2008 FEDERAL RADIONAVIGATION PLAN

Published by
Department of Defense,
Department of Homeland Security, and
Department of Transportation

This document is available to the public
through the National Technical Information
Service, Springfield, Virginia 22161
DOT-VNTSC-RITA-08-02/DoD-4650.5

2008 Federal Radionavigation Plan

The *Federal Radionavigation Plan* is the official source of radionavigation policy and planning for the Federal Government and is required by the National Defense Authorization Act for Fiscal Year 1998 (10 USC 2281(c)). It is prepared jointly by the Departments of Defense (DOD), Homeland Security (DHS), and Transportation (DOT) with the assistance of other government agencies. This edition of the Federal Radionavigation Plan combines the Federal Radionavigation Systems (FRS) document and Federal Radionavigation Plan (FRP) into one document. The 2008 edition updates and replaces the 2001 Federal Radionavigation Systems document and the 2005 Federal Radionavigation Plan. It also covers common-use radionavigation systems (i.e., systems used by both civil and military sectors). Systems used exclusively by the military are covered in the Chairman, Joint Chiefs of Staff Master Positioning, Navigation, and Timing Plan.

The Federal Radionavigation Plan includes the introduction, policies, radionavigation system user requirements, system descriptions, and operating plans and will allow more efficient and responsive updates of policy and planning information.

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

Mary E. Peters Secretary of Transportation	Robert M. Gates for Secretary of Defense	Michael Chertoff Secretary of Homeland Security
Mary E. Peters	Gordon England	Paul A. Schneider
Date: 12/04/08	Date: 1-23-09	Date: 1/16/09

Table of Contents

List of Figures

List of Tables

Executive Summary

The Federal Radionavigation Plan (FRP) reflects the official radionavigation policy and planning for the Federal Government. The FRP covers both terrestrial and space-based, common-use, Federally operated radionavigation systems. These systems are sometimes used in combination with each other or with other systems. Systems used exclusively by the military are covered in the Chairman, Joint Chiefs of Staff (CJCS) Master Positioning, Navigation, and Timing Plan (MPNTP). The plan does not include systems that mainly perform surveillance and communication functions. The policies and operating plans described in this document cover the following radionavigation systems:

- Global Positioning System (GPS)
- Augmentations to GPS
- Long Range Navigation (Loran)
- Very High Frequency (VHF) Omni-directional Range (VOR)
- Distance Measuring Equipment (DME)
- Tactical Air Navigation (TACAN)
- Instrument Landing System (ILS)
- Microwave Landing System (MLS)
- Aeronautical Nondirectional Radiobeacons (NDB)

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. The Department of Transportation (DOT) is responsible under Title 49 United States Code Section 101 (49 USC § 101) (Ref. 1) for ensuring safe and efficient transportation. The Department of Defense (DoD) is responsible for maintaining aids to navigation required exclusively for national defense. The DoD is also required by 10 USC § 2281(b) (Ref. 2) to provide for the sustainment and operation of GPS for peaceful civil, commercial, and scientific uses on a continuous worldwide basis free of direct user fees.

A major goal of DoD and DOT is to ensure that a mix of common-use (civil and military) systems is available to meet user requirements for accuracy, reliability, availability, continuity, 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, unique requirements exist for military as well as civil users. For example, 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. Similarly, civil users desire higher accuracy and integrity for future highway, rail, and other safety-of-life applications. Cost is always a major consideration that must be balanced with a needed operational capability.

As the full civil potential of GPS and its augmentations is realized, the services provided by other Federally provided radionavigation systems will be considered for divestment to match the reduction in demand, provided those services are not a part of a back-up navigation strategy for critical applications or safety-of-life services.

The Federal Government conducts 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. Civil R&D activities focus mainly on enhancements of GPS for civil uses. Military R&D activities mainly address military mission requirements and national security considerations.

A detailed discussion of agencies' roles and responsibilities, user requirements, and system descriptions can be found in this edition of the FRP.

The FRP is composed of the following sections:

Section 1 - Introduction to the Federal Radionavigation Plan: Delineates the purpose, scope and objectives of the plan and discusses radionavigation system selection considerations.

Section 2 - Roles and Responsibilities: Presents DoD, DOT, DHS, and other Federal agencies' roles and responsibilities for the planning and providing of radionavigation services.

Section 3 - Policy: Describes the U.S. policy for providing each Federal radionavigation system identified in this document.

Section 4 –Radionavigation System User Requirements: Summarizes performance requirements for Federally provided radionavigation services that are available to civil users.

Section 5 – Operating Plans: Summarizes the plans of the Federal Government to provide radionavigation systems or services for use by the civil and military sectors. This chapter also presents the research and development efforts planned and conducted by DoD, DOT, DHS, and other Federal organizations.

Appendix A – Geodetic Datums and Reference Systems

Appendix B – System Parameters and Descriptions

Appendix C – List of Acronyms

Appendix D – Glossary

References

1

Introduction to the Federal Radionavigation Plan

This section describes the background, purpose, and scope of the Federal Radionavigation Plan (FRP). It summarizes the events leading to the preparation of this document, the national objectives for coordinating the planning of radionavigation services, 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 Defense (DoD) and Department of Transportation (DOT) plan for radionavigation systems had been developed. With the transfer of the United States Coast Guard (USCG) from DOT to the Department of Homeland Security (DHS) through Public Law (PL) 107-296 (116 Stat. 2135), DHS has also been added as a signatory to the FRP. This updated plan, which merges the 2005 FRP and 2001 Federal Radionavigation Systems (FRS) documents, reflects the policy and planning for all present and future Federally provided radionavigation systems.

A Federal Radionavigation Plan is required by Title 10 United States Code, Section 2281(c) [10 USC § 2281(c)] (Ref. 2).

1.2 Purpose

The purpose of the FRP is to describe the U.S. Government's (USG):

- policy and plan for operating Federal radionavigation systems, regulating non-Federal radionavigation systems, and identifying the relationship between these systems and international standards;

- approach for implementing new radionavigation systems and consolidating existing radionavigation systems; and
- policy on dual-use radionavigation systems (i.e., those used by both civil and military communities).

1.3 Scope

This plan covers Federally provided radionavigation systems used for positioning, navigation, and timing (PNT) applications. The plan does not include electronic systems that are used primarily for surveillance, communication, and time (e.g., radar, cell phones, WWV).

The systems addressed in this FRP are:

- Global Positioning System (GPS)
- Augmentations to GPS
- Long Range Navigation (Loran)
- Tactical Air Navigation (TACAN)
- Instrument Landing System (ILS)
- Microwave Landing System (MLS)
- Aeronautical Nondirectional Beacons (NDB)
- Very High Frequency (VHF) Omnidirectional Range (VOR)
- Distance Measuring Equipment (DME)

1.4 Objectives

The objectives of USG radionavigation system policy are to:

- strengthen and maintain national security;
- provide safety of travel;
- promote efficient and effective transportation systems;
- promote increased transportation capacity and mobility of people and products;
- aid in the protection of the environment; and
- contribute to the economic growth, trade, and productivity of the United States.

1.5 Authority to Provide Radionavigation Services

Several Departments and Agencies provide radionavigation services including DHS/USCG, DOC/NOAA/NGS, DoD, DOT/FAA, DOT/SLSDC, and NASA.

DOT is responsible under 49 USC § 101 for ensuring safe and efficient transportation. Radionavigation systems play an important role in carrying out this responsibility. The two DOT elements that operate radionavigation systems are the Federal Aviation Administration (FAA) and St. Lawrence Seaway Development Corporation (SLSDC). Per Secretary of Transportation Memorandum dated August 1, 2007, the Administrator, DOT/Research and Innovative Technology Administration (RITA) is responsible for coordinating radionavigation planning within DOT and with other civil Federal elements.

FAA has the responsibility for the development and implementation of radionavigation systems to meet the needs for safe and efficient air navigation. 49 USC § 44505 states that the Administrator of the Federal Aviation Administration shall: develop, alter, test, and evaluate systems, procedures, facilities, and devices, and define their performance characteristics, to meet the needs for safe and efficient navigation and traffic control of civil and military aviation, except for needs of the armed forces that are peculiar to air warfare and primarily of military concern; and select systems, procedures, facilities and devices that will best serve those needs and promote maximum coordination of air traffic control and air defense systems. FAA also has the responsibility to operate air navigation aids required by international treaties.

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 Management Corporation of Canada.

The Secretary of Transportation has authority under PL 105-66, § 346 to implement the Nationwide Differential GPS (NDGPS) service in support of surface transportation and other terrestrial civil positioning and navigation missions. RITA is currently acting as the lead agency for this function; operations are provided by the USCG under a Memorandum of Agreement (MOA) in a coordinated fashion with the USCG-provided Maritime DGPS as a combined national differential GPS utility.

Several additional elements within DOT also participate in radionavigation planning. These elements include the the Federal Highway Administration (FHWA), the Federal Motor Carrier Safety Administration (FMCSA), the Federal Railroad Administration (FRA), the Federal Transit Administration (FTA), Maritime Administration (MARAD), the National Highway Traffic Safety Administration (NHTSA), and the Pipeline and Hazardous Materials Safety Administration (PHMSA).

Although USCG is now a DHS component, its underlying authorities to establish, maintain, and operate aids to navigation, including 14 USC § 81, remain in full effect. USCG provides aids to navigation for safe and efficient marine navigation.

Other Federal agencies that participate in radionavigation planning include the National Aeronautics and Space Administration (NASA), and within the Department of Commerce, the National Oceanic and Atmospheric Administration's National Geodetic Survey Program (DOC/NOAA/NGS).

DoD is responsible for developing, testing, evaluating, implementing, operating, and maintaining aids to navigation and user equipment required solely for national defense. DoD is also responsible for ensuring that military vehicles operating in consonance with civil vehicles have the necessary navigation capabilities.

DoD is required by 10 USC § 2281(b) (Ref. 2) to provide for the sustainment and operation of the GPS Standard Positioning Service (SPS) for peaceful civil, commercial, and scientific uses on a continuous worldwide basis free of direct user fees. DoD is also required to provide for the sustainment and operation of the GPS Precise Positioning Service (PPS). USG agency roles and responsibilities are described in more detail in Chapter 2.

1.6 Radionavigation System Selection Considerations

Many factors are considered in determining the optimum mix of Federally provided radionavigation systems. These factors include operational, technical, economical, institutional, radio frequency spectrum allocation, national defense needs, and international parameters. Important technical parameters include system accuracy, integrity, coverage, continuity, availability, reliability, and radio frequency spectrum. Certain unique parameters, such as anti-jamming performance, apply principally to military needs but can also affect civil availability.

The current investment in service provider equipment and user equipment must also be considered. In some cases there are international commitments that must be honored or modified in a fashion mutually agreeable to all parties.

In most cases, the systems that are currently in place today were developed to meet different user 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 this 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 FRP reflects policy direction from the *U.S. Space-Based Positioning, Navigation, and Timing Policy* (Ref. 3), dynamic radionavigation technology, changing user profiles, budget considerations, and international activities. With the creation of DHS, DOT and DoD will maintain the current working relationship with USCG via Memoranda of Agreement.

In the final analysis, provisioning of USG 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.

When, after appropriate analysis and study, the need or economic justification for a particular system or capability 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.

1.6.1 Operational Considerations

1.6.1.1 Military Selection Factors

Operational requirements determine DoD's selection of radionavigation systems. Precise PNT information is a key enabler for a variety of systems and missions. In conducting military operations, it is essential that PNT services be available with the highest possible confidence. These services must meet or exceed mission requirements. In order to meet these mission requirements, military operators may use a mix of independent, self-contained, and externally referenced PNT systems, provided that these systems can be traced directly to the DoD reference standards WGS 84 (World Geodetic System 1984) and UTC (Coordinated Universal Time)/USNO (U.S. Naval Observatory). Only DoD approved PNT systems will be used for combat, combat support, and combat service support operations. Factors for military selection of radionavigation systems include, but are not limited to:

- flexibility to accommodate new weapon systems and technology;
- resistance to intentional or unintentional interference or degradation;
- interoperability with DoD and allied systems to support coalition operations;

- position and time accuracy relative to common grid and time reference systems, to support strategic and tactical operations;
- availability of alternative means for obtaining PNT data;
- worldwide mobility requirements; and
- compatibility with civil systems and operations.

Military-specific selection criteria may be found in the Chairman of the Joint Chiefs of Staff (CJCS) Instruction 6130.01D, *DoD Master Positioning, Navigation, and Timing Plan* (Ref. 4).

1.6.1.2 Civil/Military Compatibility

The Federal Aviation Act of 1958 requires the FAA to develop a combined civil and military aviation system. The Administrator must "select, procedures, facilities, and devices that will best serve those needs and promote maximum coordination of air traffic control and air defense systems." Through ICAO, the FAA promulgates these radionavigation system standards ensuring worldwide interoperability. The National Interstate and Defense Highways Act of 1956 (Federal Highway Act of 1956) requires the FHWA to develop a combined civil and military interstate highways systems. The USCG is required to operate radionavigation systems to support both civil and military traffic within the waterways.

Military aircraft, vehicles, and ships operate in civil environments. Accordingly, they may use civil PNT systems consistent with DoD policy in peacetime scenarios as long as the systems in use meet International Maritime Organization (IMO), International Civil Aviation Organization (ICAO), USCG, or FAA specifications. PNT systems intended to support peacetime operations may not support combat operations. In those cases, the DoD may need to develop additional PNT capability to combat wartime threats.

1.6.1.3 Review and Validation

DoD radionavigation system requirements review and validation process:

- identifies the unique components of PNT mission requirements;
- identifies technological deficiencies; and
- investigates system costs, user populations, and the relationship of candidate systems to other systems and functions.

