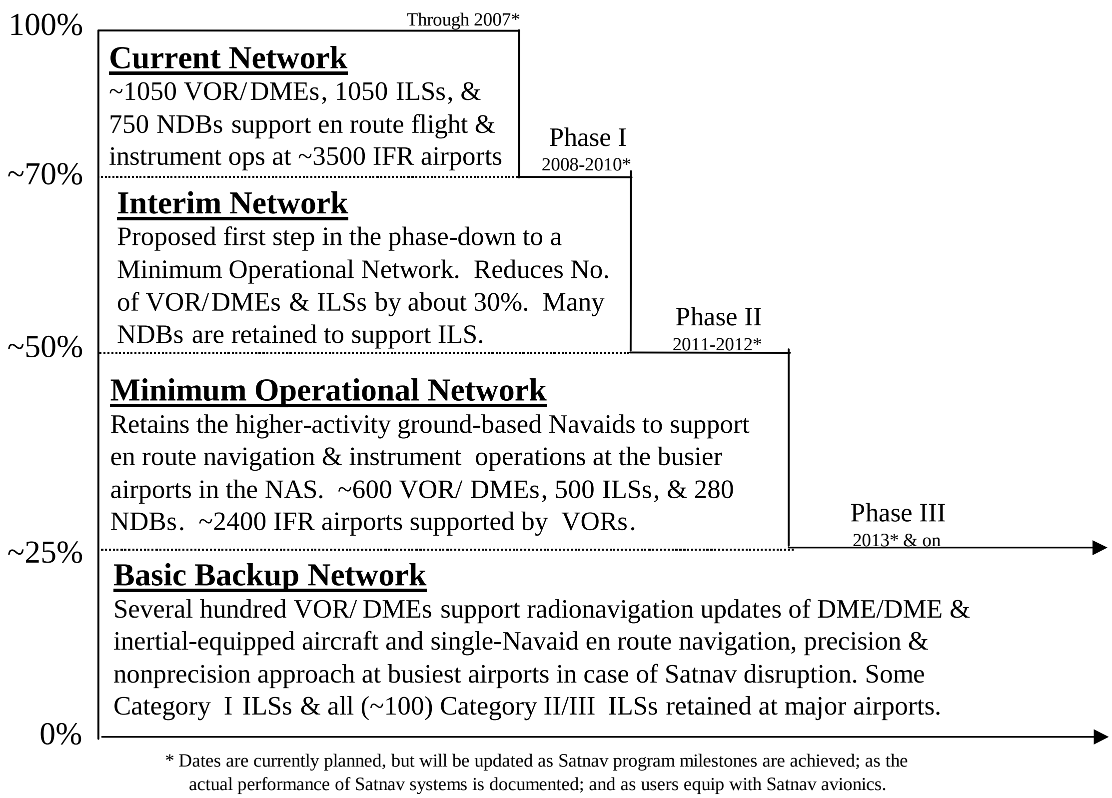


Figure 3-3. Proposed Civil Aeronautical Navaid Phase-Down Steps

The phase-down is planned to begin in 2008 based on projected Satnav program milestones and anticipated user equipage rates.

The specific Navaids that would no longer qualify for Federal support, at each step of the phase-down, would be determined based on specific criteria, currently under development. Navaids supporting en route procedures would be decommissioned. Navaids supporting terminal procedures could be decommissioned or transitioned to a non-Federal sponsor.

The discontinuance criteria would be published as early as possible and well ahead of the phase-down. A site-specific list of Navaids fitting the discontinuance criteria would be published later—perhaps at the time of WAAS FOC. The advanced site-specific notice would afford users the opportunity to plan their transition to Satnav based upon the operational schedule for the specific Navaids they use most often.

- *Phase I* – Many currently under-utilized VORs and ILSs would be discontinued at the first step of the phase-down. Preliminary analysis indicates that approximately 350 VORs and 300 ILSs would no longer qualify for Federal support at this first step. (The population of NDBs would remain essentially intact to support ILS approaches.) Although this represents an approximate 30 percent reduction in the number of Navaids, it would be expected to cause a relatively minor impact on the NAS.

- *Phase II* – The second step, planned to occur in 2011, would further reduce the population of ground-based Navaids to the level of the proposed Minimum Operational Network. The Phase II Navaids are intended to support continued operation in the NAS by those aircraft not yet equipped with Satnav avionics, albeit at a reduced level of efficiency. Although this represents an approximate 50 percent reduction in the number of Federally supported Navaids, the remaining network would continue to support a robust set of IFR operations.

- *Phase III* – Previous plans were to complete the transition to Satnav with the phase-out of all the remaining ground-based Navaids. However, a more conservative approach now planned by the FAA is to step-down to a subset of ground-based Navaids that would continue to support Satnav operations beyond 2012. A candidate "Basic Backup Network" composed of several hundred conventional VOR/DME Navaids would allow aircraft equipped with DME/DME avionics to continue en route navigation using dual-DME position updates. It would also provide a nonprecision instrument approach capability at selected airports. A limited number of Category I ILSs, and virtually all existing Category II/III ILSs, would also be retained to support prevision instrument approaches at major airports.

3.3.2 Satnav as an Only Means of Radionavigation

The FAA's goal is to approve Satnav as the only radionavigation system required to be installed in an aircraft to support operations anywhere in the NAS. The Air Transport Association of America and the Aircraft Owners and Pilots Association conducted a risk assessment of using Satnav technology as an only means of radionavigation in the NAS. The study was conducted by the Johns Hopkins University Applied Physics Lab under the oversight of the RTCA Free Flight Steering Committee and with FAA funding. The final report concluded that GPS with appropriate WAAS/LAAS configurations can satisfy the required navigation performance as the only navigation system installed in the aircraft and the only navigation service provided by the FAA (see Section 3.2.4.6). However, from a service provider perspective, the FAA plans to continue operating a subset of conventional ground-based Navaids for those users choosing to remain equipped with conventional avionics.

There is concern about potential disruptions to Satnav service, primarily due to the relatively weak signals received from the GPS satellites. As one example, the President's Commission on Critical Infrastructure Protection highlighted GPS vulnerability and questioned its use as the only means of radionavigation in the NAS. The predominant concerns relate to a potential loss of service from intentional jamming, unintentional radio frequency interference, or ionospheric scintillation during severe solar storms. Intentional jamming is the most difficult threat to overcome.

- The effects of jamming and unintentional interference are primarily to increase the workload of both the users and the air traffic controllers. Pilots and controllers will work together to assure safety, but a loss of navigation and landing capabilities increases the demand for services. Operational restrictions would likely be necessary in the event of an outage to balance demand and assure safety.

- Solar effects are expected to have only minimal impact on CONUS airspace. The greatest impact is expected in the polar regions and near the equator. Most aircraft operating on polar routes are equipped with inertial systems and can operate for many hours between radionavigation updates before violating separation requirements. Some care will be needed in high-latitude and equatorial zone Satnav-based instrument approaches at night.

A loss of GPS service in the absence of any other means of radionavigation would have varying negative effects on air traffic operations. These effects range from nuisance events requiring standard restoration of capabilities to an inability to provide service within one or more sectors of airspace for a significant period of time.

3.3.3 Mitigation of Potential Satnav Disruptions

Several solutions have been identified to help mitigate the effects of a Satnav service disruption, but each has its limitations.

- The L5 civil frequency planned for GPS will help alleviate the impacts of both solar activity and unintentional interference, but it may be 2013 or later before a full constellation of dual-frequency satellites is available. The cost implications of the L5 civil frequency are not yet defined.

- Modern transport-category turbojet aircraft, when engaged in relatively stable en route flight, may be able to continue navigating safely an hour or more after losing radionavigation position updating. In some cases, this capability may prove adequate to depart an area with localized jamming or proceed under visual flight rules during good visibility and high ceilings. However, inertial performance without radionavigation updates degrades substantially faster on a maneuvering aircraft, and the viability of continued terminal-area navigation is unclear. There is no assurance of compliance with airspace requirements after executing a procedural turn or entering a holding pattern, even in en route airspace.

- Integrated GPS/inertial avionics having significant anti-jam capability could greatly reduce the area affected by a GPS jammer or by unintentional interference. Industry research is proceeding to develop this technology, with an expectation that it might be marketed to the general aviation community. However, significant certification challenges will be encountered, and some users may still find this technology to be unaffordable.

- A basic backup network composed of several hundred conventional VOR/DME Navaids would allow aircraft equipped with DME/DME avionics to continue en route navigation using dual-DME position updates. It would also provide a nonprecision instrument approach capability at selected airports. However, low-altitude users may need to be vectored by air traffic controllers into an area with VOR coverage or to an area in visual meteorological conditions. Additional Navaids (where required) may also be needed for missed approaches and departures where terrain or obstruction clearances must be maintained—particularly in non-radar environments.

- Users may have an option to equip with IFR-certified Loran-C avionics, pending the improvements needed to achieve a nonprecision instrument approach capability with Loran. A combined Loran/Satnav receiver could provide navigation and nonprecision instrument approach service throughout any disruption to Satnav service.

- If a majority of operations are conducted by aircraft equipped with an additional navigation capability (e.g., inertial or Loran), then the balance should be able to be managed with air traffic control vectors based on an independent (radar) surveillance system. Additional research may be necessary to validate this concept in terms of the impact to air traffic controller workload and the sensitivity to the proportion of backup-equipped aircraft.

- An ILS (or MLS) may need to be retained at major airports to provide a backup precision approach capability, and where necessary to support international compatibility. ILSs may also be needed at a few remote airports where the distance to the closest major (ILS-equipped) airports is excessive.

3.3.4 Long-Term Transition Plans

The pace and extent of the transition to Satnav will depend upon a number of factors related to system performance and user acceptance. The FAA plans to reduce ground-based Navaids subject to these factors.

A decision to retain a selected subset of ground-based Navaids to support satellite navigation does not need to be made until well after experience is gained with Satnav technology. Some site-specific Navaids will face the end of their serviceable life before 2010. The need to replace selected Navaids will require investment analysis and investment decisions on what specific Navaids to retain.

The FAA's plans for the transition to Satnav and for the phase-down of ground-based Navaids will be periodically reevaluated. These plans need to remain flexible, and may need to be adjusted as Satnav program milestones are achieved, as the actual performance of Satnav systems is demonstrated, and as users equip with Satnav avionics. The transition plans will continue to be closely coordinated with airspace users and with the FAA's air traffic control community.

3.4 Interoperability of Radionavigation Systems

3.4.1 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 offset 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.

3.4.2 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 Minimum Operation Performance Standard (MOPS) for a combined GPS and GLONASS system. The Airlines Electronic Engineering Committee (AEEC) is developing specifications for a multimode receiver that 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 that could take advantage 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.

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. 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.

DOD R&D activities mainly address evaluations by Armed Forces acquisition agencies that 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.

Although there are some similarities between the DOD and DOT analyses, DOD military missions place more 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.

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 that meet identified civil user requirements.
- DOT will provide DOD with the most current information on civil user requirements that may have a significant impact on DOD-operated radionavigation systems.
- DOD will provide information to DOT on GPS receiver designs that may be applicable to civil receiver development.
- 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 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. Initially, efforts 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, under the direction of the Secretary of Transportation, has the responsibility to operate safe, efficient air navigation services. To accomplish this, the United States must maintain a leadership role in the definition and development of future technologies while maintaining the appropriate standards and practices governing the use of GPS technology by the airlines, general aviation users, avionics manufacturers, and the traveling public.

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, such as LAAS, which 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. The FAA has demonstrated the technical capability of LAAS to support Category II and III operations and is pursuing LAAS to meet the Category II/III precision approach requirements. 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 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 2000.