1.6.2 Technical Considerations

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

- spectrum availability;
- received signal strength;
- multipath effects;
- system accuracy;
- system precision;
- signal acquisition and tracking continuity;
- system integrity;
- system availability;
- signal continuity;
- platform dynamics;
- signal coverage;
- noise effects;
- signal propagation;
- susceptibility to natural or man-made disruption, e.g., radio frequency interference (RFI);
- installation requirements (service provider and user equipment);
- environmental effects;
- communications security;
- human factors engineering; and
- system reliability

1.6.2.1 Vulnerability of GPS in the National Transportation Infrastructure

The final report of the President's Commission on Critical Infrastructure Protection concluded that GPS services and applications are susceptible to various types of RFI, and that the effects of these vulnerabilities on civilian transportation applications should be studied in detail. As a result of the report, Presidential Decision Directive (PDD) 63 gave DOT 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.

The Volpe National Transportation Systems Center (Volpe Center) conducted this evaluation and identified GPS vulnerabilities and their potential impacts to aviation, maritime, rail, highway, and non-positioning systems. The final report, *Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System* (Ref. 5), was published in 2001 and is available on the Coast Guard Navigation Center website www.navcen.uscg.gov. The report's main conclusion is that GPS has vulnerabilities for civilian users of the national transportation infrastructure. The report also states that care must be taken to ensure that adequate back-up systems or procedures can be used when needed.

The Volpe report offered several key recommendations for improving the safety and efficiency of the national transportation infrastructure while preserving security by ensuring availability of back-up systems and operating procedures in the event of a loss of GPS service. The Secretary of Transportation accepted the recommendations contained in the report and requested each modal administrator to develop plans for mitigating the risks associated with loss of GPS services.

The *U.S. Space-Based Positioning, Navigation, and Timing Policy* (Ref. 3) states that GPS shall be maintained as a component of multiple sectors of the U.S. Critical Infrastructure, consistent with Homeland Security Presidential Directive-7 (HSPD-7). It also defines responsibilities for locating and resolving interference. The mitigation of disruptions to satellite-based navigation services is discussed in Section 3.3 of this document.

1.6.2.2 Interference Detection and Mitigation Plan

PNT services are widely recognized as an integral part of the technological foundation of civil and commercial worldwide infrastructure; and they are a critical component of numerous parts of the U.S. critical infrastructure for transportation and communications. The importance of PNT services raised the question of system vulnerability to unintentional as well as intentional interference, with potential risk issues defined and quantified in various analyses and studies. This heightened recognition was the impetus behind efforts to plan and prepare for incidents of any kind of interference to these systems, establish procedures and techniques to identify interference events, and provide guidance for the timely resolution and mitigation to quickly restore PNT services. DHS developed and published the *National Positioning, Navigation, and Timing, Interference Detection and*

Mitigation (IDM) Plan (August 2007) and the *National IDM Plan Implementation Strategy* (January 2008) to address these concerns. These documents provide a framework and guidance from which to execute the responsibilities required to fulfill the directives from the U.S. Space-Based PNT Policy.

1.6.2.2.1 Aviation Interference Detection, Location, and Mitigation

Because of the unique requirements of aviation, FAA is planning to develop enhanced interference detection and locating capabilities to help mitigate the impacts of RFI on present and future National Airspace System (NAS) systems. New capabilities such as GPS, aeronautical data link systems, and Automatic Dependence Surveillance-Broadcast (ADS-B) will require enhanced radio frequency and electromagnetic interference detection capabilities. Program requirements include:

- developing the ability to detect, locate, and mitigate the impact of both intentional and unintentional interference on NAS elements and capacity; and
- scoping a robust but affordable program that will prevent a loss in the projected system gains achieved by the new NAS systems, while assuring that the end users benefit from the significant investments being made.

1.6.3 Economic Considerations

The USG must continually review the costs and benefits of the navigation systems or capabilities it provides. This continuing analysis can be used both for setting priorities for investment in new systems, and determining the appropriate mix of systems to be retained. In some cases, systems may need to be retained for safety, security, or economic reasons, or to allow adequate time for the transition to newer systems and user equipment; however, these systems must be periodically evaluated to determine whether their continued sustainment is justified.

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 operated air navigation facilities do not provide sufficient economic benefit to qualify for operation by the Federal Government, they may provide significant economic benefit to specific user groups or local economies. In most cases they are also available for public use. The FAA regulates and inspects air navigation facilities in accordance with Federal Aviation Regulations (FAR), Title 14 Part 171 of the Code of Federal Regulation (CFR) Non-Federal Navigation Facilities, and FAA directives.

1.6.4 Institutional Considerations

1.6.4.1 Cost Recovery for Radionavigation Services

In accordance with general policy and the User Fee Statute, 31 USC § 9701, the USG recovers 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. Cost recovery for radionavigation services is either through general tax revenues or through transportation trust funds, which are generally financed with indirect user fees. In the case of GPS, the 2004 U.S. Space-Based PNT Policy states that GPS civil services and GPS augmentations shall be provided free of direct user fees. For NDGPS, PL 105-66, Title III, § 346 (111 Stat. 1449) authorizes the Secretary of Transportation to manage and operate the NDGPS and to ensure that the service is provided without the assessment of any user fee.

1.6.4.2 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, making contingency planning necessary. The U.S. national policy is that all radionavigation systems operated by the USG will remain available for peaceful use, subject to direction by the President in the event of a war or threat to national security.

In order to minimize service disruptions and prevent situations threatening safety or efficient use of GPS, any transmission on the GPS frequencies is strictly regulated through Federal regulations. These regulations require all transmissions on GPS frequencies to be coordinated with the National Telecommunications and Information Administration (NTIA) and with other potentially impacted Federal agencies (including FAA). In the case of DoD interference testing and Electronic Attack (EA), NTIA has delegated coordination of these activities to DoD as delineated in CJCS Manual 3212 (series), *Performing Electronic Attack in the United States and Canada for Test, Training, and Exercises* (per para 7.14 of the NTIA *Manual of Regulations and Procedures for Federal Radio Frequency Management*). DoD coordinates all interference testing and EA with other impacted Federal agencies, and FAA coordination and concurrence (through the ATC Spectrum Engineering Services Office) is a required step in this process. DHS, in coordination with DOT and DoD, and in cooperation with other departments and agencies, coordinates the use of Federal capabilities and resources to identify, locate, and mitigate interference within the U.S. that adversely affects GPS and its augmentations.

1.6.4.3 Role of the Non-Federal Sector

Radionavigation systems have historically been provided by the USG to support safety, security, and commerce. These services have supported air, land, and marine navigation and timing or frequency-based services, surveying, mapping, weather forecasting, precision farming, and scientific applications. For certain applications such as landing, positioning, and surveying, in areas where Federal systems are not justified, a number of non-Federally operated systems are available to the user as an alternative.

Air navigation facilities, owned and operated by non-Federal service providers, are regulated by FAA under Title 14 Part 171 of the CFR "Non-Federal Navigation Facilities." A non-Federal sponsor may coordinate with FAA to acquire, install and turn a qualified air navigation facility over to the FAA for operation and 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 agreement with FAA. This program includes recurrent ground and flight inspections of the facility to ensure that it continues to be operated in accordance with this agreement.

A number of factors need to be considered when examining non-Federal involvement in the provision of air navigation services:

- divestment of a Federally operated radionavigation service to non-Federal operation as a viable alternative to decommissioning the service;
- commercial development of air navigation equipment for both Federal and non-Federal facilities;
- impact of non-Federally 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 (RF) spectrum issues; and
- type approval of the equipment and certification of the air navigation facility, service provider, flight operator, and air traffic controller.

In addition to those services provided for air navigation, a number of commercial services exist to provide for precise land and marine applications, e.g., agriculture and marine construction.

1.6.5 International Considerations

Radionavigation services and systems are provided in a manner consistent with the standards and guidelines of international groups, including the North Atlantic Treaty Organization (NATO) and other allies, ICAO, the International Telecommunication Union (ITU), and 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. ICAO establishes standards for internationally used civil aviation radionavigation systems. IMO plays a similar role for the international maritime community. The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) also develops international radionavigation guidelines. The International Hydrographic Organization (IHO) and IMO cooperate in the operation of a worldwide marine navigation warning system, which includes warnings of radionavigation system outages. IMO reviews existing and proposed radionavigation systems to identify 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. 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. International negotiations and consultations occur under the auspices of the Department of State (DOS).

1.6.6 Interoperability Considerations

National and international radionavigation systems are sometimes used in combination with each other or with other systems. These combined systems are often implemented to provide improved or complementary performance. In the case of GPS, the USG encourages future interoperability with foreign space-based PNT systems for civil, commercial, and scientific uses worldwide. Examples of existing or future foreign space-based PNT systems are Russia’s Global Navigation Satellite System (GLONASS), the European Union’s Galileo, Japan’s Quasi Zenith Satellite System (QZSS), China’s Compass, and India’s Regional Navigation Satellite System (RNSS). Properly designed receivers that take advantage of these systems may benefit from additional satellite signals, increased redundancy, and improved performance over that obtained from just one system alone. A critical aspect of system interoperability is ensuring compatibility among radionavigation services. For example, the USG has concerns about radionavigation signal structures that could adversely impact the military and civil use of GPS. The USG has also fostered the use of interoperable augmentations through its adherence to international standards for DGPS and space-based augmentation system services. These include Maritime DGPS and the Wide Area Augmentation System.

1.6.7 Radio Frequency Spectrum Considerations

Radionavigation services use a significant amount of RF spectrum to provide the world with a safe and robust transportation system. Radionavigation services require sufficient bandwidth, an appropriate level of signal availability and integrity, and adequate protections from sources of interference. Spectrum engineering management is a key foundation for radionavigation system policy, implementation, and operation.

In planning for radionavigation systems and services, careful consideration must be made of the U.S. and international regulatory environments in terms of spectrum allocations and management. A significant trend in spectrum use is spectrum sharing. As a result, restricted bands could be subjected to unintentional RFI from incompatible radio services. For this reason, electromagnetic compatibility analysis remains a key requirement for planning and certification of existing and new radionavigation systems. Power levels, antenna heights, channel spacing, total bandwidth, spurious and out-of-band emissions, and geographic location must all be factored into implementing new systems, and ensuring adequate protection for existing services. Rights and responsibilities of primary and secondary allocation incumbents and new entrants are considered on specific, technically defined criteria.

Within the U.S., two regulatory bodies oversee the use of radio frequency spectrum. The Federal Communications Commission (FCC) is responsible for all non-Federal use of the airwaves, while NTIA manages spectrum use for the Federal Government. As part of this process, the NTIA hosts the Interdepartment Radio Advisory Committee (IRAC), a forum consisting of Executive Branch agencies that act as service providers and users of Government spectrum, including safety-of-life bands. FCC participates in IRAC meetings as an observer. Per Secretary of Transportation Memorandum dated August 1, 2007, national transportation spectrum policy is coordinated through RITA, while spectrum for DoD is coordinated through the Assistant Secretary of Defense for Networks and Information Integration [ASD (NII)].

The broadcast nature of radionavigation systems also provides a need for U.S. regulators to go beyond domestic geographic boundaries and coordinate with other nations through such forums as the ITU. ITU is a specialized technical arm of the United Nations (UN), charged with allocating spectrum on a global basis through the actions of the World Radiocommunication Conference (WRC), held every 3-4 years. As a result of the WRC process, where final resolutions hold treaty status among participating nations, spectrum allocations stay relatively consistent throughout the world, and end users can use the same radionavigation equipment free from RFI regardless of where they operate.

Non-interference with radionavigation RF spectrum is crucial. All domestic and international radionavigation services are dependent on the uninterrupted broadcast, reception and processing of radio frequencies in protected radio bands. Use of these frequency bands is restricted because stringent accuracy, availability, integrity, and continuity parameters must be maintained to meet service provider and end user performance requirements. Representatives from DoD, DOT, and DHS work with other government and private sector agents as members of the U.S. delegation to jointly advocate radionavigation requirements, and considerable effort is put forth to ensure that radionavigation services are protected throughout WRC deliberations and other international discussions. The specific ITU band designations that define U.S. radionavigation services are listed below:

- Aeronautical Radionavigation Service (ARNS);
- Radionavigation Satellite Service (RNSS);
- Radionavigation Service (RNS)

The certification and use of radionavigation services is the shared responsibility of DOT, DHS, and DoD. DOT, DHS, and DoD are Federal users of spectrum, as well as service providers and operators of radionavigation systems. Within DOT, FAA use of spectrum is primarily in support of aeronautical safety services used within the NAS. Within DHS, USCG uses internationally protected spectrum to operate radionavigation systems used on waterways, specifically DGPS and Loran.

Other DOT agencies (FHWA, FRA, FTA, NHTSA, and RITA) also work with private sector, and state and local governments to use spectrum for Intelligent Transportation System (ITS) and Intelligent Railroad System applications. Many ITS applications will use GPS, GPS augmentations, and other radiodetermination systems to make roadway travel safer and more efficient by providing differential corrections and location information in an integrated systems context. Collision avoidance systems, emergency services management, and incident detection are some examples of ITS applications that require in-vehicle positioning and navigational support. Intelligent Railroad Systems applications and research, Positive Train Control (PTC) safety systems, rail defect detection, and automated rail surveying rely on NDGPS and rail industry telecommunications frequencies to improve safety, and economic and operating efficiency. Spectrum used for transportation, military, and homeland security applications must remain free from interference due to public safety and security requirements.

2

Roles and Responsibilities

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

The *U.S. Space-Based Positioning, Navigation, and Timing Policy* (Ref. 3) establishes guidance and implementation actions for space-based PNT programs, augmentations, and activities for U.S. national and homeland security, civil, scientific, and commercial purposes. The policy establishes a permanent National Space-Based PNT Executive Committee (ExComm). The National Space-Based PNT ExComm advises and coordinates, with and among the departments and agencies responsible for the strategic decisions regarding policies, architectures, requirements, and resource allocation for maintaining and improving U.S. space-based PNT infrastructures, including GPS, its augmentations, security for these services, and relationships with foreign PNT services. The National Space-Based PNT ExComm is co-chaired by the Deputy Secretaries of Defense and Transportation. The National Space-Based PNT ExComm management structure is shown in Figure 2-1.

2.1 National Executive Committee for Space-Based PNT

The *U.S. Space-Based Positioning, Navigation, and Timing Policy* established the National Executive Committee for Space-Based PNT to provide top-level guidance on matters concerning space-based PNT (but not all federal radionavigation systems). The National Executive Committee is chaired jointly by the Deputy Secretaries of Defense and Transportation. Its membership includes equivalent-level officials from the Departments of State, the Interior, Agriculture, Commerce, and Homeland Security, as well as the Joint Chiefs of Staff and NASA. Components of the Executive Office of the President participate as observers to the National Executive Committee, and the FCC Chairman participates as a liaison.

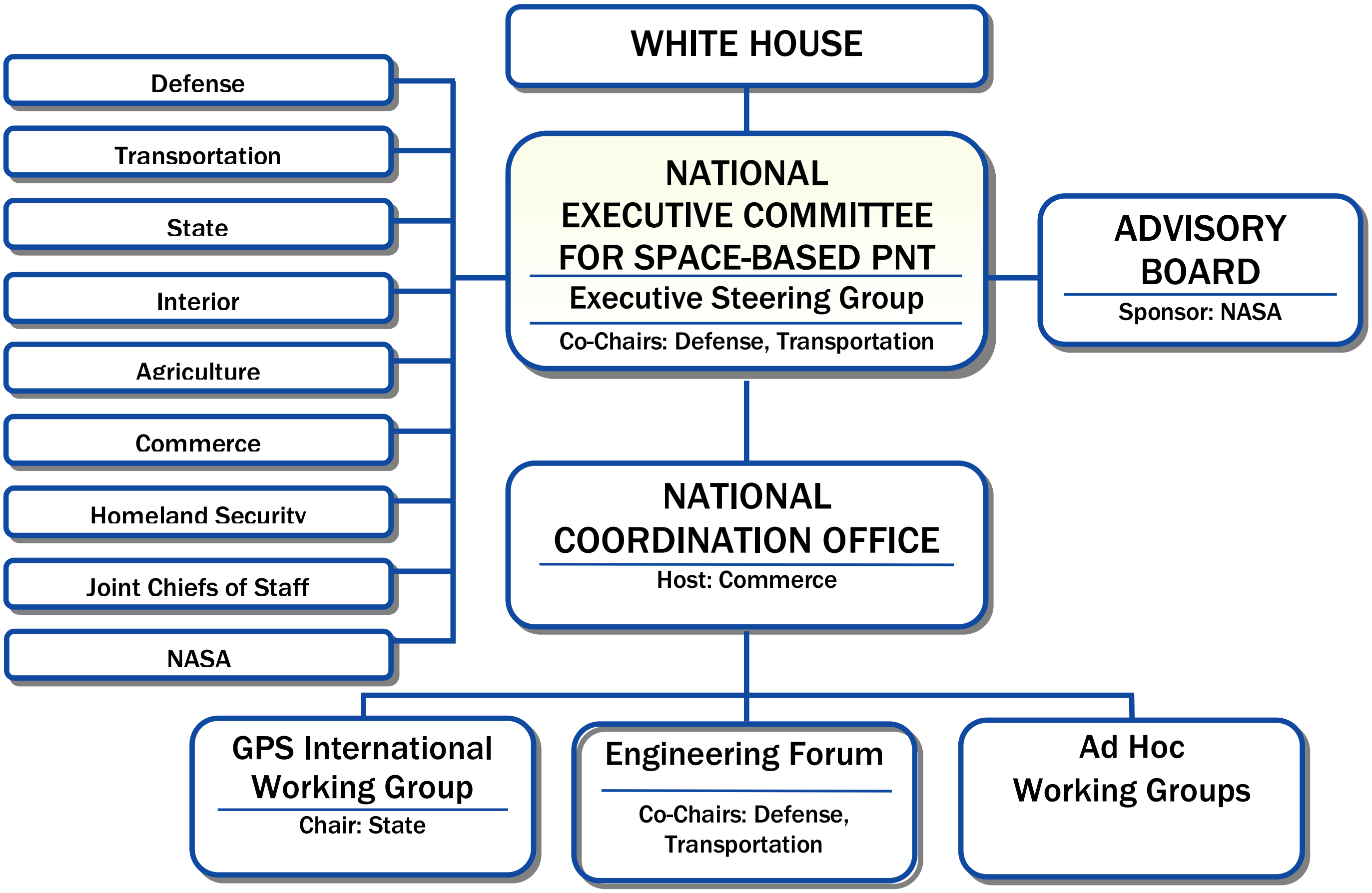

Figure 2-1. National Space-Based Positioning, Navigation, and Timing Management Structure

The National Executive Committee makes recommendations to its member departments and agencies and to the President through the representatives of the Executive Office of the President. In addition, the National Executive Committee advises and coordinates with and among the departments and agencies responsible for the strategic decisions regarding policies, architectures, requirements, and resource allocation for maintaining and improving U.S. space-based PNT infrastructures, including the GPS, its augmentations, security for these services, and relationships with foreign PNT services. Specifically, the National Executive Committee works to:

- Ensure that national security, homeland security, and civil requirements receive full and appropriate consideration in the decision-making process and facilitate the integration and deconfliction of these requirements for space-based PNT capabilities, as required;

- Coordinate individual departments' and agencies' PNT program plans, requirements, budgets, and policies, and assess the adequacy of funding and schedules to meet validated requirements in a timely manner;
- Ensure that the utility of civil services exceeds, or is at least equivalent to, those routinely provided by foreign space-based PNT services;
- Promote plans to modernize the U.S. space-based PNT infrastructure, including: (1) development, deployment, and operation of new and/or improved national security and public safety services when required and to the maximum practical extent; and (2) determining the apportionment of requirements between the GPS and its augmentations, including consideration of user equipment; and
- Review proposals and provide recommendations to the departments and agencies for international cooperation, as well as spectrum management and protection issues.

The National Executive Committee advises and coordinates the interdepartmental resource allocation for the Global Positioning System and its augmentations on an annual basis. The details are outlined in a Five-Year National Space-Based PNT Plan approved annually by the National Executive Committee.

The National Executive Steering Group (ESG) performs tasks, builds consensus and resolves issues on behalf of the National Executive Committee. The Departments of Defense and Transportation co-chair the ESG at the Under/Assistant Secretary level.

The National Coordination Office for Space-Based PNT provides day-to-day staff support to the National Executive Committee and ESG. It is led by a full-time Director chosen by and reporting to the National Executive Committee, and includes a cadre of full-time staff provided by departments and agencies represented on the National Executive Committee.

The National Space-Based PNT Advisory Board provides independent advice to the National Executive Committee. The Advisory Board is comprised of experts from outside the United States Government and is chartered through NASA as a Federal Advisory Committee.

Several working groups support the National Executive Committee through staff-level, interagency collaboration on specific topics. These include the

GPS International Working Group and the National Space-Based PNT Systems Engineering Forum.

2.2 DoD Responsibilities

DoD is responsible for developing, testing, evaluating, implementing, operating, and maintaining aids to navigation and user equipment that are peculiar to warfare and primarily of military concern. DoD is also responsible for ensuring that military vehicles operating in consonance with civil vehicles have the necessary navigation capabilities.

DoD is required by 10 USC § 2281(b) (Ref. 2) to provide for the sustainment and operation of the GPS SPS for peaceful civil, commercial, and scientific uses, on a continuous worldwide basis, free of direct user fees.

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 meet mission requirements;

g. identify special military route and airspace requirements;

h. foster standardization and interoperability of systems with 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 GPS including a SPS that will be available on a continuous, worldwide basis and a PPS for use by the U.S. military and other authorized users;

l. cooperate with the Director of National Intelligence (DNI), DOS 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; and

n. ensure that the U.S. Armed Forces have the capability to use GPS effectively despite hostile attempts to prevent use of the system.

The National Geospatial-Intelligence Agency (NGA) is responsible for providing geospatial information and intelligence to DoD and the Intelligence Community (IC). This includes mapping, charting, and geodesy data and products, such as digital terrain elevation data, digital feature analysis data, digital nautical chart data, Notice to Mariners, aeronautical charts, flight information publications, global gravity and geomagnetic models, geodetic surveys, and the WGS 84. This support also includes geodetic positioning of transmitters for electronic systems and tracking stations for satellite systems, maintenance of a global GPS monitor station network, and generation and distribution of GPS precise ephemerides. Within DoD, NGA 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 NGA are available to the civil sector.

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 United States Navy (USN) 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 USNO in Washington, DC.

DoD carries out its responsibilities for radionavigation coordination through the internal management structure shown in Figure 2-2. The figure 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 CJCS Master Positioning, Navigation and Timing Plan (MPNTP) and other DoD documents.

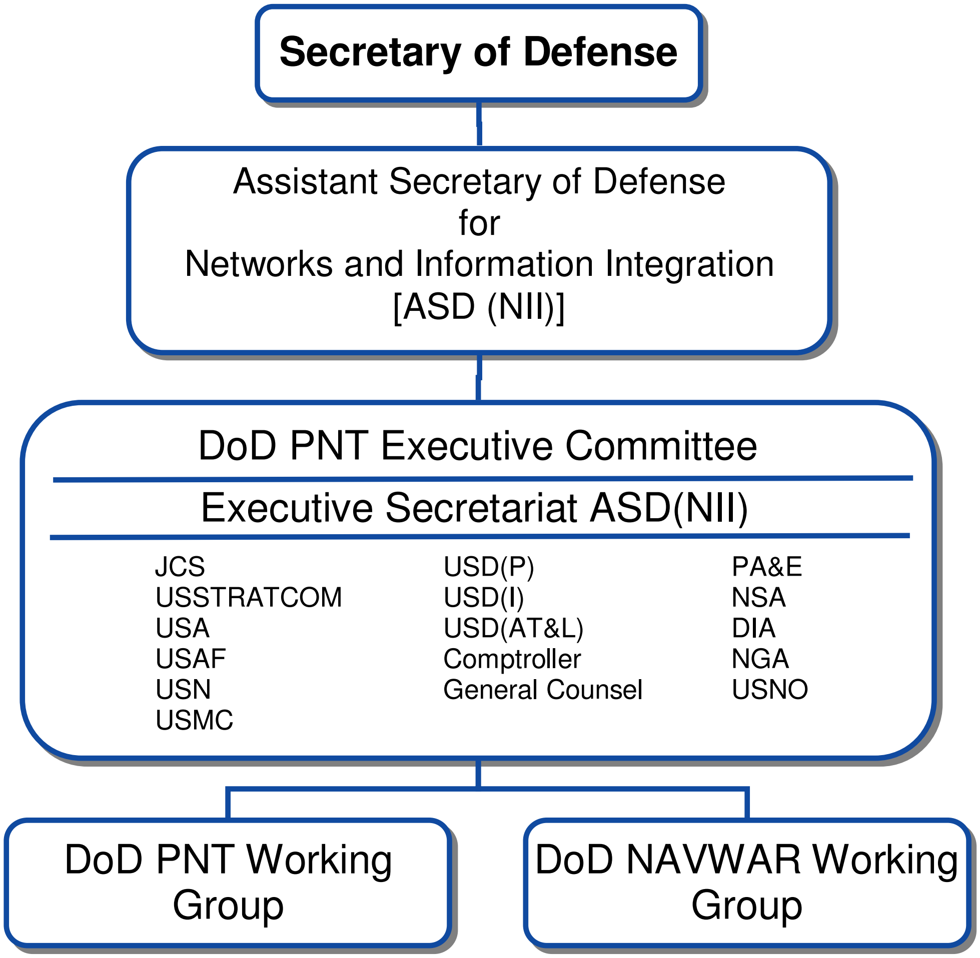

Figure 2-2. DoD PNT Management Structure

2.2.1 Operational Management

The Chairman, Joint Chiefs of Staff, supported by the Joint Staff, is the primary military advisor to the President and the Secretary of Defense. The Joint Chiefs of Staff (JCS) 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.

The MPNTP is the official PNT policy and planning document of the CJCS, which addresses operational defense requirements.

The following organizations also perform navigation management functions:

The Directorate for Command, Control, Communications and Computer Systems Support, Joint Staff (J-6), is responsible for:

- analysis, evaluation, and monitoring of navigation system planning and operations;
- general joint warfighter PNT matters; and
- authoring and publishing 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.

2.2.2 Administrative Management

Four permanent organizations provide radionavigation planning and management support to ASD (NII). These organizations are the DoD PNT Executive Committee; the DoD PNT Working Group; the DoD Navwar Working Group; and the Military Departments/Service Staffs. Brief descriptions are provided below.

2.2.2.1 DoD PNT Executive Committee

The DoD PNT Executive Committee is the DoD focal point and forum for all DoD PNT matters. It provides overall management supervision and decision processes, including intelligence requirements (in coordination with the IC). The Executive Committee contributes to the development of the FRP and coordinates with the DOT POS/NAV Executive Committee.

2.2.2.2 DoD PNT Working Group

The DoD PNT 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.

2.2.2.3 DoD Navwar Working Group

The DoD Navwar Working Group is composed of subject matter experts within DoD organizations that provide the DoD PNT Executive Committee with support and recommendations regarding Navwar doctrine, policy, needs, and implementation.

2.2.2.4 Military Departments/Service Staffs

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.

2.3 DOT Responsibilities

DOT is responsible under 49 USC § 101 for ensuring safe and efficient transportation. Radionavigation systems play an important role in carrying out this responsibility. The two elements within DOT that operate radionavigation systems are the FAA and SLSDC. The RITA Administrator is responsible for coordinating radionavigation planning within DOT and with other civil Federal elements.