The FAA is actively participating in the implementation of a seamless global navigation system. In order to provide safe, efficient GNSS to the aviation users at a reduced cost with improved performance, the FAA is actively participating on GNSS panels working toward the final objective of implementation of “Free Flight” initiatives in the United States. The WAAS and LAAS will provide satellite navigation to all aviation users for all phases of flight down to a Category III precision approach. Research efforts for these two systems are broken out as follows:

WAAS R&D Activities:

- Quantify and mitigate both scintillation effects and rapid changes in ionospheric range delay.
- Address the likelihood and potential severity of interference on GPS and SBAS implementations.
- Ensure clock performance for SBAS internal and external interfaces.
- Investigate and define international connectivity requirements.

LAAS R&D Activities:

- Continue research into ground reference receiver multipath and corresponding techniques for mitigation.
- Explore and investigate various availability enhancements as a result of additional ranging sources provided by pseudolites, GLONASS, WAAS, and other satellites being considered for the WAAS payload.
- Investigate LAAS VHF Data Broadcast (VDB) optimization techniques and identify the most optimal signal generation techniques and broadcast format(s).
- Evaluate effects of RF interference on GPS ground reference receivers, and evaluate methods of mitigation.
- Evaluate methods of LAAS ground system integrity monitoring.

The FAA has established a number of grants and interagency agreements. Contracts are also in place with industry, academia, and other government agencies to leverage their expertise and capabilities in satellite navigation research. In addition, a number of cooperative and bilateral agreements are in place to facilitate and promote the international communication and information transfer for a seamless GNSS.

Possibilities exist to develop receiver avionics that 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.

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 transmit position and altitude data derived from onboard systems via a datalink for use by air traffic control, other aircraft, and certain airport surface vehicles. 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 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

The USCG conducted mission needs analysis of DGPS with the following conclusions. DGPS can meet performance requirements to provide all weather navigation capability with a safety level equivalent to visual aids to navigation in most ports and waterways. However, mariners are still required to use all available means of navigation.

The Coast Guard is working to create a vision of marine navigation services for the 21st century. A central issue for the Coast Guard is to devise an evolving system of aids to navigation that safely and effectively accommodates new navigation technologies. The Aid Mix Project will provide the information and tools for this task. One goal of this project is to develop a set of analysis tools to allow performance evaluations of navigation systems in specific ports and waterways. These tools will help assess the relative level of safety expected from radio aids, navigation equipment, and short range aids to navigation intended to be used for harbor entrance and approach.

In addition, the USCG is exploring accuracy enhancement and the integration of DGPS with other navigation sensors. Particular emphasis is being placed upon the integration of DGPS with Inertial Navigation Systems (INS). Ongoing efforts are being conducted to determine the ability to INS to enhance DGPS/GPS navigation service, and to provide heading information for Electronic Chart Display Information System (ECDIS) use. Work with RTCM Special Committee 104 (SC104) in developing new high accuracy messages, including ones optimized for use with SA off, is being conducted. This work includes the development of corrections for ranging signals broadcast from geo-stationary satellites. Also, several promising improvements to the DGPS data link hold the potential to further mitigate the effects of impulse noise and interference and are being studied.

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 CORS standards developed by the 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. Implementation of the NDGPS began in 1997 with the installation of the proof of concept site in Appleton, WA. NDGPS implementation is expected to take five years with a target completion date of December 31, 2003.

In its first report, the NDGPS PIT revalidated the 1994 augmentation study and developed cost summaries for the full implementation. Implementation of the NDGPS service began in 1998 with the installation sites in Whitney, NE, Savannah, GA, and Chico, CA. Full implementation is expected to take 3-4 years with a target date of December 31, 2003.

Several agencies are already evaluating GPS and the new NDGPS for specific applications. For example, 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. 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 Transportation Systems Projects, January 1998* (Ref. 12). 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 (AVL) 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 is replacing Loran-C for vehicle location.

Dallas Area Rapid Transit (DART) has installed an Integrated Radio System that includes AVL. 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 were 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, 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.

Several railroads and state governments and FRA are participating in and supporting several positive train control projects that use GPS and NDGPS for position and speed determination. Shown in Table 4-1, these projects are aimed at the development of safer, lower cost control systems for both freight and passenger train operations.

Table 4-1. Current Positive Train Control Projects Using GPS

Project	Sponsors	Location
Incremental Train Control System	Michigan DOT Amtrak FRA Harmon Electronics	Kalamazoo – New Buffalo, MI
Positive Train Control	Illinois DOT Association of American Railroads FRA	Springfield – Mazonia, IL
Precision Train Control	Alaska Railroad FRA GE-Harris	Seward – Anchorage – Fairbanks, AK
Communications-Based Train Management	CSX Wabco	Spartanburg, SC – Augusta, GA
Train Guard	Burlington Northern Santa Fe Railway Wabco	Los Angeles – Barstow, CA

4.3 NASA R&D

NASA is conducting R&D in a number of 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. Initial work in this area indicates that significant improvements will be achieved in real-time determination of satellite position through improved GPS satellite signal visibility as well as improved integrity protection for satellite users.

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.

In addition, there is promising research being conducted in the use of spaceborne GPS receivers as scientific instruments for atmospheric research. This research involves the use of dual frequency GPS receivers to measure the occultation of the GPS satellite radio signals through the atmosphere. This research could lead to an important new instrument for use in weather forecasting.

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 International GPS Service for Geodynamics (IGS). Areas of research include continued enhancement of the software used to determine GPS 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 GPS 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.

Joint Precision Approach and Landing System

The DOD has established the JPALS program to provide its next generation precision approach and landing system capability. JPALS provides for U.S. forces to perform assigned conventional and special operations missions from fixed base, tactical, shipboard, and special mission environments under a wide range of meteorological conditions. No existing system satisfies the mission need for worldwide deployment and interoperability among the Services and Civil Reserve Air Fleet (CRAF). Interoperability with the national and international civil precision approach systems (such as the FAA's WAAS and LAAS) is also driving the need for JPALS.

The DOD has designated the Air Force as the lead service for JPALS. The October 1997 Analysis of Alternatives (AoA) recommended the most promising alternative in the land based environments (and in conjunction with the Automatic Carrier Landing System in the shipboard environment). In addition, the AoA identified several critical risk areas requiring further research and development. On 14 Sep 98, the Under Secretary of Defense for Acquisition and Technology (USD (A&T)) formally approved the JPALS program to enter a three-year Architecture and Requirements Development (ARD) phase. In this phase, LDGPS and ACLS systems will be prototyped and tested, and analyses and programmatic assessments conducted, in order to meet the following four objectives:

- Provide sufficient evidence that key technical risks have been reduced, including the areas of 1) guidance quality, 2) signal-in-space availability, 3) transportability, 4) set-up time and personnel, 5) probability of detection, classification, and exploitation, 6) vulnerability to signal disruption/spoofing, 7) shipboard compatibility, and 8) standardization, interoperability, and commonality. A key risk area identified in the JPALS AoA is the compatibility of JPALS with GPS anti-jamming enhancements such as those developed under the NAVWAR program.

- Define the JPALS technical architecture. The architecture must be supported by a set of standards and technical documentation (e.g., specifications) and risk assessments that provide sufficient evidence that risks associated with meeting the critical performance parameters have been reduced or mitigated.

- Synchronize JPALS with other programs such as the FAA's WAAS and LAAS, the GPS JPO NAVWAR program, the Army Navy, and Marine Corps Communications, Navigation and Surveillance/Air Traffic Management (CNS/ATM) efforts and the Air Force Global Air Traffic Management (GATM) effort.

- Provide data to support the milestone decision, including an acquisition strategy for the development, integration, installation and production of JPALS systems.

One implementation of JPALS that provides for maximum interoperability is the multi-mode receiver (MMR). Initially developed to provide both MLS and ILS capabilities, the USAF successfully demonstrated the insertion of a GPS card in the production MMR. In 1995, the prototype MMR successfully conducted numerous approaches against a prototype SCAT-I landing system with CAT I or better accuracy. The multi-mode solution is planned for expansion to include WAAS, LAAS, and the P/Y-code LDGPS capability as developed in the JPALS R&D program.

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.

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

U.S. Government Agency Radionavigation Roles and Responsibilities

This appendix outlines the roles and responsibilities of the Government agencies involved in planning for and providing radionavigation services.

The Department of Transportation (DOT) is responsible under Title 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 three elements within DOT that operate radionavigation systems are the United States Coast Guard (USCG), the Federal Aviation Administration (FAA), and the St. Lawrence Seaway Development Corporation (SLSDC). 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 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). Other Federal agencies that participate in radionavigation planning include the National Aeronautics and Space Administration (NASA), and the National Geodetic Survey (NGS).

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

The DOD is also required by statute 10 U.S.C. 2281(c) (Ref. 1) to provide for the sustainment and operation of the GPS Standard Positioning Service for peaceful civil, commercial, and scientific uses on a continuous worldwide basis free of direct user fees.

A.1 DOD Responsibilities

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 allies.

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

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

l. 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.

m. 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.

n. Ensure that the United States Armed Forces have the capability to use GPS effectively despite hostile attempts to prevent use of the system.

The National Imagery and Mapping Agency (NIMA) is responsible for mapping, charting, and geodesy (MC&G) support to DOD navigation systems which includes charts, digital terrain elevation data, digital feature analysis data, digital hydrographic chart data, point-positioning databases, geodetic surveys, and the World Geodetic System 1984 (WGS 84). This support also includes geodetic positioning of transmitters for electronic systems and tracking stations for satellite systems, maintenance of GPS fixed site operations, and generation and distribution of GPS precise ephemerides. Within DOD, NIMA acts as the primary point of contact with the civil community on matters relating to geodetic uses of navigation systems and provides calibration support for certain airborne navigation systems. Unclassified data prepared by 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 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 A-1. Figure A-1 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 Positioning, Navigation and Timing Plan (MPNTP) and other DOD documents.

A.1.1 Operational Management

The President or the Secretary of Defense, with the approval of the President, is the National Command Authority. The Chairman, Joint Chiefs of Staff, supported by the Joint Staff, is the primary military advisor to the National Command Authority. 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 MPNTP.

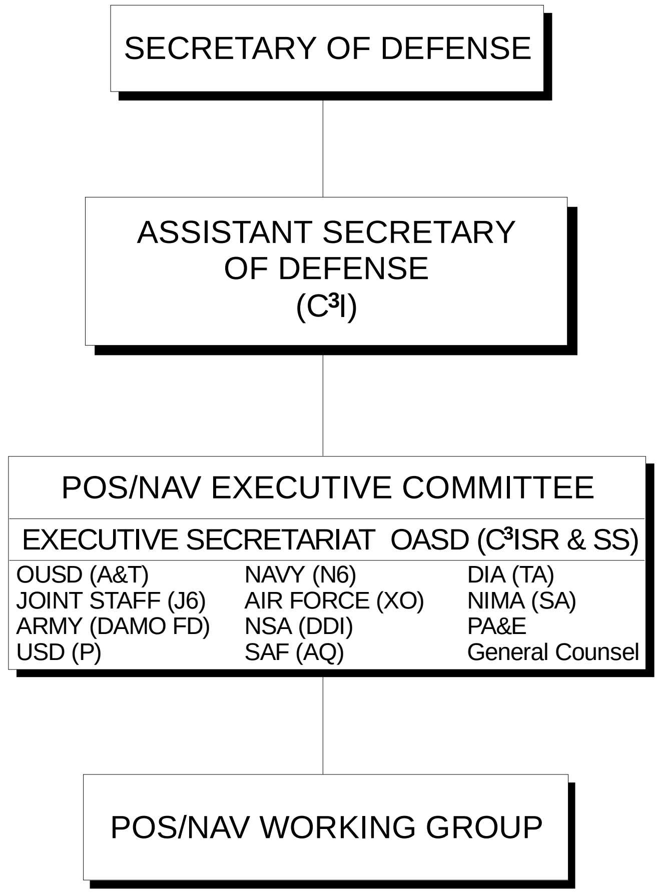


Figure A-1. DOD Navigation Management Structure

The MPNTP is the official positioning, navigation, and timing policy and planning document of the CJCS, 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 MPNTP.

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 MPNTP.

A.1.2 Administrative Management

Three permanent organizations provide radionavigation planning and management support to the Assistant Secretary of Defense (C3I). 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 MPNTP 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.

A.2 DOT Responsibilities

Specific DOT responsibilities are to:

a. Provide aids to navigation used by the civil community and certain systems used by the military.

b. Prepare and promulgate radionavigation plans in the civilian sector of the United States.

c. Serve as the lead agency within the U.S. Government for all Federal civil GPS matters,

d. Develop and implement U.S. Government augmentations to the basic GPS for transportation applications,

e. 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

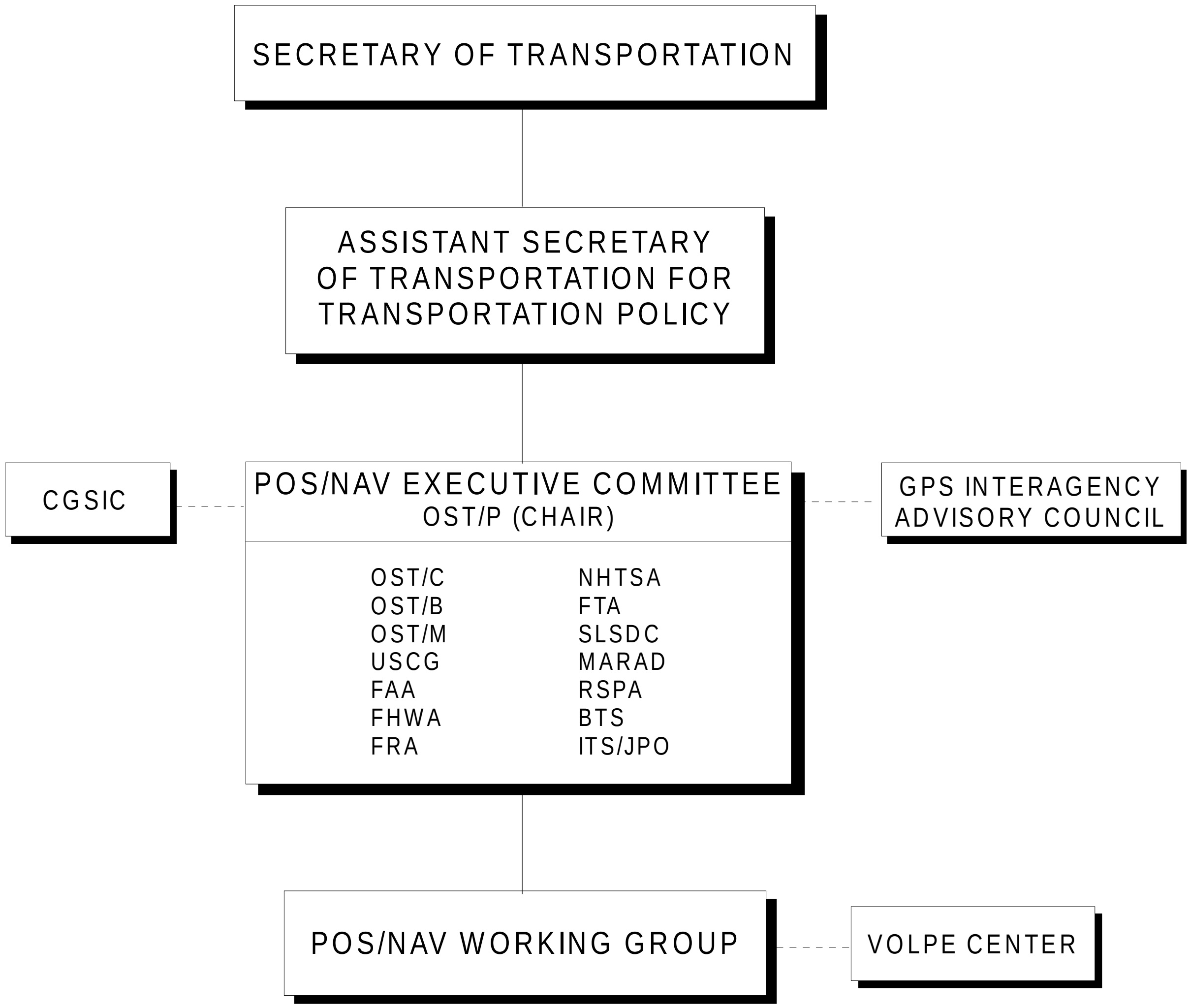


Figure A-2. DOT Navigation Management Structure

f. Coordinate U.S. Government-provided GPS civil augmentation systems to minimize cost and duplication of effort.

DOT carries out its responsibilities for civil radionavigation systems planning through the internal management structure shown in Figure A-2. The structure was originally established by DOT Order 1120.32 (April 27, 1979) and revised by DOT Order 1120.32C (October 11, 1994) to:

a. 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.

b. 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.

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

d. Provide a DOT focal point for multimodal or inter-departmental navigation and positioning issues.

e. Provide liaison with DOD.

f. 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. Non-transportation Federal civil users of GPS are represented in the POS/NAV Executive Committee by the GPS Interagency Advisory Council (GIAC). The Civil GPS Service Interface Committee (CGSIC), chaired by OST/P, is DOT's official committee for information exchange with all GPS users.

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 Secretary of Transportation, under 49 U.S.C. Section 301, has overall leadership responsibility for navigation 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.

DOT's Civil GPS Service Interface Committee is an outreach to the user, and facilitates the exchange of issues and requirements between DOT and the GPS user, in the U.S. and internationally. The Coast Guard manages the operations of the Committee for DOT.

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 that 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.

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

MARAD investigates the application of advanced technologies for navigation, as well as the training of shipboard crews in all aspects of ship operations. These efforts are intended to enhance the efficiency and safety of ship operations in U.S. waters.

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 navigation satellite systems for civil aircraft, ship, and spacecraft navigation and position determination.

A.3 DOD/DOT Joint Responsibilities

A Memorandum of Agreement (MOA) between DOD and DOT provides for radionavigation planning. 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.

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 navigation 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 the FRP to be implemented by internal departmental actions. This plan will be reviewed and updated biennially.
- Assure that other government agencies involved in radionavigation and positioning systems research, development, operation, or use are aware of and, where appropriate, are included in system planning and implementation.
- Coordinate on polices and procedures for in-band GPS testing activities.
- Chair the Interagency GPS Executive Board as directed by the Presidential Decision Directive on GPS, NSTC-6, signed March 28, 1996 (Ref. 2).
- Prepare standard definitions of requirements, and joint requirements documents for dual use systems.

- Convene joint meetings of the DOD and DOT POS/NAV Working Groups as necessary.

- Form a joint modeling and simulation effort to facilitate the coordination of radionavigation and positioning systems planning. This joint effort may include analysis of both civil and military radionavigation systems and the elimination of the potential for interference from other systems. One example is the Joint Tactical Information Distribution System (JTIDS) that currently operates in the radionavigation spectrum.* The objective is for DOD and DOT to agree upon and use a common set of analytical tools for assessing systems interactions.

A.4 Department of State Responsibilities

The PDD (Ref. 2) 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.

* The Interdepartmental Radio Advisory Committee (IRAC) Spectrum Planning Subcommittee (SPS) Working Group 1 is responsible for meeting these objectives.

Appendix B

Radionavigation Systems Selection Considerations

B.1 Background and Approach

Many factors are considered in determining the optimum mix of Federally provided radionavigation systems. These factors include: 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 also must be considered. 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 different requirements. This resulted in the proliferation 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, an updated recommendation on the future mix of radionavigation systems would be issued with each edition of the FRP. The 1999 recommendation reflects policy direction from the PDD (Ref. 2), 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 solicit and consider inputs from users of radionavigation systems in the decision-making process on radionavigation systems. Developments in GPS augmentations and the changing user needs 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.

When the need or economic justification for a particular system appears to be diminishing, the Department operating the system will notify the appropriate Federal agencies and the public, by publishing the proposed discontinuance of service in the Federal Register.

In the final analysis, 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.

B.2 Operational 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.
- Resistance 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.
- Availability 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.

B.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

B.4 Economic Considerations

At the present time, there are several systems being operated by FAA, USCG, DOD and others. The Government must continually review the costs and benefits of the navigation systems it provides. 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. 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.

In many instances aids to air navigation that do not economically qualify for ownership and operation by the Federal Government are needed by private, corporate, or state organizations. While these non-Federally owned/operated (non-Fed) systems do not provide sufficient economic benefit on a national scale, they may provide significant economic benefit to local economies. In most cases they are also available for public use. The FAA regulates and inspects the facilities in accordance with Federal Aviation Regulations, Part 171, and FAA directives.

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.

B.5 Institutional Considerations

The PDD supports 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

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. The amount of use of present Federal radionavigation services by individual users or groups of users cannot be easily measured; therefore, it would be difficult to apportion 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 user 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. In the case of GPS, the PDD has stipulated that there will be no direct user fees for GPS SPS.

Currently, 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 war or threat to national security.

C. Role of the Private Sector

Radionavigation systems have historically been provided by the Government to support safety, security, and commerce. These services have supported air, land and marine navigation and time or frequency-based services. For certain applications such as landing, positioning, and surveying, in areas where Federal systems are not economically justified, a number of privately operated systems are available to the user as an alternative or adjunct service.

Air navigation facilities, owned and operated by non-Federal service providers, are regulated by the FAA under Title 14 Part 171 of the Code of Federal Regulations (CFRs) "Non-Federal Navigation Facilities." Approximately 2000 non-Federal air navigation facilities provide air navigation services in the NAS. These include ILS, MLS, VOR, DME, NDB, Simplified Direction Finder (SDF), Transponder Landing System (TLS), special Category I differential GPS (SCAT-I DGPS), and Automated Weather Observing System (AWOS) facilities. Non-Federal facility sponsors may be states, municipalities, airport authorities, airlines, companies, etc. Local benefit, like local economic development or increased business commerce, may justify the cost of installing and operating an air navigation facility even though the benefit accrued at the Federal level does not. A non-Federal sponsor may coordinate with the FAA to acquire, install and turn an air navigation facility over to the FAA for maintenance because waiting for a Federally provided facility would cost too much in lost business opportunity. Non-Federal facilities are operated and maintained to the same standards as Federally operated facilities under an Operations and Maintenance Manual agreement with the FAA. This program includes annual ground and flight inspections of the facility to ensure that it continues to be operated in accordance with this agreement. When the facility is available for public use, ground and flight inspections are provided without compensation, but reimbursement of these expenses must be sought if the facility only supports private operations.

The number of non-Federal services provided may increase as air navigation facilities lose eligibility for continued Federal subsidy. This occurs when the benefit accrued at the Federal level is lower than the cost of continuing to provide the service. The local benefit may be greater, however, prompting a non-Federal sponsor to assume the role of continuing to provide this service. For example, the FAA's predecessor, the Civil Aviation Authority (CAA), acquired almost 2,500 airway light beacons from 1926 through the late 1950s. Although the FAA dismantled the system with the replacement of radio ranges with VOR/DME and VORTAC, the state of Montana still owns and operates 17 of the Federally acquired visual airway beacons.