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 U.S.;

c. serve as the lead department within the USG for all Federal civil GPS matters;

d. develop and implement USG augmentations to the basic GPS for transportation applications;

e. promote commercial applications of GPS technologies and the acceptance of GPS and U.S. Government augmentations as standards in domestic and international transportation systems;

f. coordinate USG-provided GPS civil augmentation systems to minimize cost and duplication of effort; and,

g. in coordination with the Secretary of Homeland Security, develop, acquire, operate, and maintain backup position, navigation, and timing capabilities that can support critical transportation, homeland security, and other critical civil and commercial infrastructure applications within the U.S., in the event of a disruption of GPS or other space-based positioning, navigation, and timing services, consistent with HSPD-7, Critical Infrastructure Identification, Prioritization, and Protection, dated December 17, 2003.

DOT carries out its responsibilities for civil radionavigation systems planning through the internal management structure shown in Figure 2-3. The structure was originally established by DOT Order 1120.32 (April 27, 1979) and revised by DOT Order 1120.32C (October 11, 1994).

The Secretary of Transportation, under 49 USC § 301, has overall leadership responsibility for navigation matters within DOT and promulgates radionavigation plans. RITA coordinates radionavigation issues and planning which affect multiple modes of transportation, including those that are intermodal in nature. RITA also interfaces with agencies outside of DOT on non-transportation uses of radionavigation systems.

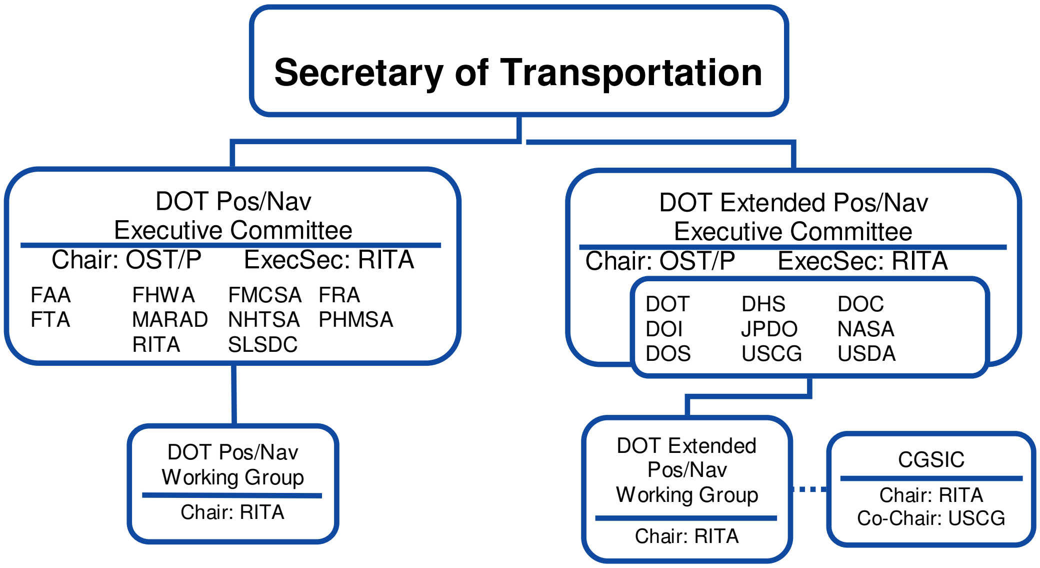

Figure 2-3. DOT Navigation Management Structure

2.3.1 DOT POS/NAV Executive Committee

The DOT POS/NAV Executive Committee is the top-level management body of the organizational structure. It is chaired by Assistant Secretary for Policy (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), FAA, FHWA, FMCSA, FRA, FTA, MARAD, NHTSA, PHMSA, RITA, and SLSDC.

2.3.1.1 DOT POS/NAV Working Group

The DOT POS/NAV Working Group is the staff working core of the organizational structure. It is chaired by RITA and consists of representatives from OST/C, OST/B, OST/M, FAA, FHWA, the ITS Joint Program Office (ITS-JPO), FMCSA, FRA, NHTSA, FTA, SLSDC, MARAD, PHMSA, and RITA, including the Bureau of Transportation Statistics (BTS) and the Volpe Center, and other DOT elements as necessary. The Center for Navigation, Volpe Center, also provides technical assistance to the POS/NAV Working Group.

2.3.2 DOT Extended POS/NAV Executive Committee

The DOT Extended POS/NAV Executive Committee is the top-level management body that interfaces with agencies outside of DOT for non-transportation use of radionavigation systems. It is chaired by OST/P and consists of policy-level representatives from DOT, DHS, DOC, DOI, JPDO, NASA, DOS, USCG, and the U.S. Department of Agriculture (USDA).

2.3.2.1 DOT Extended POS/NAV Working Group

The DOT Extended POS/NAV Working Group is the staff working core that interfaces with agencies outside of DOT for non-transportation use of radionavigation systems. It is chaired by RITA and consists of consists of representatives from DOT, DHS, DOC, DOI, JPDO, NASA, DOS, USCG, and USDA. The Center for Navigation, Volpe Center, also provides technical assistance to the POS/NAV Working Group.

2.3.2.2 Civil GPS Service Interface Committee (CGSIC)

CGSIC, chaired by RITA with DHS/USCG as Deputy Chair and Executive Secretariat, is DOT's official committee for information exchange with all GPS users, national and international.

2.3.3 Other DOT Agencies

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 Administrator of the FAA is required to develop a common civil and military airspace system. 49 USC § 44505(a) states the following:

"General Requirements.—

(1) The Administrator of the Federal Aviation Administration shall –

(A) develop, alter, test, and evaluate systems, procedures, facilities, and devices, and define their performance characteristics, to meet the needs for safe and effective navigation and traffic control of civil and military aviation, except for needs of the armed forces that are peculiar to air warfare and primarily of military concern; and

(B) select systems, procedures, facilities, and devices that will best serve those needs and promote maximum coordination of air traffic control and air defense systems.

(2) The Administrator may make contracts to carry out this subsection without regard to section 34324(a) and (b) of title 31.

(3) When a substantial question exists under paragraph (1) of this subsection about whether a matter is of primary concern to the armed forces, the Administrator shall decide whether the Administrator or the Secretary of the appropriate military department has responsibility. The

Administrator shall be given technical information related to each research and development project of the armed forces that potentially applies to, or potentially conflicts with, the common system to ensure that potential application to the common system is considered properly and that potential conflicts with the system are eliminated."

SLSDC has responsibility for assuring safe navigation along the St. Lawrence Seaway. 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, FMCSA, FRA, FTA, NHTSA, and RITA 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.

2.4 DHS Responsibilities

DHS is responsible for identifying the PNT requirements for homeland security purposes. In addition, the Secretary of Homeland Security, in coordination with the Secretary of Transportation, has the responsibility to develop, acquire, operate, and maintain backup PNT capabilities in the event of a disruption of GPS.

In coordination with the Secretary of Transportation, and with other departments and agencies, DHS will promote the use of the GPS positioning and timing standards for use by Federal agencies, and by state and local authorities responsible for public safety and emergency response.

In coordination with the Secretary of Defense, and in cooperation with the Secretaries of Transportation and Commerce, DHS will ensure:

- mechanisms are in place to identify, understand, and disseminate timely information regarding threats associated with the potential hostile use of space-based positioning, navigation, and timing services within the U.S.; and

- procedures are developed, implemented, and routinely exercised to request assistance from the Secretary of Defense should it become necessary to deny hostile use of space-based position, navigation and timing services within the U.S.

In coordination with the Secretaries of Defense, Transportation, and Commerce, DHS will develop and maintain capabilities, procedures, and techniques, and routinely exercise civil contingency responses to ensure continuity of operations in the event that access to GPS is disrupted or denied.

In coordination with the Secretaries of Transportation and Defense, and in cooperation with other departments and agencies, it is DHS's responsibility to coordinate the use of existing and planned Federal capabilities to identify, locate, and attribute any interference within the U.S. that adversely affects use of GPS and its augmentations for homeland security, civil, commercial, and scientific purposes.

Finally, in coordination with the Secretaries of Transportation and Defense, and the DNI, and in cooperation with other departments and agencies, DHS will:

- develop a repository and database for reports of domestic and international interference to the civil services of GPS and its augmentations for homeland security, civil, commercial, and scientific purposes; and

- notify promptly the Administrator, NTIA, the Chairman of the FCC, the Secretary of Defense, the DNI, and other departments and agencies in cases of domestic or international interference with space-based PNT services to enable appropriate investigation, notification, and/or enforcement action.

2.4.1 United States Coast Guard (USCG)

As an agency within DHS, USCG defines the need for, and provides, aids to navigation and facilities required for safe and efficient navigation. 14 USC § 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 U.S.;

2) aids to air navigation required to serve the needs of the armed forces of the U.S. peculiar to warfare and primarily of military concern as determined by the Secretary of Defense or the Secretary of any department within the DoD 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 U.S. peculiar to warfare and primarily of military concern as determined by the Secretary of Defense or any department within the DoD; or (b) required to serve the needs of the maritime commerce of the U.S.; or (c) required to serve the needs of the air commerce of the U.S. as requested by the Administrator of the FAA.

These aids to navigation other than electronic aids to navigation systems shall be established and operated only within the U.S., the waters above the Continental Shelf, the territories and possessions of the U.S., the Trust Territory of the Pacific Islands, and beyond the territorial jurisdiction of the U.S. at places where naval or military bases of the United States are or may be located. USCG may establish, maintain, and operate aids to marine navigation under paragraph (1) of this section by contract with any person, public body, or instrumentality."

2.5 DOC Responsibilities

The U.S. Space-Based PNT Policy (Ref. 4) assigns certain roles and responsibilities to the DOC, including: representing U.S. commercial interests in the review of system requirements; providing civil space system requirements for space-based PNT to DOT; protecting space-based PNT spectrum through appropriate spectrum management that preserves existing and evolving uses of GPS while allowing development of other radio frequency technologies and services; and promoting federal, state, and local use of space-based PNT.

DOC hosts the National Space-Based PNT ExComm and its National Coordination Office (NCO), providing office space, staffing, support services, and other resources. Through NOAA, DOC manages the U.S. Continuously Operating Reference Stations (CORS) network and its Online Positioning User Service (OPUS). NOAA also serves as the current Analysis Center Coordinator for the International GNSS Service (IGS). Through the National Institute of Standards and Technology (NIST), DOC performs atomic clock research, contributes to the determination of UTC, and conducts calibration services and analysis for the GPS satellites. NIST operates the U.S. primary frequency standard.

2.6 DOS Responsibilities

DOS responsibilities are included in Reference 2. The Policy directs that DOS:

- in cooperation with the Secretary of Defense, the Secretary of Transportation, and other Departments and Agencies promote the use of civil aspects of GPS and its augmentation services and standards with foreign governments and other international organizations;
- take the lead for negotiating with foreign governments and international organizations regarding civil and, as appropriate and in coordination with the Secretary of Defense, military positioning, navigation, and timing matters, including but not limited to coordinating interagency review of:
    - instructions to U.S. delegations for bilateral and multilateral consultations relating to the planning, management, and use of GPS and related augmentation systems;
    - international agreements with foreign governments and international organizations regarding the planning, operation, management, and/or use of GPS and its augmentations; and
    - modify and maintain, in coordination with the Secretaries of Defense, Commerce, and Energy, the DNI, and the NASA Administrator, the Sensitive Technology List created by U.S. Commercial Remote Sensing Space Policy, dated April 25, 2003. In particular, include sensitive technology items and/or information related to PNT applications.

2.7 NASA Responsibilities

NASA's mission is to pioneer the future in space exploration, scientific discovery and aeronautics research. This research includes a number of GPS application areas in the space, aeronautics, and terrestrial environments. The 2004 U.S. Space-Based PNT Policy tasks the NASA Administrator, in cooperation with the Secretary of Commerce, to develop and provide to the Secretary of Transportation, requirements for the use of GPS and its augmentations to support civil space systems. In support of this policy, NASA’s participation in the National Space-Based PNT ExComm includes: (1) ensuring that the utility of GPS civil space services exceeds, or is at least equivalent to, those routinely provided by foreign space-based PNT services; (2) promoting plans to modernize the U.S. space-based PNT infrastructure; and (3) providing support and funding to the space-based PNT Advisory Board.

3

Policy

This section describes the U.S. policy for providing each Federal radionavigation system identified in this document.

3.1 General

The Federal Government operates radionavigation systems as one of the necessary elements to enable safe transportation and encourage commerce within the U.S. A goal of the USG is to provide reliable radionavigation services to the public in the most cost-effective manner possible.

As the full civil potential of GPS services and its augmentations are implemented, the demand for services provided by other Federally provided radionavigation systems is expected to decrease. The USG will reduce non-GPS-based radionavigation services with the reduction in the demand for those services. However, it is a policy objective of the USG not to be critically dependent upon a single system for PNT. The USG will maintain back-up capabilities to meet: (1) growing national, homeland, and economic security requirements, (2) civil requirements, and (3) commercial and scientific demands. Operational, economic, safety, and security considerations will dictate the need for complementary PNT systems. While some operations may be conducted safely using a single radionavigation system, it is Federal policy to provide redundant radionavigation service where required. Backups to GPS for safety-of-life navigation applications, or other critical applications, can be other radionavigation systems, or operational procedures, or a combination of these systems and procedures to form a safe and effective backup. Backups to GPS for timing applications can be a highly accurate crystal oscillator or atomic clock and a communications link to a timing source that is traceable to UTC.