Commercial development of air navigation facilities is filling an increasing role in meeting both Federal and non-Federal service provider needs. A number of factors have converged to make privately funded commercial development attractive. The end of the "cold war" has opened up rapidly growing markets for air transportation services throughout the world. This has increased the market opportunities outside the United States. Commercial components have replaced military components, so the Federal version and the commercial version of the air navigation facility are identical. New development efforts have been privately funded to support non-standard facility types. Commercial development of standard type facilities (NDB, DME, ILS, then portable ILS receiver (PIR)) preceded Federal acquisition. Differential GPS systems were commercially developed to support Special Category I (SCAT-I) procedures. With the development of International Civil Aviation Organization (ICAO) standards for LAAS, a commercial development of Category I LAAS is proceeding the public/private partnership funded Category II/III LAAS development program. The Transponder Landing System (TLS) was privately developed to support Category I operations, without aircraft modifications, authorized under a Special Category I procedure.

A number of factors need to be considered when examining private sector involvement in the provision of air navigation services:

- Consideration of phase-over to private operation as a viable alternative to phaseout of a Federally operated radionavigation service.

- Private sector development of air navigation facilities for both non-Federal and Federal use.
- Impact of privately operated services on usage and demand for Federally operated services.
- Need for a Federally provided safety of navigation service even if commercially provided services are available.
- Liability considerations for the developer, service provider, and user.
- Radio frequency spectrum issues.
- Certification of the equipment, service, service provider, operator, and controller.

B.6 International Considerations

Radionavigation services and systems consider the standards and guidelines of international groups, including NATO and other allies, ICAO, the International Telecommunications Union (ITU), and the International Maritime Organization (IMO).

The goals of performance, standardization, and cost minimization of user equipment influence the search for an international consensus on a selection of radionavigation systems. The ICAO establishes standards for internationally used civil aviation radionavigation systems. The IMO plays a similar role for the international maritime community. 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.

In planning U.S. radionavigation systems, consideration is also given to the possible future use of internationally shared systems. 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 operational, 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 under the auspices of the Department of State will be required to resolve the issues.

Department of State responsibilities for international cooperation on GPS are discussed in Section A.4.

B.7 Radio Frequency Spectrum Considerations

Radionavigation services are major users of the radio frequency spectrum in the United States and worldwide. 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 that support the Federal radionavigation systems planning process. Spectrum policy for DOT is coordinated through OST.

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 navigation system is electromagnetic compatibility analysis, which helps determine its operational criteria and protection limits (e.g., power, channel spacing, spurious emissions, and total bandwidth).

The FAA, DOD, 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 used within the National Airspace System (NAS). This exclusively allocated 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), Loran-C (90-110 kHz), maritime radiobeacons (285-325 kHz).

The White House Commission on Aviation Safety and Security recognized the importance of radio spectrum to our Nation's air traffic control system when it directed the FAA to develop a plan to ensure that, "the FAA's spectrum needs during modernization are not compromised." In response, the FAA conducted a broad study, and released its final report on February 12, 1997 (Ref. 13). This report provides information on aeronautical radio systems and frequency bands, existing and predicated problems concerning them, and details a frequency plan, which can support these emerging aviation technologies and architectures.

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.

Appendix C

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
- VOR, VOR/DME, and TACAN
- ILS
- MLS
- Aeronautical Nondirectional Beacons
- Maritime Radiobeacons

C.1 System Parameters

All of the systems described are defined in terms of system parameters that 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

C.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 navigation information.

C.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 that 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 D 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.

C.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 navigation 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.

C.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.

C.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.

C.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.

C.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 navigation signals is also included.

C.1.8 System Capacity

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

C.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.

C.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.

C.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 C.1. All of the systems used for civil navigation are discussed. The systems that are used exclusively to meet the special applications of DOD are discussed in the CJCS MPNTP.

C.2.1 GPS

GPS is a space-based dual use military/civil radionavigation system that is operated for the Government of the United States by the U.S. Air Force. The U.S. Government provides two levels of GPS service. 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 GPS Control Segment has five monitor stations and four dedicated 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 C-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 ranging signal received by the user is a 2.046 MHz null-to-null bandwidth signal centered about L1. The transmitted ranging signal that comprises the GPS-SPS is not limited to the null-to-null signal and extends through the band 1563.42 to 1587.42 MHz. The minimum SPS received power is specified as -160.0 dBW. The navigation data contained in the signal are composed of satellite clock and ephemeris data for the transmitting satellite plus GPS constellation almanac data, GPS to UTC (USNO) 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 are sent 25 separate times so they repeat every 30 seconds. As long as a satellite indicates a healthy status, a receiver can continue to operate using these data for the validity period

Table C-1. GPS/SPS Characteristics (Signal-in-Space)

SPS ACCURACY (METERS) 95%*			SERVICE		SERVICE	FIX	FIX	SYSTEM	AMBIGUITY
PREDICTABLE	REPEATABLE	RELATIVE***	AVAILABILITY*	COVERAGE*	RELIABILITY**	RATE	DIMENSION	CAPACITY	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

** Accuracy, availability, and coverage percentages are computed using 24 hour measurement intervals. Accuracy is the average for any point on the globe. Availability and coverage are global averages. Use 99.16% and 96.90%, respectively, for availability and coverage when computing percentages for worst-case point on globe.*

*** 500 meter not to exceed predictable horizontal error reliability threshold. Reliability measurement interval is one year, averaged from daily values over the globe. Use 99.79% when daily averages are computed from the worst-case point on the globe.*

**** Receivers using the same satellites with position solutions computed at approximately the same time.*

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 are encrypted and not available for private civil use. For more detail, refer to Ref. 10.

of the data (up to 4 or 6 hours). The receiver will update these data whenever the satellite and ephemeris information are 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 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 99.90 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 is 99.97 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. Receiver Autonomous Integrity Monitoring (RAIM), a receiver algorithm, is one method to satisfy integrity requirements.

C.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, accidental perturbations of signal timing, or other factors.

The basic GPS must be augmented to meet current civil aviation, land and marine integrity requirements. DGPS is one method to satisfy 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 ranging measurements 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 navigation 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 and computes corrections based on its measurements and geodetic position. These corrections are then broadcast to GPS users to improve their navigation solution. A well-developed methods of handling this is by 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 commonly used method is an all-in-view receiver at the reference site that 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 USCG Maritime DGPS Service, the Nationwide DGPS (NDGPS) service, and the FAA LAAS.

The above 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 accuracy within a few centimeters accuracy or employ post processing to achieve accuracies within a few decimeters to a few meters, 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 sub-centimeter to a 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 are 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 numbers of 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 that 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 sub-decimeter 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.

C.2.2.1 Maritime DGPS

Figure C-1 shows the maritime DGPS architecture using pseudorange corrections. The reference station's and other 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.

A. Signal Characteristics

The datalinks for DGPS corrections are broadcast sites transmitting between 285 and 325 kHz using MSK modulation. 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 Maritime DGPS Service operated by the USCG does not use data encryption. The characteristics of the Maritime DGPS Service are summarized in Table C-2.

B. Accuracy

The predictable accuracy of the Maritime DGPS Service within all established coverage areas is better than 10 meters (2 drms). The Maritime DGPS Service accuracy at each broadcast site is carefully controlled and is typically better than 1 meter. Achievable accuracy degrades at an approximate rate of 1 meter for each 150 km distance from the

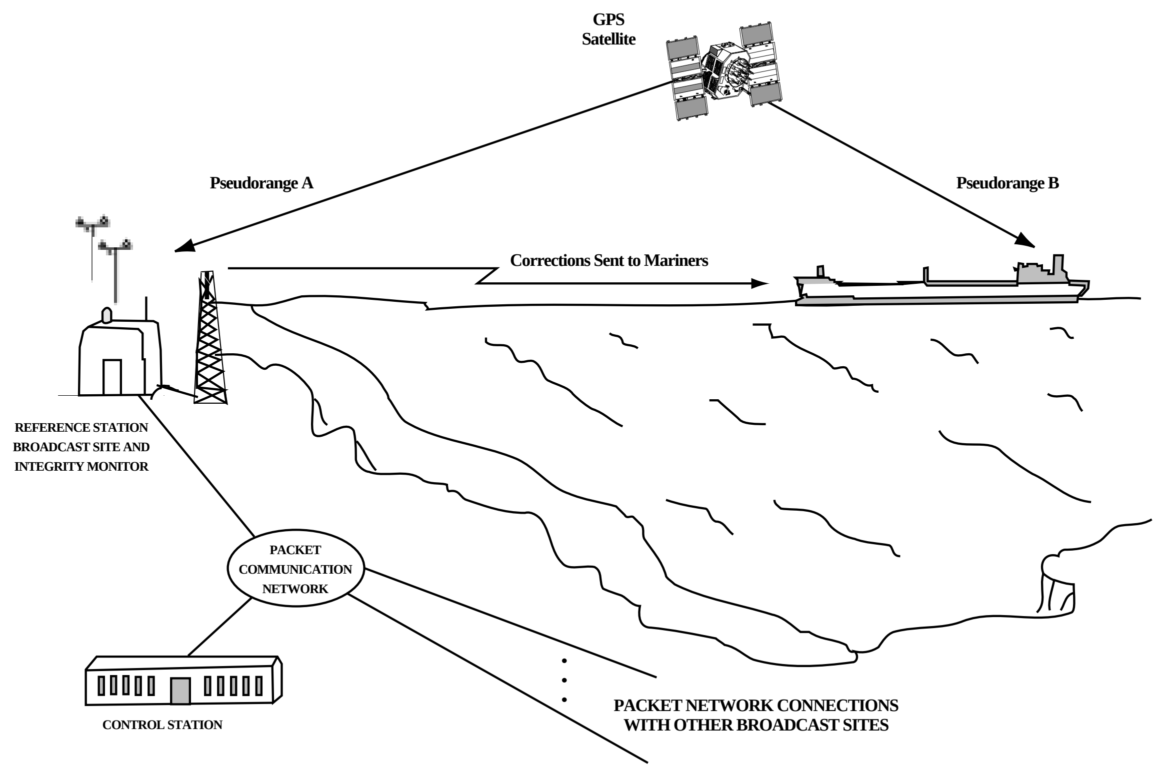


Figure C-1. Maritime DGPS Navigation Service

Table C-2. Maritime DGPS Service Characteristics (Signal-in-Space)

ACCURACY (2drms)	AVAILABILITY (%)	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL	INTEGRITY
<10 meters	99.9 selected areas 99.7 all other areas	U.S. coastal areas, selected areas of HI, AK, PR and major inland rivers	< 500 outages/1,000,000 hours	1-20 per second	3D	Unlimited	None	On-site integrity monitor and 24-hour DGPS control center

SYSTEM DESCRIPTION: The Maritime DGPS Service is a medium frequency beacon-based augmentation to GPS. The Maritime DGPS Service operated by the USCG consists of two control stations and more than 55 remote broadcast sites. The DGPS service broadcasts correction signals on marine radiobeacon frequencies to improve accuracy and integrity of the Global Positioning System.

broadcast site. Accuracy is further degraded by computational and other uncertainties in user equipment and the ability of user equipment to compensate for other error sources such as multipath and propagation distortions. A broadcast site accuracy of 1 meter should allow typical user equipment to achieve the stated 10-meter accuracy in all established coverage areas when the various factors that degrade accuracy are considered. High-end user equipment may achieve accuracies better than 3 meters by compensating for the various degrading factors.

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 C-2 shows the approximate coverage of the Maritime DGPS Service operated by USCG. In accordance with the USCG's DGPS Broadcast Standard (COMDTINST M16577.1), the Maritime DGPS Service is designed to provide complete coastal DGPS coverage (to a minimum range of 20 nm from shore) of the continental U.S., selected portions of Hawaii, Alaska, and Puerto Rico, and inland coverage of the major inland rivers.

E. Reliability

The number of outages per site will be less than 500 in one million hours of operation.

F. Fix Rate

USCG DGPS Broadcast sites transmit a set of data every 2.5 seconds or better. Each set of data points includes both pseudorange and range rate corrections that permit a virtually continuous position update, but the need for receiver processing results in typical user fix rates of 1-20 per second.

G. Fix Dimensions

Through the application of pseudorange corrections, maritime DGPS provides three-dimensional positioning.

H. System Capacity

Unlimited.

I. Ambiguity

None.

J. Integrity

Integrity of the Maritime DGPS Service operated by the USCG is provided through an integrity monitor at each broadcast site. Each broadcast site is remotely monitored and controlled 24 hours a day from a DGPS control center. Users will be notified of an out-of-tolerance condition within 6 seconds.

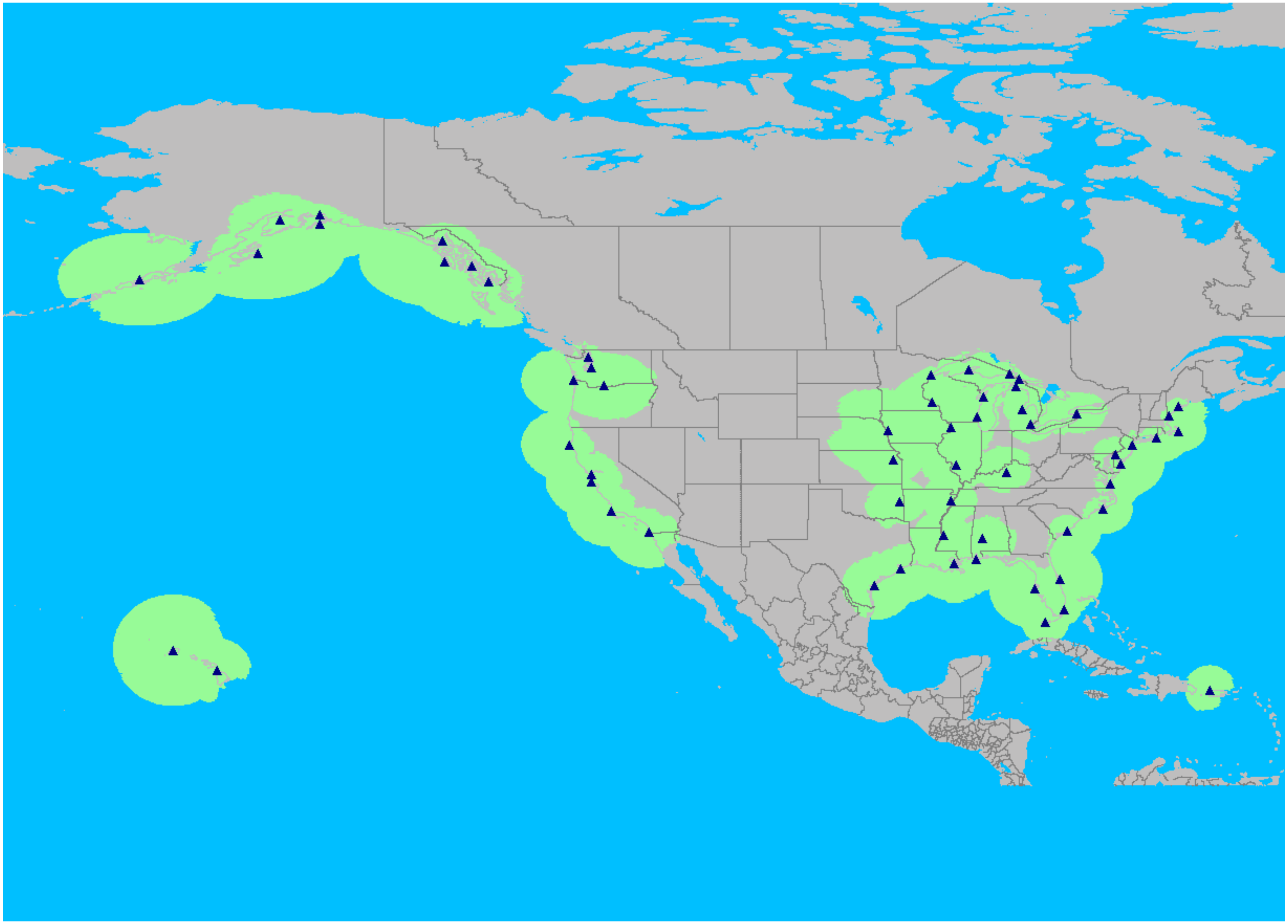


Figure C-2. U.S. Maritime DGPS Service Coverage

In addition to providing a highly accurate navigation signal, maritime 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 Maritime DGPS Service can often extend the use of unhealthy GPS satellites by providing accurate corrections, or will direct the navigator to ignore an erroneous GPS signal.

C.2.2.2 Nationwide DGPS

The Nationwide DGPS (NDGPS) is based on the architecture of the Maritime DGPS Service. Figure C-3 shows the NDGPS architecture using pseudo-range corrections. Figure C-3 and the following discussion describe the characteristics of the NDGPS system.

A. Signal Characteristics

The datalinks for DGPS corrections are broadcast sites transmitting between 285 and 325 kHz using MSK modulation. 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 NDGPS does not use data encryption.

B. Accuracy

The predictable accuracy of the NDGPS Service within all established coverage areas is better then 10 meters (2 drms). NDGPS accuracy at each broadcast site is carefully controlled and is typically better than 1 meter. Achievable accuracy degrades at an approximate rate of 1 meter for each 150 km distance from the broadcast site. Accuracy is further degraded by computational and other uncertainties in user equipment and the ability of user equipment to compensate for other error sources such as multipath and propagation distortions. A broadcast site accuracy of 1 meter should allow typical user equipment to achieve the stated 10-meter accuracy in all established coverage areas when the various factors that degrade accuracy are considered. High-end user equipment may achieve accuracies better than 3 meters by compensating for the various degrading factors.

C. Availability

Availability will be 99.9 percent for dual coverage areas and 99.7 percent for single coverage areas. Availability is calculated on a per site per month basis, generally discounting GPS anomalies.

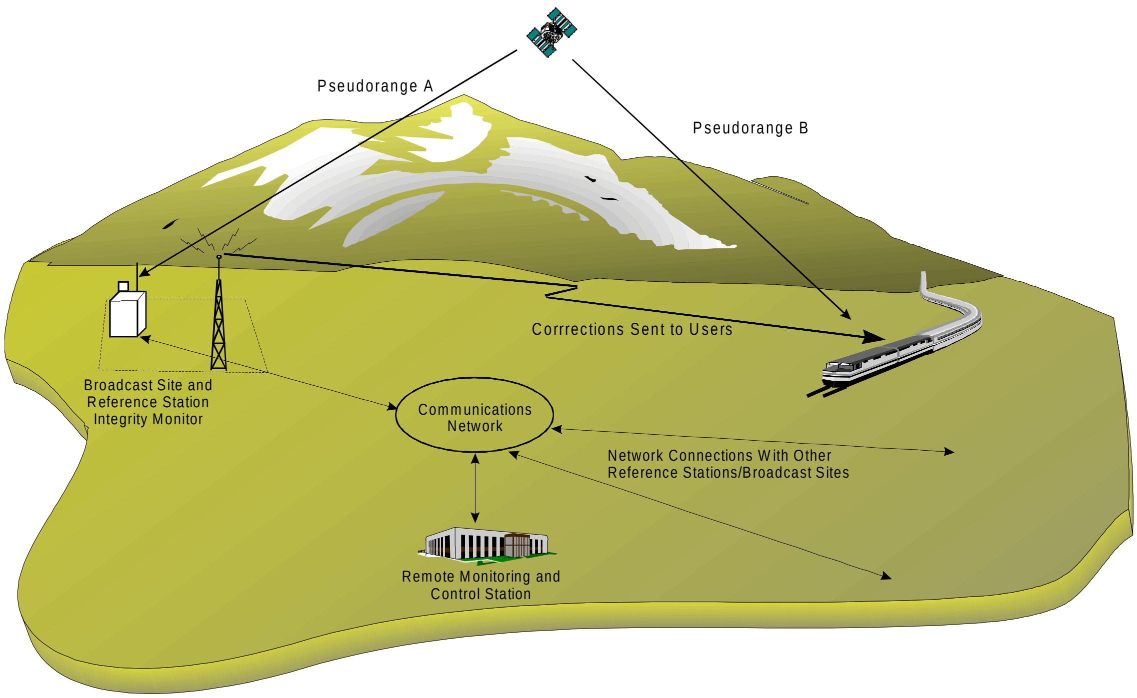


Figure C-3. NDGPS Navigation Service

D. Coverage

Figure C-4 shows the approximate locations of the NDGPS broadcast sites. Current plans envision providing dual coverage in the continental U.S. and in the transportation corridors in Alaska with single coverage in other areas.

E. Reliability

The number of outages per site will be less than 500 in one million hours of operation.

F. Fix Rate

USCG DGPS Broadcast sites transmit a set of data points every 2.5 seconds or better. Each set of data points includes both pseudorange and range rate corrections that permit virtually continuous position update, but the need for receiver processing results in typical user fix rates of 1-20 per second.

G. Fix Dimensions

Through the application of pseudorange corrections, maritime DGPS improves the accuracy of GPS three-dimensional positioning and velocity.

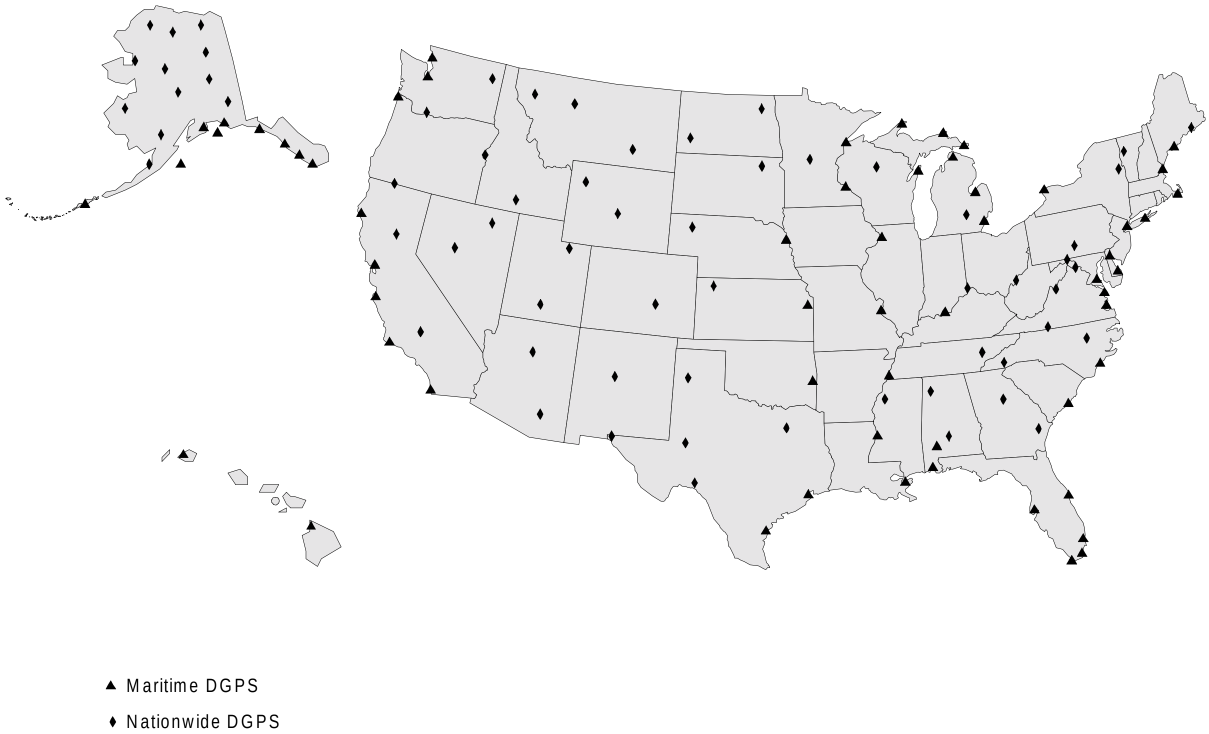


Figure C-4. Planned NDGPS Broadcast Sites

H. System Capacity

Unlimited.