When the benefits, including the safety benefits, derived by the users of a radionavigation service or capability are outweighed by its sustainment cost, by policy the Federal Government can no longer continue to provide that service or capability. Divestment criteria are established so that when usage falls below the sustainment threshold, the service or capability is offered to state, local, or other non-Federal service providers prior to decommissioning. A policy decision may be made to divest the Federal Government of all facilities of a certain type of radionavigation service or capability. A suitable transition period is established prior to divestment, based on factors such as user equipment availability, radio spectrum transition issues, cost, user acceptance, budgetary considerations, and the public interest. International commitments will affect certain types and levels of navigation services provided by the Federal Government to ensure interoperability with international users.

Radionavigation systems established primarily for safety of transportation and national defense also provide significant benefits to other civil, commercial, and scientific users. In recognition of this, the USG will consider the needs of these users before making any changes to the operation of radionavigation systems.

The U.S. national policy is that all radionavigation systems operated for public use by the USG will remain available for peaceful use subject to direction by the President in the event of a 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 communications links, including those used to transmit differential GPS corrections and other GPS augmentations, are also subject to the direction of the President.

3.2 GPS

3.2.1 Executive Policy

On December 8, 2004, the President issued national policy that establishes guidance and implementation actions for space-based PNT programs, augmentations, and activities for U.S. national and homeland security, civil, scientific, and commercial purposes. This policy provides guidance for:

- development, acquisition, operation, sustainment, and modernization of GPS and U.S.-developed, owned and/or operated systems used to augment or otherwise improve the GPS and/or other space-based PNT signals;
- development, deployment, sustainment, and modernization of capabilities to protect U.S. and allied access to and use of GPS for national, homeland, and economic security, and to deny adversaries

access to space-based PNT services, as required in times of conflict; and

- foreign access to the GPS and USG augmentations, and international cooperation with foreign space-based PNT services, including augmentations.

Over the past decade, GPS has grown into a global utility whose multi-use services are integral to U.S. national security, economic growth, transportation safety, and homeland security, and are an essential element of the worldwide economic infrastructure. In the May 1, 2000 "*Statement by the President Regarding the United States' Decision to Stop Degrading Global Positioning System Accuracy,*" the U.S. recognized the increasing importance of GPS to civil and commercial users by discontinuing the deliberate degradation of accuracy for non-military signals, known as Selective Availability (SA). Since that time, commercial and civil applications of GPS have continued to multiply and their importance has increased significantly. Services dependent on GPS information are now an engine for economic growth, enhancing economic development, and improving safety of life, and the system is a key component of multiple sectors of U.S. critical infrastructure. In September 2007, the USG announced its decision to procure the future generation of GPS satellites, known as GPS III, without the SA feature. In doing this, the USG makes the policy decision of 2000 permanent and eliminates a source of uncertainty in GPS performance that has been of concern to civil GPS users worldwide for some time.

3.2.2 GPS Service

While the growth in civil and commercial applications continues, PNT information provided by GPS remains critical to U.S. national security. Likewise, the continuing growth of services based on the GPS presents opportunities, risks, and threats to U.S. national, homeland, and economic security. The widespread and growing dependence on GPS of military, civil, and commercial systems and infrastructures has made many of these systems inherently vulnerable to an unexpected interruption in PNT services.

Therefore, the U.S. must continue to improve and maintain GPS, augmentations, and backup capabilities to meet growing national, homeland, and economic security requirements, for civil requirements, and to meet commercial and scientific demands.

The U.S. will continue to maintain space-based PNT services, augmentation, back-up, and service denial capabilities that: (1) provide uninterrupted availability of PNT services; (2) meet growing national, homeland, economic security, and civil requirements, and scientific and commercial demands; (3) remain the pre-eminent military space-based

PNT service; (4) continue to provide civil services that exceed or are competitive with foreign civil space-based PNT services and augmentation systems; (5) remain essential components of internationally accepted PNT services; and (6) promote U.S. technological leadership in applications involving space-based PNT services. To achieve this goal, the USG will:

- provide uninterrupted access to U.S. space-based global, precise PNT services for U.S. and allied national security systems and capabilities through GPS, without being dependent on foreign PNT services;

- provide on a continuous, worldwide basis civil space-based, PNT services free of direct user fees for civil, commercial, and scientific uses, and for homeland security through GPS and its augmentations, and provide open, free access to information necessary to develop and build equipment to use these services;

- improve capabilities to deny hostile use of any space-based PNT services, without unduly disrupting civil and commercial access to civil PNT services outside an area of military operations, or for homeland security purposes;

- improve the performance of space-based PNT services, including more robust resistance to interference for, and consistent with, U.S. and allied national security purposes, homeland security, and civil, commercial, and scientific users worldwide;

- maintain GPS as a component of multiple sectors of the U.S. Critical Infrastructure, consistent with HSPD-7, Critical Infrastructure Identification, Prioritization, and Protection, dated December 17, 2003;

- encourage foreign development of PNT services and systems based on GPS. Seek to ensure that foreign space-based PNT systems are interoperable with the civil services of GPS and its augmentations in order to benefit civil, commercial, and scientific users worldwide. At a minimum, seek to ensure that foreign systems are compatible with GPS and its augmentations and address mutual security concerns with foreign providers to prevent hostile use of space-based PNT services; and

- promote the use of U.S. space-based PNT services and capabilities for applications at the Federal, state, and local level, to the maximum practical extent.

3.2.2.1 Standard Positioning Service (SPS)

The USG has made the SPS of GPS available for worldwide use by the international community. The maritime community has documented this promise in IMO Assembly Resolution A.953(23). The aviation community has documented this promise at the ICAO Tenth Air Navigation Conference and at the 29th ICAO Assembly. The USG has made clear that it intends to make the GPS SPS available for the foreseeable future, on a continuous, worldwide basis, and free of direct user fees, subject to the availability of funds as required by U.S. law. This service is being made available on a nondiscriminatory basis to all users at the performance levels specified in the SPS Performance Standard (PS). The USG will take all necessary measures for the foreseeable future to maintain the integrity, reliability and availability of the GPS SPS and expects to provide at least six years' notice to the maritime community and ten years' notice to the aviation community prior to any termination of GPS operations or elimination of the GPS SPS.

3.2.2.2 Precise Positioning Service (PPS)

The USG has made available uninterrupted global access to the PPS of the GPS to U.S. and allied national security systems.

3.2.3 Navigation Warfare (Navwar)

In the December 2004 U.S. Space-Based PNT Policy, the President directed that the Secretary of Defense shall develop, acquire, operate, realistically test, evaluate, and maintain Navwar capabilities.

The DoD Navwar program exists to ensure that the U.S. retains a military advantage in an area of conflict by: protecting authorized use of GPS; preventing the hostile use of GPS and its augmentations; and preserving civilian uses outside an area of conflict. The Navwar program will require periodic testing which may impact the civil use of GPS.

3.2.4 GPS Backup

The USG recognizes the benefits of providing a back-up capability to GPS to mitigate the safety, security, or economic effects of a disruption of GPS service. In accordance with *U.S. Space-Based Positioning, Navigation, and Timing Policy*, the Secretary of Transportation, in coordination with the Secretary of Homeland Security, will develop, acquire, operate, and maintain backup position, navigation, and timing capabilities that can support critical transportation, homeland security, and other critical civil and commercial infrastructure applications within the U.S., consistent with HSPD-7.

In March 2007, the DOT Pos/Nav Executive Committee and the DHS Geospatial/PNT Executive Committee accepted the findings of the Institute for Defense Analysis' Independent Assessment Team and approved to pursue the designation of Enhanced-Loran, commonly referred as *eLoran*, as a national PNT backup for the U.S. homeland. At its March 2007 meeting, the National Space-based PNT ExComm supported this approach and tasked DOT and DHS to complete an action plan that includes identifying an executive agent, developing a transition plan to address funding and operations and requesting the approval by the DOT and DHS Secretaries resulting in a final decision. DoD has not approved *eLoran* as a GPS backup for military applications.

In March 2008, the National Space-based PNT ExComm endorsed the DOT/DHS decision to transition the LORAN system to *eLoran*.

With respect to transportation to include aviation, commercial maritime, rail, and highway, the DOT has determined that sufficient alternative navigation aids currently exist in the event of a loss of GPS-based services, and therefore Loran currently is not needed as a back-up navigation aid for transportation safety-of-life users. However, many transportation safety-of-life applications depend on commercial communication systems and DOT recognizes the importance of the Loran system as a backup to GPS for critical infrastructure applications requiring precise time and frequency.

Currently, DHS is determining whether alternative backups or contingency plans exist across the critical infrastructure and key resource sectors identified in the National Infrastructure Protection Plan in the event of a loss of GPS-based services. An initial survey of the Federal critical infrastructure partners indicates wide variance in backup system requirements. Therefore, DHS is working with Federal partners to clarify the operational requirements.

3.2.5 Timing

USNO provides GPS with the underlying UTC timing reference necessary for precise PNT operations. USNO operates a primary and backup Master Clock system from its headquarters in Washington, DC and the Alternate Master Clock facility co-located with the GPS Master Control Segment (MCS) at Schriever Air Force Base in Colorado Springs, CO. The USNO Master Clock system is made up of an ensemble of more than 50 precise atomic clocks that are fully traceable to the internationally accepted standard for timing, promulgated by the International Bureau of Weights and Measures (BIPM). USNO uses an ensemble of specialized GPS timing monitor station receivers to continuously monitor the GPS signal and provide the GPS MCS with this precise timing data. Details about obtaining calibration of GPS timing receivers and traceability to UTC time can be found at http://tycho.usno.navy.mil.

3.2.6 GPS Signal Monitoring

NGA generates precise, post-fit GPS orbits for DoD as well as predicted orbits. NGA operates a global network of 11 GPS monitor stations geographically placed to complement the six United States Air Force (USAF) monitor stations. The NGA stations are controlled with complete redundancy in key components and provide high quality data. The NGA data are also transmitted in near-real-time to the Air Force Space Command for incorporation in their real-time GPS operations. The combined NGA-USAF GPS tracking network is used to define the WGS 84 reference frame, the standard geodetic reference system for GPS and for all DoD positioning, navigation and geospatial products. GPS data and products from NGA can be found at http://earth-info.nga.mil/GandG/sathtml.

3.2.7 Modernized GPS Signals

3.2.7.1 Civil Signals

In addition to the L1 Coarse/Acquisition (C/A) signal, the USG will add three additional coded signals to support future civil applications:

- L1C, frequency 1575.42 MHz, providing better performance than the current C/A signal being used by civilian receivers;
- L2C, frequency 1227.6 MHz; and
- L5, frequency 1176.45 MHz, to meet the needs of critical safety-of-life applications, such as civil aviation.

The L1C signal is designed to be interoperable with the European Galileo system and is being promoted as a future world standard for incorporation into Global Navigation Satellite Systems (GNSS). The next generation of GPS satellites, GPS III, will begin broadcasting L1C around 2014.

The performance specifications in the current SPS PS apply to users of the L1 C/A (1575.42 MHz) signal. As new modernized GPS civil signals (L1C, L2C, and L5) achieve initial operating capability (IOC), performance standards for services utilizing these signals will be developed.

3.2.7.2 Discontinuation of Codeless and Semi-Codeless GPS Access

As published in the Federal Register on September 23, 2008 (Volume 73, Number 185), the USG commits to maintaining the existing GPS L1 C/A, L1 P(Y), L2C and L2 P(Y) signal characteristics that enable codeless and semi-codeless GPS access until at least 31 December 2020. To enable an orderly and systematic transition, users of semi-codeless and codeless receiving equipment are expected to transition to using civil-coded signals by this date.

3.2.7.3 Military Signals

Currently, GPS military users are provided P(Y) code signals on L1 and L2. These will be supplanted in the future by the M-Code, the next generation military GPS signal. The first GPS Block IIR-M satellite began broadcasting M-Code in September 2006. M-Code will significantly improve exclusivity of access because, in addition to being encrypted, it will be spectrally separate from civilian signals and other radionavigation satellite service signals, thereby enabling U.S. navigation warfare operations through spectral separation. Navigation warfare involves protecting U.S. and allied use of GPS while simultaneously preventing hostile forces access to GPS services and preserving peaceful civil GPS use outside of an area of military operations. The M-Code will permit higher power operation than the present signal design and will facilitate localized tactical denial of GPS civil signals to prevent their use by hostile forces. Military GPS receivers, when tracking the encrypted military signals, are much more resistant to interference than commercial GPS equipment. The newest generation of military GPS receivers that can access military GPS signals directly are even more resistant to interference; however, future improvements in signal availability and receiver performance will continue to be necessary.

3.2.8 Military Use of GPS Civil Signals

DoD does not have an operational requirement to use the GPS civil signals, designated L1C, L2C, and L5, or the Wide Area Augmentation System (WAAS), with the exception of the Army validated WAAS requirement documented in the Global Air Traffic Management (GATM) Operational Requirements Document (ORD). Since DoD policy prohibits the use of civil signals or augmentation systems in wartime environments and dual equipage is not fiscally practical, type approval of military aviation receivers is required to eliminate the need for civil GPS equipage on military aircraft. This will provide an enhanced capability to span the operational environment for military aviation—from flight in civil airspace in peacetime to combat operations worldwide. Commercial operators of Civil Reserve Air Fleet (CRAF) airframes may elect to equip with L5 and/or WAAS if there is a demonstrated benefit at the civil airports where these aircraft are operated.

DoD is performing a type approval of military aviation receivers for use in the NAS and in international airspace. This approval is being done in accordance with civil aviation standards, while maintaining the capability to use military signals. DoD will also work with the military establishments of its international allies to seek approval for use of these receivers in foreign airspace.

3.2.9 The Future of GPS

GPS will be the primary Federally provided radionavigation system for the foreseeable future. GPS will be augmented and improved to satisfy future civil and military requirements for accuracy, availability, continuity, coverage, and integrity.