I. Ambiguity

None.

J. Integrity

NDGPS system integrity is provided through an on-site integrity monitor and 24-hour operations at a NDGPS control center. Users will be notified of an out-of-tolerance condition within 6 seconds.

In addition to proving a highly accurate navigation signal, NDGPS 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 NDGPS 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.

C.2.2.3 Aeronautical GPS Wide Area Augmentation System (WAAS)

The WAAS will be a safety-critical system consisting of the equipment and software that augments the DOD-provided GPS Standard Positioning Service (see Figure C-5). 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 are 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 these data on the GPS Link I (LI) frequency with a modulation similar to that used by GPS.

Figure C-5. WAAS Architecture

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.

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	4×10^{-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.

C.2.2.4 GPS Local Area Augmentation System (LAAS)

The LAAS will be a safety critical precision navigation and landing system consisting of equipment to augment the DOD-provided GPS Standard Positioning Service with differential GPS pseudorange corrections. It will provide a signal-in-space to LAAS-equipped users with the specific goal of supporting terminal area navigation through Category III precision approach, including autoland. The LAAS signal-in-space will provide; (1) local area differential corrections for GPS PRNs, WAAS/Space-Based Augmentation System (SBAS), GEOs, and Airport Pseudolites (APLs), (2) the associated integrity parameters, and (3) precision approach final approach segment description path points.

The LAAS will utilize multiple GPS reference receivers and their associated antennas, all located within the airport boundary, to receive and decode the GPS, WAAS GEO, and APL range measurements and navigation data. Data from the individual reference receivers are processed by Signal Quality Monitoring, Navigation Data Quality Monitoring, Measurement Quality Monitoring, and Integrity Monitoring algorithms. An averaging technique is used to provide optimal differential range corrections for each measurement and possessing the requisite fidelity to meet accuracy, integrity, continuity of service, and availability criteria.

The individual differential range measurement corrections, integrity parameters and final approach segment path points descriptions for each runway end being served are broadcast to aircraft operating in the local terminal area (nominally 20 nm) via a LAAS VHF data broadcast transmission.

Airborne LAAS capable receivers receive and apply the differential correction to their own satellite and pseudolite pseudorange measurements and assess error parameters against maximum allowable error bounds for the category of approach being performed.

A. Signal Characteristics

The LAAS will collect raw GPS, WAAS GEO, and APL range data from all available range sources that support the navigation service.

The LAAS ground facility will generate differential correction messages as well as pseudorange correction error parameters for each of the GPS, WAAS GEO and APL ranging measurements. The LAAS VHF data broadcast transmitter will then broadcast the LAAS DGPS data to LAAS users.

The GPS L1 frequency and a GPS-like modulation including a wideband PRN code will be used for the LAAS APL availability augmentation transmission. The VHF ARNS band, 108-117.975 MHz, is planned for the LAAS VHF data broadcast.

B. Accuracy

Accuracy for the LAAS has been derived from the aviation accuracy requirements of the ILS. For Category I precision approach the lateral accuracy is 16.0 meters, 95 percent.

The LAAS Category I vertical accuracy is 4.0 meters, 95 percent (per the RTCA LAAS MASPS).

C. Availability

The availability of the LAAS is airport dependent, but ranges between 0.999 - 0.99999 (per the draft FAA LAAS specification).

D. Coverage

The LAAS full service volume is defined as:

Vertically: Beginning at the runway datum point out to 20 nm above 0.9 degrees and below 10,000 feet.

Horizontally: 450 ft. either side of the runway beginning at the RDP and projecting out ± 35 degrees either side of the approach path out to 20 nm (per the draft FAA LAAS spec.).

E. Reliability

Reliability figures have not been developed.

F. Fix Rate

The LAAS broadcast fix rate is 2Hz. The fix rate from the airborne receiver is at least 5Hz.

G. Fix Dimensions

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

H. System Capacity

There is no limit on the LAAS System Capacity.

I. Ambiguity

There is no ambiguity of position associated with the LAAS.

J. Integrity

Assurance of position integrity of the GPS SPS by the LAAS is a required capability that is both an operational characteristic and a technical characteristic. The required system performance is defined for each of the categories of approach. Integrity is specified for two separate parameters: PHMI and Time to Alarm.

Category I		Category II/III	
PHMI	$1x10^{-7}$	PHMI	$1x10^{-9}$
Time to Alarm	6 seconds	Time to Alarm	2 seconds

C.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. Loran-C is also certified as an en route supplemental navigation aid for civil aviation.

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 that 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 C-3.

Table C-3. Loran-C System Characteristics (Signal-in-Space)

ACCURACY (2 drms)					FIX	FIX	SYSTEM	AMBIGUITY
PREDICTABLE	REPEATABLE	AVAILABILITY	COVERAGE	RELIABILITY	RATE	DIMENSIONS	CAPACITY	POTENTIAL
0.25nm (460m)	60-300 ft. (18-90m)	99.7%	U.S. coastal areas, continental U.S., selected overseas areas	99.7%*	10-20 fix/sec.	2D + Time	Unlimited	Yes, easily resolved

* *Triad reliability.*

SYSTEM DESCRIPTION: Loran-C is a Low Frequency (LF) 100 kHz 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. The limit of coverage in a given area is determined by the lesser of: a) predictable accuracy limits of 0.25 nm; or b) signal-to-noise ratio limit of 1:3 SNR. Current Loran-C coverage is shown in Figure C-6.

Expansion of the Loran-C system into the Caribbean Sea and the North Slope of Alaska has been investigated.

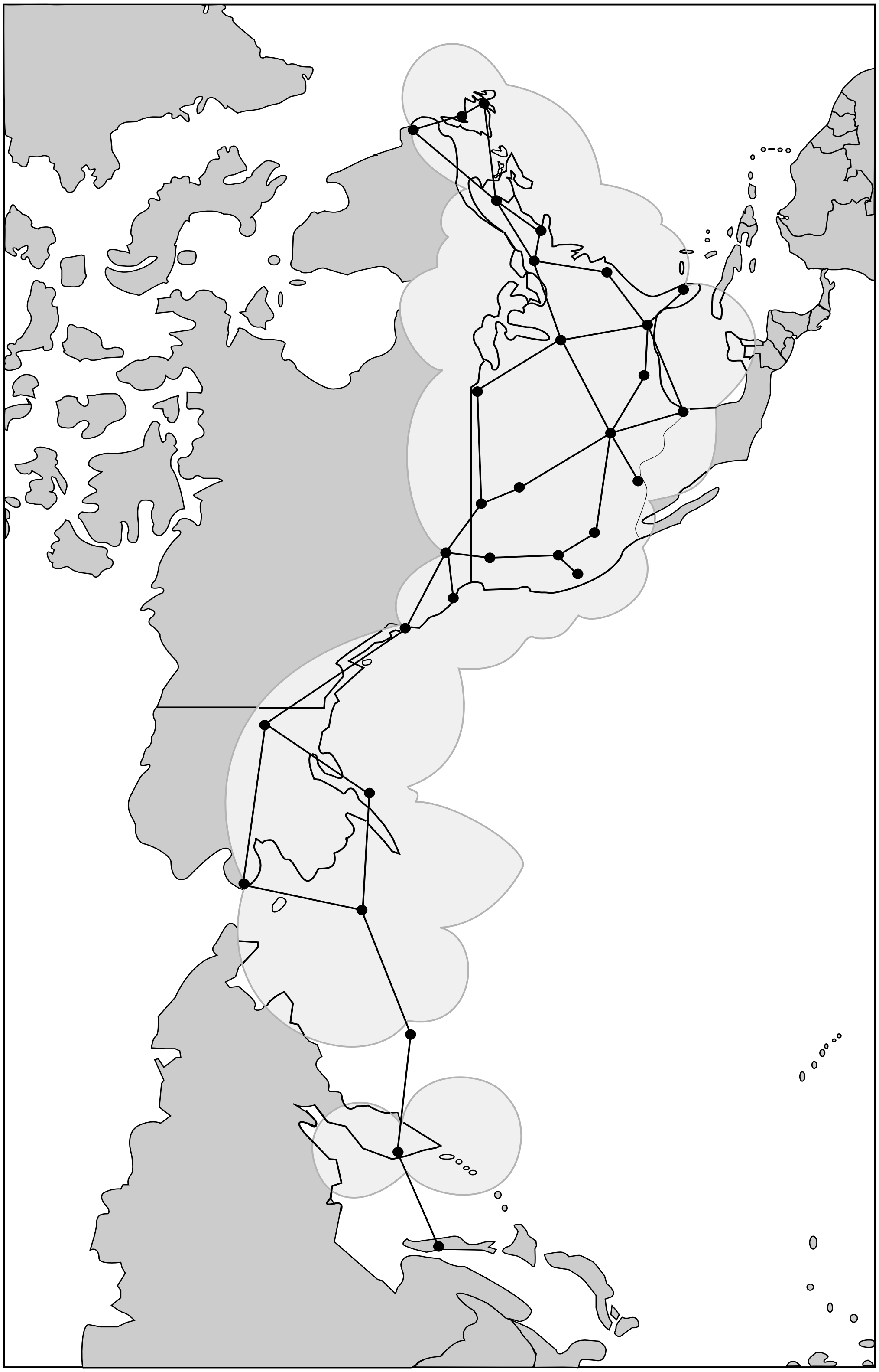


Figure C-6. Coverage Provided by U.S. or Supported Loran-C Stations

E. Reliability

Loran-C stations are constantly monitored. Stations that 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 provides a two-dimensional fix plus time.

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 signals are constantly monitored to detect signal abnormalities that would render the system unusable for navigation purposes. The secondary stations "blink" to notify the user that a master-secondary pair is unusable. Blink is manually initiated immediately upon detection of an abnormality. The USCG and the FAA are installing automatic blink equipment and a concept of operations based on factors consistent with aviation use. Where automatic blink equipment is installed in the NAS, secondary blink is automatically initiated within ten seconds of a timing abnormality exceeding ± 500 nanoseconds, 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.

C.2.4 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 C-4. VORs are assigned frequencies in the 108 to 117.975 MHz ARNS 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.

Table C-4. VOR and VOR/DME System Characteristics (Signal-in-Space)

ACCURACY (2 Sigma)									
PREDICTABLE	REPEATABLE	RELATIVE	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
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 ± 0.35°. These values are for ± 0.35° 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.

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.

- 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 that 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 C-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) that 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 962-1215 MHz ARNS 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 have 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 (962-1215 MHz ARNS band) radionavigation system designed primarily for military 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 C-5.