3.3 Mitigating Disruptions to Satellite Navigation Services

DOT, in conjunction with other governmental agencies, is developing and implementing mitigation plans in response to the recommendations of the Volpe Center report: *Vulnerability Assessment of the Transportation Infrastructure Relying on Global Positioning System* (Ref. 5), as well as other USG critical infrastructure protection initiatives. In addition, the U.S. Space-Based PNT Policy directs DOT, in coordination with DHS, to develop, acquire, operate, and maintain back-up PNT capabilities for critical civil and commercial applications within the U.S., in the event of a disruption to GPS or its augmentations.

3.3.1 Mitigating Disruptions in Aviation Operations

FAA will continue to operate and maintain a network of ground-based navigation aids (NAVAID) for the foreseeable future, however, the FAA is committed to delivering satellite-based navigation service capable of supporting operations throughout the NAS without routine reliance on other navigation systems. Even when this goal is attained, many operators are expected to choose to retain other radionavigation receivers, and it is possible that inertial navigation systems could be required for some operations. Procedural means will also be used to maintain safe operations in the event of a loss of GPS. FAA will update the navigation strategy as necessary to ensure safe and reliable air transportation. Critical issues to be addressed are discussed below.

Ionospheric scintillation during severe solar storms is also a concern, but is expected to have only minimal impact on en route, terminal and nonprecision approach operations, however, ionospheric anomalies may cause periodic outages of localizer performance with vertical guidance (LPV) approach capability using WAAS until the system is upgraded.

A loss of GPS service, due to either intentional or unintentional interference, in the absence of any other means of navigation, would have varying negative effects on air traffic operations. These effects could range from nuisance events requiring standard restoration of capabilities, to an inability to provide normal air traffic control service within one or more sectors of airspace[*] for a significant period of time.

In addition to FAA plans of retaining a minimum network of VOR, DME, and ILS facilities to serve as a backup to GPS for the near future, several other solutions have been identified to help mitigate the effects of a satellite navigation (SATNAV) service disruption:

---

[*] The NAS is divided into hundreds of air traffic control “sectors.” A single air traffic controller has the responsibility to keep aircraft safely separated from one another within each sector and from other sectors. Sector dimensions vary, and are established based on predominant traffic flows, altitude, and controller workload.

- The L5 civil frequency planned for GPS will help mitigate the impacts of both solar activity and unintentional interference, but it may be 2018 before a full constellation of dual-frequency satellites (L1 and L5) is available. The dual frequency capability with L5 will address ionospheric scintillation by enabling receivers to calculate actual ionospheric corrections, thereby preserving LPV capability during severe ionospheric storms.

- Modern transport-category turbojet aircraft with inertial systems may be able to continue navigating safely for a period of time after losing radionavigation position updating depending on the route or procedure being flown. 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 with time and will eventually fail to meet airspace requirements.

- Integrated GPS/inertial avionics having anti-jam capability could reduce the area affected by GPS jamming or unintentional interference. Industry research is proceeding to develop this technology, with an expectation that it might be marketed to the general aviation community at some point in the future.

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

3.3.2 Mitigating Disruptions in Maritime Operations

USCG has identified two critical maritime applications:

- inland waterway and harbor entrance and approach; and
- timing and synchronization [maritime Automatic Identification System (AIS) standard].

For the most part, mariners practice conventional navigation, and employ a variety shipboard and external systems such as GPS, Differential GPS (DGPS), shipboard radar, visual aids to navigation, fathometers, paper and electronic charts, Vessel Traffic Service (VTS) and pilotage. In addition, USCG exercises a certain amount of control over the waterway, under the authority vested in the Captain of the Port, and may close waterways or restrict marine activity during adverse conditions or special operations. These combined elements facilitate safe marine navigation. Because of the extensive backup network of visual aids to navigation and independent shipboard systems, vessels operating in the harbor entrance and approach and inland waterways could continue to operate with some level of degradation to safety and efficiency during GPS disruptions.

AIS is an example of how a new technology can be designed around GPS while at the same time implementing measures that, if used, can mitigate the impact of the potential vulnerabilities of GPS. Specifically, the AIS design team was aware of the potential of GPS interruptions. Although AIS uses GPS for primary timing, secondary timing is provided by an external synchronization method that is based upon the reception of other AIS stations' broadcasts and, secondary positioning information can be utilized from an electronic navigation system other than GPS/DGPS, but only if such a system is installed on the vessel. Although loss of GPS timing or positioning will not technically prevent individual AIS transceivers from operating, the system's capability to apply accurate "time tags" and accurate "vessel positions" to the data packets will otherwise be lost. This will eliminate the system's ability to serve its safety and security functions.

3.3.3 Mitigating Disruptions in Land Operations

Surface transportation users currently use radionavigation services from GPS and its augmentations to supplement other available non-radionavigation systems. Under this operational paradigm, users seamlessly use other existing techniques to mitigate both the short-term loss of GPS due to obstructions and the longer-term loss due to failed on-board user equipment and adverse operating environments. In future applications, accuracy requirements are expected to become much more stringent, and GPS and its augmentations are likely to play a more critical role. The loss of GPS and its augmentations will be carefully evaluated within the overall operational environment to ensure continued safe and efficient operation of the land transportation system.

Surface transportation agencies are working with industry to ensure that safety critical systems that use GPS and its augmentations consider the loss of these radionavigation services and are able to mitigate its effects in order to continue safe and efficient operation of the nation's surface transportation infrastructure. This is accomplished today by outreach to user groups and local transportation agencies and defining minimum operational or functional standards. In the future, training for application developers, state and local highway and transit agencies, and motor carriers on the operational capabilities of GPS as well as what to do when failures occur may be necessary. Finally, since it is expected that signal availability from GPS may not be adequate for surface users experiencing canopy/urban obstructions, alternate systems that perform a verification test on the GPS navigation solution and that support continued operation in the event of a loss of GPS will be employed in a system-of-systems configuration.

3.3.4 Mitigating Disruptions in Railroad Operations

FRA's Intelligent Railroad Systems initiative encourages an integrated approach to technology that incorporates systems that are interoperable, synergistic and redundant. For example, since GPS is susceptible to jamming and unintentional interference, FRA encourages the use of technologies and procedures that cannot be jammed or interfered with as a backup. These technologies and procedures include inertial navigation systems, sensor circuits, signaling systems, and dispatcher operations. These redundant systems and procedures ensure the safe and efficient operation of the railroad system during the loss or disruption of GPS. Similarly, since all radionavigation systems are susceptible to interference, radionavigation systems are not considered acceptable backups to GPS for rail applications.

Recognizing that satellite navigation services can be disrupted, FRA will:

- work towards bringing anti-jam capable receivers to the railroad industry;
- encourage the incorporation of low cost Inertial Navigation Units (INU) in PTC systems;
- develop the capability to update INUs automatically via inputs from railroad sensors, and manually when a locomotive passes a milepost;
- develop equipment standards and architectures for use in railroad applications;
- advocate robust signal structures for satellite navigation services and their augmentation systems such as NDGPS; and
- work with other agencies and the international community to prevent and mitigate disruptions of satellite navigation services and their augmentation systems such as NDGPS.

3.3.5 Mitigating Disruptions in Non-Navigation Applications

Common positioning applications include: surveying and mapping; precision agriculture; emergency response and law enforcement; fire services; environmental resource management; utility location and management; asset inventory and management; and logistics. These applications have a highly variable duration and involve sporadic areas of operation. Because of the flexible character of positioning applications, operations will typically be halted until the GPS or GPS Augmentation signal is restored in an area. Optical and inertial surveying equipment are back-up options that could meet the accuracy requirements of these applications, depending on the capabilities and preparation of these operators.

3.3.6 Mitigating Disruptions in NASA Applications

GPS PPS receivers are used for Space Shuttle navigation, and were chosen for being less susceptible to disruption.

The Inertial Navigation System (INS), which is the primary navigation system, is updated through position fixes from GPS (single string) and TACAN in OV-103 (Discovery) and OV-104 (Atlantis), and a three string GPS on OV-105 (Endeavour). Therefore, brief disruptions in GPS would initially be compensated by the INS. Should GPS service be disrupted prior to entry, emergency procedures call for tracking using ground-based C-Band radar. Additional redundancy is provided through drag and barometric altimeters, as well as MLS at the landing sites at NASA's Kennedy Space Center, FL; Edwards Air Force Base, CA; and White Sands Missile Range, NM; and the emergency launch-abort landing sites in France and Spain. During entry operations, the landing sites may be monitored for interference to GPS. During re-entry, the landing site at Kennedy Space Center is continuously monitored for GPS interference.

A number of GPS receivers have been tested on spacecraft for real-time navigation and attitude determination. GPS facilitates autonomous operations in Earth orbit and reduces operational costs and communications bandwidth. Should GPS service be disrupted, then ground-based tracking could be used for navigation and on-board backup instruments such as magnetometers, Earth sensors, and directional antennas for attitude determination. Mitigations range from the use of lower accuracy navigation methods to no mitigation.

3.4 Aeronautical Transition Policy

3.4.1 Transition to Satellite-Based Radionavigation

FAA is transitioning to providing SATNAV services based primarily on GPS augmented by:

- aircraft-based augmentation systems (ABAS), such as Receiver Autonomous Integrity Monitoring (RAIM);
- space-based augmentation systems (SBAS), such as WAAS; and
- ground-based augmentation systems (GBAS), such as the Local Area Augmentation System (LAAS).

As a result of this transition, the need for ground-based navigation services will diminish, and the number of Federally provided ground-based facilities will be reduced accordingly, but with sufficient time for users to equip with SATNAV avionics.

The pace and extent of the transition to SATNAV will depend upon a number of factors, including:

- NAS performance;
- achievement of GPS and GPS augmentation systems program milestones; and
- user acceptance.

The specific NAVAID facilities to be divested will be determined based on criteria currently under development. The transition plans will continue to be coordinated with airspace users and the aviation industry.

3.4.2 SATNAV Transition Issues

GPS represents a fundamental departure from traditional ground-based navigation systems with respect to aviation operations. Ground-based systems provide services that are limited to the locations where they are installed. VOR/DME and TACAN provide azimuth and distance relative to the facility, supporting point-to-point navigation. GPS supports area navigation (RNAV) operations. During transition, both types of users need to be accommodated. Most ground-based systems (such as an ILS) provide service to only a single runway. GPS approach operations can be made available to any existing runway in the NAS with or without ground-based radionavigation equipment. Required mitigations to terrain and obstructions, as well as airport improvements, are unchanged from ILS-based precision approach operations. To realize the full benefit of GPS approach operations, new criteria need to be developed for airports that do not meet the precision approach criteria. GBAS LAAS supports precision approach operations to multiple runway ends at an airport, and is not affected by multipath interference from signals reflecting off other aircraft. LAAS thus allows a higher acceptance rate than ILS, but mixed usage must be accommodated during transition.

4

Radionavigation System User Requirements

As used in this document, the term “requirements” encompasses a broad spectrum of user wants, needs, and “must haves.” Not all agencies of the Government arrive at their requirements in the same way. Agencies must consider the needs of civil and military users that they provide services to within their enabling statutes. DoD users need to operate worldwide with civil and NATO radionavigation systems while simultaneously maintaining the capability to use military radionavigation signals.

By statute (49 USC § 44505), the FAA must operate a common aviation system that meets the “needs for safe and efficient navigation and traffic control of civil and military aviation, except for the needs of the armed forces that are peculiar to air warfare and primarily of military concern.” To meet these aviation user requirements the “Administrator of the FAA shall…select systems…that will best serve those needs and promote maximum coordination of air traffic control and air defense systems.”

By statute (14 USC § 81), the USCG “… 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.” By request of the DoD, USCG can operate aids to air navigation and electronic aids to navigation systems “…required to serve the needs of the armed forces of the United States peculiar to warfare and primarily of military concern.”

By statute (1956 Federal Highways Act), the Interstate and National Defense Highway System was developed to meet the needs of commerce and national defense. This Act was not structured to support national operation of radionavigation systems for highways.

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 differentiated primarily by the characteristics of the navigation problem as the vehicle passes through different regions in its voyage. 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.

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 a 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.

4.1 Radionavigation System Requirements

Radionavigation requirements are determined by a process that begins with acknowledgment of a need for service in an area or for a class of users. These needs are normally identified to support commerce, national defense, or public safety. They are generated internally by the operatng administration, other Federal agencies, the user public, or as required by Congress, and defended by cost/benefit analysis. 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 USG, user, and general public as a function of the service provided;
- 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; and
- the total cost impact of any government decision on radionavigation system users.

The provision of Government provided radionavigation services is subject to the Congressional budgetary process and priorities for allocations among programs by agencies.

4.2 Aviation Radionavigation Requirements

Aircraft navigation is the process of piloting aircraft from one place to another and includes position determination, orientation, 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, the aircraft proximity to terrain and to other aircraft, and the air traffic control process.

Navigation under Visual Flight Rules (VFR) is conducted primarily by referencing features on the ground visually but can be aided with aircraft avionics. Navigation avionics are frequently used in VFR flight below Flight Level (FL) 180 and are required when operating under IFR.

Aircraft separation criteria, established by FAA, take into account limitations of the communications, navigation, and surveillance (CNS) service, but are strongly affected by other factors, e.g., wake turbulence, prevailing weather conditions, and air traffic control's intervention capabilities. Surveillance service normally falls into two categories:

- Cooperative: Surveillance in which the target cooperates with the process by using onboard equipment in the provision, acquisition, or derivation of surveillance information (position measurements, ID, etc.).
- Non-cooperative: Surveillance of a target without depending on information provided by the target.

Separation criteria 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 aviation navigation systems. "Navigation system" means all of the elements necessary to provide navigation services throughout 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, navigation system requirements include:

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

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, must be near 100 percent and 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 confirm the performance of airborne and external navigation 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 must 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 must provide information to the pilot and aircraft systems for performance of the following functions:

  - continuous determination of aircraft position;
  - continuous track deviation guidance;
  - continuous determination of along-track distance;
  - manual or automatic position reporting;
  - continuous monitoring of navigation system performance; and
  - manual or automatic flight.

j. the navigation system must be compatible with the overall Air Traffic Control (ATC) system that includes the performance requirements for communications and surveillance;

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 aircraft is bounded within established protected airspace areas at all times, (b) execute required holding patterns and approach procedures, and (c) annunciate when the system does not satisfy the requirements for the operation;

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 or 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 installed in aircraft or on the ground.;

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

s. the navigation system must operate in appropriate radio spectrum and there must be suitable radio spectrum available to support the navigation system.

For any IFR route, procedure or operation, an aircraft is required to have navigation equipment appropriate to the route to be flown. In many cases this requires carriage of a specific navigation system, such as VOR or ILS. New RNAV-based routes (designated as “Q” and “T” routes) and procedures are being developed to accommodate a variety of navigation systems such as GPS, GPS/WAAS, DME/DME, and DME/DME/IRU, although operations will continue to be restricted to the available and qualified systems.

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 the 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.

4.2.1 Air Navigation Phases of Flight and Current Accuracy Requirements

The four phases of aerial navigation are en route (including oceanic/remote areas), terminal, approach/landing, and surface. Table 4-1 summarizes the navigation infrastructure and services the NAS.

4.2.1.1 En Route Phase

This phase is the portion of flight after departure and prior to the transition to approach. The general requirements in Section 4.2 are applicable. In addition, to facilitate aircraft navigation in this phase, the navigation system used must be operationally compatible with the system used for approach and landing.

Operations in both the high and low altitude route structures 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 the ground monitoring of aircraft position. Altimeter information is also required for safe and efficient flight.

4.2.1.1.1 Oceanic/Remote Areas En Route

This subphase covers operations over the ocean and remote areas generally characterized by low traffic density. Remote areas are special geographic or environmental areas typically characterized by challenging 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 navigation system used must provide capability commensurate with the need in specific areas in order to permit safe navigation and the application of lateral separation criteria. The organized track systems in the North Atlantic and in the Pacific gain the benefit of optimum meteorological conditions. New CNS avionics and procedures have allowed reduced spacing for participating aircraft where radar is not available. New technology has reduced separation previously maintained by procedural means (e.g., position reports and timing) while maintaining an equivalent level of safety.

Table 4-1. Navigation Infrastructure Elements and Services

		Supporting Systems/Infrastructure			
Operational Services		Ground Based NAVAIDs	GNSS	Self-Contained on-Board Systems	Airport Lighting
Non-Area Navigation Operations -- Operations Referenced to Ground Based NAVAIDs	En Route	VOR (Victor and Jet routes) VORTAC (Victor and Jet routes) TACAN* DME (fix definition) NDB (in Alaska and for some offshore airways)	GPS, SBAS (approved as a substitute for NDB, DME)	Barometric altimetry, Inertial	N/A
	Arrival and Departure	VOR (SIDs, STARs) VORTAC (Victor and Jet routes) TACAN* (SIDs, STARs) DME (fix definition) NDB	GPS, SBAS (approved as a substitute for NDB, DME)	Barometric altimetry, Inertial	N/A
	Approach and Landing				
	Instrument Approach	ILS, Localizer, LDA VOR DME NDB TACAN* Radar approaches (ASR)*	N/A	Barometric altimetry	Lighting as required for type of operation and/or minima requirements. See AC 150/5300-13
	Vertical Guidance for Instrument Approach	ILS, PAR*	See "Area Navigation Operations" below	Barometric altimetry, radar altimetry, baro-VNAV, EFVS/HUD***	Lighting as required for type of operation and/or minima requirements. See AC 150/5300-13
Area Navigation Operations	En Route	DME/DME** VOR/DME** Loran-C (AC 90-45A) *eLoran*****	GPS, SBAS	Inertial (as part of a multi-sensor system)	N/A
	Arrival and Departure	DME/DME** VOR/DME** Loran-C (AC 90-45A) *eLoran*****	GPS, SBAS	Inertial (as part of a multi-sensor system)	N/A
	Approach & Landing				
	RNAV and RNP Instrument Approach (horizontal guidance)	VOR/DME** RNAV approaches (limited application) *eLoran*****	GPS, SBAS,GBAS	Inertial (as part of a multi-sensor system), barometric altimetry, baro-VNAV	Lighting as required for type of operation and/or minima requirements. See AC 150/5300-13
	RNAV and RNP Instrument Approach (with vertical guidance)	Baro VNAV in conjunction with ground-based NAVAIDs, e.g., *eLoran***** DME/DME/INS RNAV.	SBAS, GBAS	Barometric altimetry, baro-VNAV, EFVS/HUD	Lighting as required for type of operation and/or minima requirements. See AC 150/5300-13

* Primarily used by DoD

** Legacy and backup services

*** While not a navigation system, EFVS/HUD acts to mitigate risk and credit is given for its use in operational approvals

**** Capable of supporting RNAV/RNP en route through LNAV nonprecision approach operations, but not yet adopted into the NAS by FAA.

The current Minimum Navigation Performance Specification (MNPS) airspace (a Required Navigation Performance (RNP) 12.6 equivalent) lateral separation standard on the Organized North Atlantic Track System is 60 nm. The RNP-10 lateral separation standard is 50 nm in parts of the Pacific Ocean, while RNP-4 airspace reduced lateral separation to 30 nm lateral/30 nm longitudinal for participating aircraft based on the implementation of both automatic dependent surveillance (ADS) and controller pilot data link communications (CPDLC) within oceanic domains.

4.2.1.2 Terminal Phase

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.

Terminal procedures provide transition from departure to the en route and en route to the approach phases of flight. Surveillance facilities provide controllers with the ability to provide radar service to IFR/VFR aircraft under their control, provide traffic and safety advisories, and sequence traffic flows into and out of airports located within the terminal area. Technological advances in aircraft navigation using RNAV and RNP specifications will reduce pilot and controller workload and facilitate more efficient airspace and procedure design. These changes will collectively result in improved safe access, capacity predictability, operational efficiency, and environmental effects within these areas.

4.2.1.2.1 Departure

Departure begins after reaching the departure end of the runway and continues until interception of the en route airway structure or until air traffic terminal services make a handoff to en route air traffic services.

4.2.1.2.2 Arrival

Arrival begins when the aircraft leaves the en route altitude and ends upon reaching the final approach fix (FAF) prior to landing.

4.2.1.3 Takeoff and Approach-to-Landing Phases

The general requirements of Section 4.2 apply to the takeoff and approach-to-landing phases. In addition, specific procedures and clearance zone requirements are specified in TERPS (*United States Standard for Terminal Instrument Procedures*, FAA Handbook 8260.3) (Ref. 6).

The minimum navigation performance criteria vary between precision and nonprecision approaches.

4.2.1.3.1 Takeoff Phase

Takeoff begins with initial roll and ends at the departure end of the runway.

4.2.1.3.2 Approach-to-Landing Phase

The Basic classifications of approach include the following:

- Nonprecision Approach Procedure: A standard instrument approach procedure where no electronic glide slope is provided.
- Approach with Vertical Guidance: an approach classification which allows the use of a stabilized descent, using vertical guidance, without the accuracy required for a traditional precision approach procedure. The U.S. has developed criteria for lateral/vertical navigation (LNAV/VNAV) and LPV approach procedures that meet this approach classification. LNAV/VNAV approaches provide guidance in both the lateral and vertical planes with operational ceiling and visibility minimums as low as 250 ft and ¾ mile. LPV approaches provide both lateral and vertical guidance with minimums as low as 200 ft and ½ mile. The LPV minimums achieved depend on the WAAS performance at the airport location, the terrain and obstruction environment around the airport, and the airport infrastructure. LPV approaches with the lowest attainable ceiling minimums (200 ft) have been termed LPV-200 approaches.
- Precision Approach Procedure: A standard instrument approach procedure where an electronic glide slope is provided to tighter tolerances than an LNAV/VNAV, LPV, or LPV-200 approach.

Note: A missed approach operation, depicted as part of a published instrument approach procedure, is conducted when a landing cannot be safely accomplished.

4.2.1.3.2.1 Nonprecision and LNAV Approach

Nonprecision approaches are based on specific navigation systems. 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 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.

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

An LNAV approach is a specific subset of the nonprecision approach category that is based on RNAV GPS guidance.

4.2.1.3.2.2 Approach with Vertical Guidance (LNAV/VNAV and LPV)

LNAV/VNAV and LPV are RNAV approach procedures that provide lateral and vertical guidance for the approach. Some flight management systems (FMS) provide LNAV/VNAV capability by incorporating lateral RNAV guidance and deviations with barometric-aided vertical guidance and deviation information. However, baro-aided VNAV accuracy is affected by both cold and hot weather, requiring operational limitations on using it for VNAV operations.

4.2.1.3.2.3 Precision Approach-to-Landing

A precision approach-to-landing operation begins at the FAF and continues through touchdown and roll-out. The final approach can be based on precise lateral and vertical positive course guidance/deviation information (precision approach).

A precision approach aid provides an aircraft with vertical and horizontal guidance and position information. The current worldwide standard system for precision approach and landing is the ILS. GBAS will provide precision approach capability in the future. The WAAS SBAS technically does not provide a precision approach capability, but does provide service equivalent to an altitude-restricted Category I (CAT-I) precision approach at airports with the appropriate infrastructure. LPV-200 can provide approach capability as low as a 200 ft decision altitude and ½ mile visibility minimum similar to the lowest CAT-I minimums. Precision approach and landing systems must automatically remove hazardously misleading signals from service within 6 sec for CAT-I, and 2 sec for CAT-II and III.

4.2.1.4 Surface Phase

Surface operations include navigation on the airport surface to and from the active runway. These operations are currently conducted visually, however, the use of navigation systems such as GPS and GBAS will enable the ability for aircraft movement without visual references in the Next Generation Air Transportation System (NextGen).

4.2.2 Evolving Aviation Navigation Requirements

The Required Navigation Performance and Special Operational Requirements Study Group (RNPSORSG) reviewed the ICAO RNP concept beginning in 2003, taking into account the experiences of early application as well as current industry trends, stakeholder requirements and existing regional implementations. It developed an agreed understanding of what is now the Performance Based Navigation (PBN) concept and the *Performance Based Navigation Manual.* This manual supersedes the RNP

Manual (Doc 9613, 2nd Edition). The change consequently affects a number of ICAO Documents including:

- *ICAO, Annex 11, Rules of the Air and Air Traffic Services*
- *ICAO, Procedures for Air Navigation, Air Traffic Management (PANS-ATM, Doc. 4444- ATM/501)*
- *ICAO, Procedures for Air Navigation, Aircraft Operations Volumes I & II (PANS-OPS, Doc 8168)*
- *ICAO, Airspace Planning Methodology for the Determination of Separation Minima (Doc 9689)*
- *ICAO, Air Traffic Services Planning Manual (Doc. 9426-AN/924)*
- *ICAO, Regional Supplementary Procedures for Air Traffic Management (Doc 7030)*

It is particularly noteworthy that expressions such as RNP Type and RNP Value previously associated with the RNP Concept (included in the earlier edition of ICAO Doc 9613, formerly titled *Manual on RNP*) are not used under the PBN Concept and are being deleted in ICAO Material.

4.2.2.1 En Route Phase

In the United States, an RNAV 2 application supports an En Route continental Airspace Concept. With the publication of AC 90-100A, *U.S. Terminal and En Route Area Navigation (RNAV) Operations*, RNAV en route procedures were aligned with ICAO RNAV 2 criteria. RNAV 2 applications support Airspace Concepts that include radar surveillance and direct controller pilot communication (voice).

4.2.2.2 Oceanic En Route

Oceanic and Remote continental Airspace Concepts are currently served by two navigation applications, RNP 10 and RNP 4. Both these navigation applications rely primarily on GNSS to support the navigation element of the Airspace Concept. In the case of the RNP 10 application, no form of surveillance service is required. In the case of the RNP 4 application, ADS contract (ADS-C) is required.

4.2.2.3 Terminal Phase

One of the major changes forecast for the terminal area is the increased use of RNAV and RNP. Existing terminal airspace concepts, which include arrival and departure, are supported by RNAV applications (RNAV 1).

4.2.2.4 Takeoff and Approach-to-Landing Phases

One of the major changes forecast for takeoff and approach-to-landing phases is the increased use of RNAV and RNP to achieve optimum airspace utilization and noise abatement. The use of RNAV and RNP for departure procedures will allow increased flexibility in departure procedure design and will increase the ability of procedures to avoid noise sensitive areas.

4.2.2.4.1 Near-Precision and Performance Based Approaches

Where airspace and geography permit, the potential to have an LPV approach will be possible everywhere in the U.S. with the advent of WAAS, something formerly not available to aviation users. The final software improvements made to the WAAS extended LPV service availability within the Conterminous United States (CONUS) and southern Alaska to greater than 99 percent. Airports with appropriate infrastructure within the signal-in-space coverage area will have LPV-200 approaches.

4.2.2.4.2 Precision Approach-to-Landing

Approach concepts cover all segments of the instrument approach, i.e., initial, intermediate, final, and missed approach. They will increasingly call for RNP specifications requiring a navigation accuracy of 0.1 nm or lower. Typically, three RNP applications are characteristic of this phase of flight: new procedures to runways never served by an instrument procedure, procedures either replacing or serving as backup to existing instrument procedures based on different technologies, and those developed to enhance airport access in demanding environments.

Increases in navigation performance increase safety levels for landing and rollout operations.

4.2.2.5 Surface Operations

Currently, surface operations remain primarily tied to the use of visual references; however, navigation will act as an input source to advanced surface movement operations in the NextGen, e.g., surveillance systems.

4.3 Marine Radionavigation Requirements

4.3.1 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.

4.3.1.1 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.