Table C-5. TACAN System Characteristics (Signal-in-Space)

ACCURACY (2 Sigma)									
PREDICTABLE	REPEATABLE	RELATIVE	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
Azimuth ±1° (± 63m at 3.75km) DME: 185m (±0.1nm)	Azimuth ±1° (± 63m at 3.75km) DME: 185m (±0.1nm)	Azimuth ±1° (±63m at 3.75km) DME: 185m (±0.1nm)	98%	Line of sight	99%	Continuous	Distance and bearing from station	110 for distance Unlimited in azimuth	No ambiguity in range Slight potential for ambiguity at multiples of 40°

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.

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 percent of the time.

D. Coverage

TACAN has a line-of-sight limitation that 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 98 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.

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.

C.2.5 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 navigation (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 C-6.

A. Signal Characteristics

The localizer facility and antenna are typically located 1,000 feet beyond the stop end of the runway and provide a VHF (108 to 111.975 MHz ARNS band) 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 ARNS band) 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 C-6. ILS Characteristics (Signal-in-Space)

ACCURACY AT DECISION HEIGHT (Meters - 2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE*	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
CATEGORY	AZIMUTH	ELEVATION							
1	± 9.1	± 3.0	Approaches 99%	Normal limits from center of localizer $\pm 10^\circ$ out to 18nm and $\pm 35^\circ$ 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 slope facility, and two or three VHF marker beacons. The VHF (108-111.975 MHz ARNS band) localizer facility provides accurate, single path horizontal guidance information. The UHF (328.6-335.4 MHz ARNS band) glide slope 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: ±2^{o}centered about runway centerline.

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

Marker Beacons: ±40^{o} (approximately) on minor axis (along approach path) ±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 that 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 that provide an audible and visual indication to the pilot are sited at specific points along the approach path as indicated in Table C-7.

Table C-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 C.2.5.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

C.2.6 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 C-8.

Table C-8. MLS Characteristics (Signal-in-Space)

ACCURACY AT DECISION HEIGHT (Meters - 2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE*	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
CATEGORY	AZIMUTH	ELEVATION							
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 ARNS band. Ranging is provided by precision DME operating in 962-1215 MHz ARNS band.

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 ARNS band. Ranging is provided by DME operating in the 962 - 1215 MHz ARNS 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 ARNS 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.

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.

C.2.7 Aeronautical Radiobeacons

Radiobeacons are nondirectional radio transmitting stations that 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 C-9.

Table C-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 non-precision approach aid at many airports. Only low frequency beacons are considered in the FRP since there is little common use of the VHF/UHF beacons. Marine radiobeacons are used as homing beacons to identify the entrance to harbors. Selected marine beacons carry differential GPS data.

A. Signal Characteristics

Aeronautical NDBs operate in the 190 to 415 kHz and 510 to 535 kHz ARNS bands. (Note: NDBs in 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.

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

J. Integrity

A radiobeacon is an omnidirectional navigation 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.

C.2.8 Maritime Radiobeacons

Radiobeacons are nondirectional radio transmitting stations that 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 C-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.

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 that 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 navigation 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.

C.3 Navigation Information Services

C.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) that 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, and DGPS radionavigation information as well as general maritime navigation information.

The NIS Website also provides the user with information on policy changes or developments about radionavigation systems, especially GPS. It works as an arm of the CGSIC in the exchange of information between the system providers and the users by:

- Automatically disseminating GPS status and outage information through a listserver.
- Collecting information from users in support of the CGSIC and the GPS managers and operators.

Specifically, the functions performed by the NIS include the following:

- Act as the single focal point for non-aviation 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.
- 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 C-10 and Figure C-7 show the services through which the NIS provides Operational Advisory Broadcasts. NAVCEN's 24-hour hotline: (703) 313-5900. NAVCEN's E-mail address: webmaster@smtp.navcen.uscg.mil. Internet WWW address: http://www.navcen.uscg.mil/.

C.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 NOTAM 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.

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.

Table C-10. NIS Services

Service	Availability	Information Type	Contact Number
NIS Watchstander	24 hours	User Inquiries	(703) 313-5900 FAX (703) 313-5920
Internet	24 hours	Status Forecast, History, Outages NGS Data, FRP and Miscellaneous Information	http://www.navcen.uscg.mil ftp://ftp.navcen.uscg.mil
NIS Voice Tape Recording	24 hours	Status Forecasts Historic	(703) 313-5907
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 broadcast	Status Forecasts	Maritime VHF Radio Band
NIMA Broadcast Warnings	When broadcast received	Status Forecasts	
NIMA Weekly Notice to Mariners	Published & mailed weekly	Status Forecasts Outages	(301) 227-3126
Navinfonet Automated Notice to Mariners system	24 hours	Status Forecasts 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 Forecasts Outages	518kHz (301) 227-4424/ 9600 baud

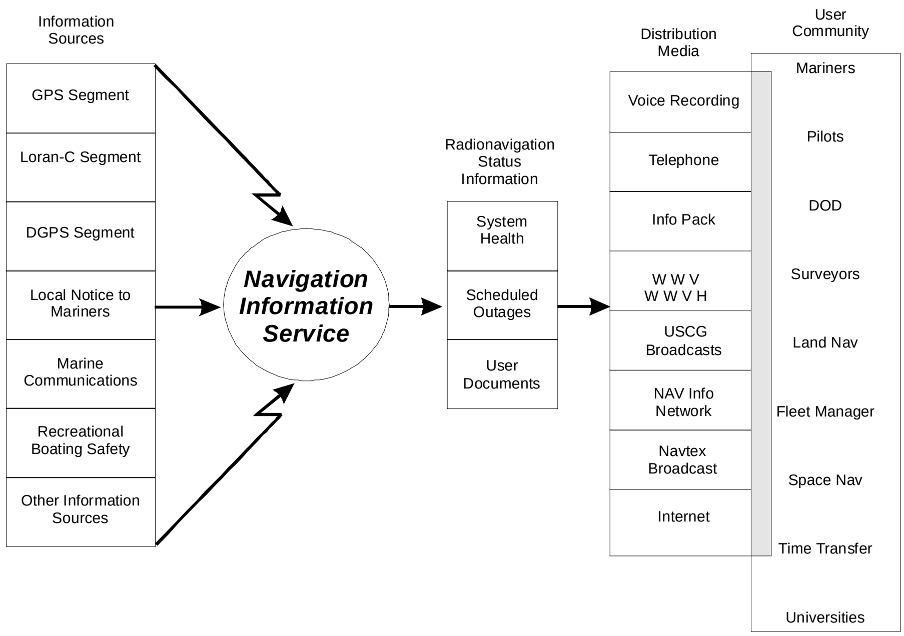


Figure C-7. NIS Information Flow

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. 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 are 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 C-8. 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.

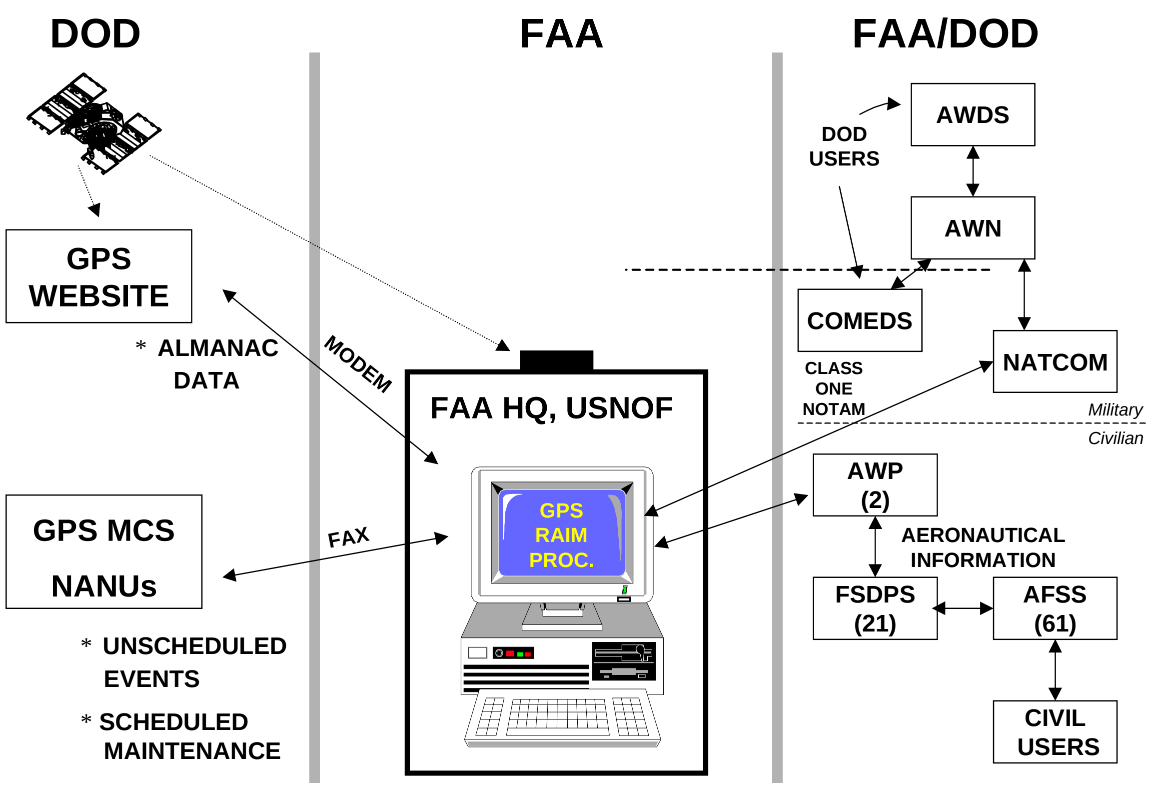


Figure C-8. GPS NOTAM/Aeronautical Information Distribution System

Appendix D

Datums and Reference Systems

D.1 Datums

Before the advent of manmade satellites, geodetic positions in surveying were determined separately, either horizontally in two-dimensions as latitudes and longitudes or vertically in the third dimension as heights or depths.

Horizontal datums, using a reference ellipsoid, an origin, and an azimuth orientation, were defined to relate surveyed horizontal positions to each other into one common local, regional, continental, or national system. All horizontal datums have been defined using geodetic data only over land areas. Examples are Old Hawaii Datum, Tokyo Datum, North American Datum 1927, or Indian Datum. These horizontal datums remained non-geocentric in definition; the largest shift from the geocenter determined so far is about two kilometers.

Vertical datums, using a Mean Sea Level (MSL) surface as an approximation to the geoid, were defined to relate surveyed vertical positions, orthometric heights or elevations, to each other in one common regional, continental, or national system. In case of ocean areas, the depths, or bathymetric data, from one region to another are defined with respect to various tidal surfaces, e.g., Mean Lower Low Water (MLLW), Lowest Astronomic Tide (LAT). Examples are Baltic or North American Vertical Datum (NAVD) 1988.

D.2 Geodetic Reference Systems

Using the satellites orbiting around the Earth, the determination of geodetic positions became three-dimensional, either as rectangular (X, Y, Z) coordinates or converted to geodetic (latitude, longitude, ellipsoidal height) coordinates using an Earth-centered ellipsoid.

The ellipsoidal heights are geometric heights, above or below the ellipsoid; they can be related to the orthometric heights by using geoidal undulations or heights. For a true geocentric geoid, the geoidal heights may vary from about 100 meters, below or above the reference ellipsoidal surface.

Examples are the World Geodetic System (WGS) 1984, or European Reference Frame (EUREF) 1989, or South American International Geodetic Reference System (SIRGAS) 1995. Recently, these geodetic systems have also been realized nationally, e.g., Korea Geodetic System (KGS) 1995. The International Terrestrial Reference Frame (ITRF) does not constitute by itself a geodetic reference system.

The geodetic reference system used by GPS is the WGS 84 (Ref. 12). The details of the models, the parameters, their uncertainties, and relationships to other systems are given in the reference. The WGS 84 reference frame and the most recent ITRF systems are in agreement to better than two centimeters.

D.3 Geoid

The geoid is a specified equipotential surface, defined in the Earth's gravity field, which is used as zero reference for orthometric heights or elevations. Historically, due to a lack of gravity data to accurately model this reference surface, vertical datums have been defined with respect to MSL even though MSL is not an equipotential surface and has a slope.

For aviation and other applications with stringent vertical accuracy requirements, an accurate, global geoid is needed to convert ellipsoidal height information from GPS determinations to orthometric heights. As a by-product of a 3-year joint project involving NASA and NIMA to determine an improved spherical harmonic model of the Earth's gravitational potential, a globally defined, high accuracy WGS 84 geoid (Ref. 12) has been produced.

Now, orthometric heights or elevations can be realized using GPS-surveyed geocentric ellipsoidal heights and the WGS 84 geoid with consistent zero definition all over the world.

D.4 Land Maps

Most of the maps over land are based on old classical datums (D.1 above). It is only with the availability of NAD 83 and WGS 84 (or its predecessor WGS 72) that horizontal topographic features/details on maps have been produced in the geocentric datums.

All vertical features and elevations on land maps are still referenced to MSL as zero reference.

D.5 Nautical Charts

Until very recently, nautical charts were surveyed on land-based horizontal datums that were extrapolated or extended to cover the adjoining ocean areas.

In 1983, International Hydrographic Organization (IHO) designated the use of the World Geodetic System as the universal datum. Since then, the horizontal features have been based on WGS 84 or in the case of U.S. charts on NAD 83, which is geodetically compatible with WGS 84.

All vertical features and depths are still defined with respect to tidal surfaces, which may differ in definition from chart to chart.

D.6 Aeronautical Charts

Until very recently, aeronautical charts were surveyed on land horizontal datums that were extended to cover the adjoining airspace overhead.

In 1989, International Civil Aviation Organization (ICAO) designated the use of the WGS 84 for all aerodromes as the universal datum. Since then, the conversion surveys have been in progress.

For horizontal features, the surveys will be based on WGS 84 or in geodetic reference systems that are geodetically compatible to it. All vertical features and elevations will be determined with respect to the WGS 84 geoid to achieve global consistency.

D.7 Map and Chart Accuracies

When comparing positions derived from GPS with positions taken from maps or charts, an understanding of factors affecting the accuracy of maps and charts is important.

Several factors are directly related to the scale of the product. Map or chart production requires the application of certain mapmaking standards to the process. Because production errors are evaluated with respect to the grid of the map, the evaluation represents relative accuracy of a single feature rather than feature-to-feature relative accuracy. This is the “specified map or chart accuracy.” Another factor is the symbolization of features. This creates an error in position because of physical characteristics, e.g., what distance is represented by the width of a line symbolizing a feature. In other words, what is the dimension of the smallest object that can be portrayed true to scale and location on a map or chart. Also, a limiting factor on accuracy is the map or chart user’s inability to accurately scale the map coordinates given by the grid or to plot a position.

Cartographic presentation or “cartographic license” is also an error source. When attempting to display two or more significant features very close together on a map or chart, the cartographer may displace one feature slightly for best presentation or clarity.

Errors in the underlying survey data of features depicted on the map or chart will also affect accuracy. For example, some hazards on nautical charts have not always been accurately surveyed and hence are incorrectly positioned on the chart.

As a final cautionary note, realize that maps and charts have been produced on a variety of datums. The coordinates for a point in one datum will not necessarily match the coordinates from another datum for that same point. Ignoring the datum shift and not applying the appropriate datum transformation can result in significant error. This applies whether one is comparing the coordinates of a point on two different maps or charts or comparing the coordinates of a point from a GPS receiver with the coordinates form a map or chart.

D.8 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 navigation 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 navigation chart. Similar to the requirements for shipborne radio equipment forming a part of the global maritime distress and safety system (GMDSS), and for electronic navigation aids, ECDIS onboard a SOLAS vessel should be in compliance with the IMO Performance Standard.

For the electronic navigation 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 navigation chart. The IMO Performance Standard further stipulates that both the ECDIS and radar use a common reference system (e.g., WGS 84), and that the chart and radar image match in scale and orientation.

Appendix E

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 and efficient 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 transmit position and altitude data derived from onboard systems via a datalink for use by air traffic control, other aircraft, and certain airport surface vehicles.

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 navigation 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 90o), 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 conversion of position coordinates from one type to another within the same datum or geodetic reference system, e.g., from geodetic coordinates (latitudes and longitudes) to Universal Transverse Mercator (UTM) system (x,y).

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.

Datum Transformation - The change of position coordinates from one geodetic datum or reference system to another datum or reference system, e.g., from European Datum 1950 to WGS 84.

Deception (electromagnetic) - Deliberate radiation, reradiation, alternation, suppression, absorption, denial, enhancement, or reflection of electromagnetic spectrum in any manner intended to convey misleading information.

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) - A system dependent state which occurs when the particular system is able to provide all of the services for which it was designed.

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) - A system dependent state which occurs when the particular system is able to provide a predetermined subset of the services for which it was designed.

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

Interference (electromagnetic) - Any electromagnetic disturbance that interrupts, obstructs, or otherwise degrades or limits the performance of user equipment.

Intrusion (electromagnetic) - Intentional insertion of electromagnetic energy into transmission paths with the objective to deceive or confuse the user.

Jamming (electromagnetic) - The deliberate radiation, reradiation, or reflection of electromagnetic energy for the purpose of preventing or reducing the effective use of a signal.

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.

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.

Navigation System Error (NSE) - The NSE is the error attributable to the navigation system in use. It includes the navigation sensor error, receiver error, and path definition error. NSE combines with Flight Technical Error (FTE) to produce the Total System Error.

Nonprecision Approach - A standard instrument approach procedure in which no electronic glide slope is provided (e.g., VOR, TACAN, Loran-C, or NDB).

Position Dilution of Precision - A scalar measure representing the contribution of the GPS satellite configuration geometry to the accuracy in three-dimensional position.

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 of service requirements. Safety is achieved by limiting flights to specific time periods and through appropriate procedural restrictions. 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 GPS receiver/processor determines the integrity of the GPS navigation signals without reference to external systems other than to the GPS satellite signals themselves or to an independent input of altitude information. 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.

Statute Mile - A unit of distance on land in English-speaking countries equal to 5,280 feet or 1,760 yards.

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.

Surveying - The act of making observations to determine the size and shape, the absolute and/or relative position of points on, above, or below the Earth's surface, the length and direction of a line, the Earth's gravity field, length of the day, etc.

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.

Total System Error (TSE) - The TSE comprises both the aircraft and its navigation system tracking errors. It is the difference between true position and desired position. This error is equal to the vector sum of the path steering error, path definition error, and position estimation error.

Universal Transverse Mercator (UTM) Grid - A rectangular grid of east-west and north-south lines, with linear scale of 0.9996 along the central meridian, and based on the Transverse Mercator projection; mostly used on military maps and charts from 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 constants and parameters describing the Earth's geometric and physical size and shape, gravity potential and field, and theoretical normal gravity.

Appendix F

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
ADS-B	Automatic Dependent Surveillance Broadcast
AEEC	Airlines Electronic Engineering Committee
AFSS	Automated Flight Service Stations
AGL	Above Ground Level
AIRSAR	Airborne Synthetic Aperture Radar
AIS	Automatic Identification Systems
ANA	Area Navigation Approach
AOC	Airport Obstruction Chart
APL	Airport Pseudolite

ARNS	Aeronautical Radionavigation Service
ARPA	Automatic Radar Plotting Aid
ASOS	Automated Surface Observing System
ATC	Air Traffic Control
ATCRBS	Air Traffic Control and Radar Beacon System
ATON	Aids to Navigation
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
CAA	Civil Aviation Authority
CCW	Coded Continuous Wave
CDI	Course Deviation Indicator
CEP	Circular Error Probable
CFR	Code of Federal Regulations
CGS	Civil GPS Service
CGSIC	Civil GPS Service Interface Committee
CIS	Commonwealth of Independent States
CJCS	Chairman, Joint Chiefs of Staff
cm	centimeter
CNS	Communication, Navigation and Surveillance
COMEDS	CONUS Meteorological Distribution System
CONUS	Continental United States
CORS	Continuously Operating Reference Stations

CRV	Crew Return Vehicle
CSE	Course Selection Error
CW	Continuous Wave
DART	Dallas Area Rapid Transit
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
DOJ	Department of Justice
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
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
FMS	Flight Management Systems
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
GITA	Global Positioning System Interference Testing Approval
GLONASS	Global Navigation Satellite System (Russian Federation System)
GMDSS	Global Maritime Distress and Safety 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
ICD	Interface Control Document

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
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
JPALS	Joint Precision Approach and Landing System
JPO	Joint Program Office
JTIDS	Joint Tactical Information Distribution System
kHz	kilohertz
km	kilometer
LAAS	Local Area Augmentation System
LADGPS	Local Area Differential GPS
LEO	Low Earth Orbit

LF	Low Frequency
LOP	Line of Position
Loran	Long-Range Navigation
m	meter
MAP	Missed Approach Point
MARAD	Maritime Administration
MASPS	Minimum Aviation System Performance Standards
MCS	Master Control Station
MCW	Modulated Continuous Wave
MHz	Megahertz
MIDS	Multi-function Information Distribution System
MLS	Microwave Landing System
mm	millimeters
MMR	Multi-Mode Receiver
ms	milliseconds
MOA	Memorandum of Agreement
MOPS	Minimum Operation Standard Performance
MPNTP	Master Positioning, Navigation, and Timing Plan
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
Navaids	Ground-Based Navigation Aids
NAVCEN	U.S. Coast Guard Navigation Center
NAVD	North American Vertical Datum

NAVWAR	Navigation Warfare
NCA	National Command Authority
NDB	Nondirectional Beacon
NDGPS	Nationwide Differential Global Positioning Service
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
NPA	Nonprecision Approach
NPOESS	National Polar-Orbiting Observational Environmental Satellite System
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
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
PIR	Portable Instrument Landing System Receiver
PIT	Policy and Implementation Team
PNT	Positioning, Navigation, and Timing
POS/NAV	Positioning and Navigation
PPS	Precise Positioning Service
PRN	Pseudo-Random Noise
ps	picosecond
PTC	Positive Train Control
PTTI	Precise Time and Time Interval
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
RLV	Reuseable Launch Vehicle
RNAV	Area Navigation
RNP	Required Navigation Performance
RNSS	Radionavigation Satellite Service

RSA	Range Standardization and Automation
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
Satnav	Satellite-Based Navigation
SBAS	Space-Based Augmentation System
SCAT I	Special Category I
SDF	Simplified Direction Finder
SLSDC	Saint Lawrence Seaway Development Corporation
SMGCS	Surface Movement Guidance and Control System
SNR	Signal-to-Noise Ratio
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
TCAS	Traffic Alert Collision Avoidance System
TD	Time Difference
TDWR	Terminal Doppler Weather Radar
TERPS	Terminal Instrument Procedures
TIS	Traffic Information Services
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
VDB	Very High Vehicle Data Broadcast
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
WWV/WWVH	Call Sign for the National Bureau of Standards Broadcast Notice to Airmen

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