4.3.1.2 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 m in width if it is used by large ships, but may narrow to as little as 120 m farther inland. Channels used by smaller craft may be as narrow as 30 m.

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.

4.3.1.3 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 m in depth), whichever is greater, where a safe path of water at least one nm wide, if a one-way path, or two nm 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; or
- 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.

4.3.1.4 Ocean Navigation

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

4.3.2 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 USG 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 4-2, 4-3, 4-4, and 4-5 identify system performance needed to satisfy maritime user requirements or to achieve special benefits. The requirements are related to safety of navigation. The USG 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 USG 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.

4.3.2.1 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 4-2.

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.

Table 4-2. 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.

4.3.2.2 *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 4-3 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 m (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.

Table 4-3. Current Maritime User Requirements/Benefits for Purposes of System Planning and Development - Harbor Entrance and Approach Phase

(a)

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

(b)

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.

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

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. Typical system performance is better than 1 meter in the vicinity of the broadcast site. Achievable accuracy degrades at an approximate rate of 1 meter for each 150 km distance from the broadcast site.

4.3.2.3 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 4-4. 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.

Table 4-4. Current Maritime User Requirements/Benefits for Purposes of System Planning and Development - Coastal Phase

(a)

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 Small Vessels)	0.25nm-2nm (460-3,700m)	-	US coastal waters	99%	**	5 minutes	2	Unlimited	Resolvable with 99.9% Confidence

(b)

BENEFITS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS								
Commercial Fishing (Include 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.

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; and
- 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 indicated in Table 4-4, 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 USN 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 4-4, 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 m (2 drms), and a fix rate of once per second for most applications.

Navigation service for operation within the coastal area is provided by Loran, 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.

Table 4-5. Current Maritime User Requirements/Benefits for Purposes of System Planning and Development - Ocean Phase

(a)

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

(b)

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.

4.3.2.4 Ocean Phase

The requirements for safety of navigation in the ocean phase for all ships are given in Table 4-5. These requirements must provide a ships' 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 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 4-5. The predictable accuracy benefits may be as stringent as 10 m 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 4-5, 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.

Navigation on the high seas is accomplished by the use of dead-reckoning, celestial fixes, self-contained navigation systems (e.g., inertial systems), Loran and GPS. GPS is now the system of choice. Worldwide coverage by most ground-based systems such as Loran is not yet practicable.

4.3.3 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.

4.3.3.1 Safety

4.3.3.1.1 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.

4.3.3.1.2 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.

4.3.3.1.3 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. DGPS and AIS are expected to play an increasingly important role in areas such as VTS.

4.3.3.2 Economics

4.3.3.2.1 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.

4.3.3.2.2 All Weather Operations

Low-visibility and ice-covered waters presently impact maritime operations. The Coast Guard is working to identify the proper mix of systems and equipment that would enable all weather operations.

4.3.3.3 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.

4.3.3.4 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.

4.4 Space Radionavigation Requirements

4.4.1 Space User Community

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

4.4.2 Space User Community Application of GPS

The U.S. space community uses GPS in a number of spacecraft and science instrument applications. Onboard the satellite, 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.

Dual-frequency GPS receivers have been certified for Space Shuttle navigation, and were chosen for being less susceptible to disruption during landing. NASA's Johnson Space Center is involved in research and development (R&D) efforts of GPS receivers for human spaceflight.

Standard GPS receivers are inadequate for certain space applications above LEO. There are specialty GPS receivers under development for such applications which would enable using GPS without reliance on other enhancements.

Research satellites use GPS receivers for precise positioning in support of onboard science instruments. The goal of this research is to provide precise satellite positioning at the 10 cm level in real time. The ability to perform at this level will enable numerous scientific measurements that are not available today to support research in areas such as oceanography and mapping.

The use of GPS signals for science observations is also the subject of continuing research. Examples of this research are the use of GPS signals for atmospheric research using occultation measurements through the Earth's atmosphere, and observations of GPS signals reflected off of the Earth's surface. The latest generation of NASA GPS space borne receivers is software programmable units.

4.4.3 Current Space Radionavigation Requirements

Space radionavigation requirements fall into the following application categories:

4.4.3.1 Spacecraft Navigation

Onboard spacecraft vehicle navigation support consists of GPS and GPS augmentations 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) with three-dimensional velocity error not to exceed 0. 1 m/sec (1 sigma),
- attitude determination error not to exceed 0.01 degree in each axis (1 sigma), and
- clock offset between UTC (USNO) and the GPS time scale not to exceed 1 microsecond (1 sigma).

It should be noted that the required accuracies listed above result from filtered GPS data and do not represent instantaneous solution requirements but are considered real-time requirements.

NASA is currently working with DoD to define the performance parameters to support navigation services in the GPS Space Service

Volume (SSV), which covers the region in space between 3,000 km and Geostationary Earth Orbit (GEO) altitude (~36,000 km).

4.4.3.2 Scientific Support

GPS scientific support decribes when data is analyzed in a post-processing mode to accurately locate instrument position in space when measurements are taken. Accuracy requirements are to determine position within 5 cm. However, more accurate positioning in the 1 to 2 cm range will be required in the future for some earth observation instruments.

GPS receivers are used for atmospheric research aboard satellites. These receivers require dual frequency GPS signals in order to measure the occultation of the GPS signals as they pass through the atmosphere.

4.4.3.3 GPS Reference Frame

NASA has undertaken the task of coordinating efforts among interested civilian and military agencies to identify the geodetic requirements needed to meet the anticipated PNT requirements over the lifetime of GPS III. Agencies participating with NASA include NGA, USNO, NOAA, the U.S. Geological Survey, and the U.S. Naval Research Laboratory (NRL).

4.5 Land Radionavigation Requirements

4.5.1 Categories of Land Transportation

4.5.1.1 Highways

Radionavigation applications for highway use range from precise static and dynamic survey (for project control before and during construction or creating as-built drawings when construction is finished) to asset tracking and route guidance. For the precise applications, geodetic accuracies, moderate integrity, and reliability are required factors. The less stringent applications have commensurately reduced accuracy, integrity, and reliability. Applications are being developed that rely on radionavigation as an input to an overall navigation solution for safety applications.

Within the surface transportation system, Federal agencies are developing ways to improve the safety and efficiency of the nation’s surface transportation system. To this end, significant effort has gone into developing approaches to address safety and efficiency, in order to reduce the loss of life and injuries that occur. GPS and its augmentations are one area that has been focused on in recent years and is the subject of ongoing research. DOT conducted ITS research to further promote the safety and reliability of travel. The National ITS Architecture defined a systems framework based on common user services delivered by transportation organizations. Table 4-6 lists those transportation user services that require radionavigation.

Table 4-6. 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

This research into developing applications that improve the safety and efficiency of the surface transportation system are the current focus for determining requirements that need to be established for radionavigation systems. Ongoing efforts are examining what is currently available and determining what levels of accuracy, integrity, and availability are required. Since these systems integrate the solution from GPS, DGPS, inertial systems, map-matching systems, wheel rotation counters, localized beacons, etc., defining the required parameters is dependent on the level of dependence on each these subsytems.

For many of the safety systems, submeter accuracies have been identified as needed to assist in improving safety and efficiency. Combined with other subsystems in the vehicle and the infrastructure, accuracies in range of 10 cm horizontal (95%) have been suggested. Ongoing research will determine this accuracy more definitively while also identifying integrity and availability levels.

4.5.1.2 Transit

Transit systems also benefit from the same radionavigation-based technologies. Automatic vehicle location techniques assist in fleet management, scheduling, real-time customer information, and emergency assistance. In addition, random route transit operations will benefit from route guidance in rural and low-density areas. Also, services such as automated transit stop annunciation are being 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 60,000 transit vehicles that employ automatic vehicle location using GPS for these fleet management functions and the deployment is continuing to spread.

4.5.1.3 Rail

NDGPS can significantly aid the development of 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 probability of 0.99999. The minimum center-to-center spacing of parallel tracks is 3.5 m. While GPS alone cannot meet the specified continuity of service and accuracy, NDGPS in combination with map matching, inertial navigation systems, accelerometers, and other devices and techniques will provide both the continuity of service and accuracy required to meet the stringent requirements set forth for PTC.

- 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 about 1 m. 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 15 m. 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.

Table 4-7. 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:	
Positive Train Control (PTC)	1
Track Defect Location (TDL)	0.3
Automated Asset Mapping (AAM)	0.1
Bridge and Tectonic Monitoring for Bridge Safety	0.001
Transit:	
Vehicle command and control	30-50
Automated voice bus stop annunciation	5*
Emergency response	75-100
Data collection	5

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

- The Association of American Railroads has updated the requirements of their member railroads. The Association also urged that the NDGPS program be completed through Full Operational Capability (FOC) and upgraded to High Accuracy NDGPS capability to support safety and efficiency improvements on the railroads. Similarly, the FRA Administrator has updated FRA PNT requirements as reflected in table 4-7.

4.5.2. Current Land Transportation 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, mayday functions, and hazardous materials tracking. Other applications continue to be investigated and developed, including resource management, highway inventory control, and positive train separation. At the present time, there are many hundreds of thousands of GPS receivers in use for surface applications. Many of these are finding their way into land vehicle applications.

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

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 *Air Force Space Command/Air Combat Command Operational Requirements Document (ORD) AFSPC/ACC 003-92-I/II/III for Global Positioning System (U)* (Ref. 7). Examples of land transportation positioning and navigation system accuracy needs and requirements are shown in Table 4-7. In addition, terrain is a very important factor and must be considered in the final system analysis.

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 will likely 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. 8) which concluded that differential GPS could satisfy the Location Determination System requirements for the next generation positive train control systems. In November 1996, FRA convened a technical symposium on *"GPS and its Applications to Railroad Operations"* to continue the dialogue on accuracy, reliability, and security requirements for railroads.

Integrity solutions for land transportation functions are dependent on specific implementation schemes. Integrity values will probably range between 1 and 15 sec, 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, availability, and integrity of the navigation and position solution to meet user needs. Integrity needs for rail use are 5 sec 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.

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.

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 and FRA have tested and continue to test GPS, NDGPS, and high accuracy NDGPS (HA-NDGPS) as part of PTC, TDL, AAM and bridge monitoring systems. 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.

4.6 Non-Navigation Applications and Requirements

The use of radionavigation systems, especially GPS, for non-navigation applications is very large and quite diverse. Most of these applications, the nature of which is discussed in sections 4.6.1 through 4.6.5, can be grouped under the following seven broad headings:

- Geodesy and Surveying;
- mapping, charting;
- Geographic Information Systems (GIS)
- agriculture and natural resources applications;
- geophysical applications;
- meteorological applications; and
- timing and frequency

4.6.1 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. 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 70,000) positioned using GPS, and the provision of GPS observations from a nationwide GPS network of national CORS for use in post-processing applications. The national CORS system currently provides data over the Internet from 1200 stations, including the Maritime Differential GPS stations (MDGPS) and Nationwide Differential GPS stations (NDGPS); 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 differencing techniques using the carrier phase observable.

4.6.2 Mapping and Charting

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.

4.6.3 Agriculture and Natural Resources Applications

Agriculture and natural resouces applications account for many civil applications of positioning and anvigation. These include, natural resources inventorites and monitoring, conservation planning and application, wildlife and wetland management, silviculture and grasslands management, water management, fire protection, law enforcement. Many natural resource applications use code range and real time differential solutions. Some applications have greater accuracy requirements and use carrier phase solutions with some methodology for post processing or augmenting GPS with real time high accuracy differential services.

4.6.4 Geographic Information System (GIS) Applications

GIS applications support recording. planning, analysis, and information output for a diverse applications ranging from natural resource applications, demographics, site planning, archeology, transpiration routing, and many more. GIS is supported by location based information derived by GPS or through remote sensing. The availability of GPS, augmentations, and PNT services has accelerated location based information data gathering to support dynamic and changing conditions. Most location based information derived with PNT, is generally more accurate than other geospatial layers in the GIS. The level of required accuracy for PNT solutions is usually defined by the purpose of the GIS. An example of accuracy variability would be the difference between representing a feature on a landscape versus pinpoint accuracy of a city utility for asset management. This variability in required accuracy means PNT solutions for GIS vary from simple code observations, with or without differential, to very accurate carrier phase observations, post processed for centimeter level positioning.

4.6.5 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 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 ground 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.

4.6.6 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 previously 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 are in wide use. 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.

4.6.7 Time and Frequency Applications

GPS-provided time and frequency has become a critical component of our national infrastructure supporting telecommunication systems, power grids, and many DoD-specific applications. GPS is used extensively for communication network synchronization supporting cell phone and traditional telephone applications. Power companies use 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. The USG recognizes the criticality of providing accurate timing services and will continue its pursuit of a potential systemic backup in the event of a GPS disruption.

4.6.8 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 4-8 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.

Table 4-8. Requirements for Surveying, Timing, and Other Applications

Surveying

TASK	MINIMUM PERFORMANCE CRITERIA								REMARKS
	ACCURACY - 1 SIGMA				COVERAGE %	AVAILABILITY %	INTERVAL		
	POSITION						MEASUREMENT RECORDING (seconds)	SOLUTION FIX	
	ABSOLUTE (m)		RELATIVE (cm)						
	HORIZONTAL	VERTICAL	HORIZONTAL	VERTICAL					
Static Survey	0.3	0.5	1.0	2.0	99	99	5	30 min	0 - 25 km
Geodetic Survey	0.1	0.2	1.0	2.0	99	99	5	4 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	

* IHO Standards for Hydrographic Surveys are published in IHO publication S-44, which can be obtained gratis from the Publications section at www.iho.int

Timing and Other Applications

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS								
	ACCURACY TRACEABLE TO UTC			COVERAGE	AVAILABILITY	FIX INTERVAL	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY
	ACCURACY	STABILITY	RELATIVE						
Communications Network Synchronization	microseconds	10^{-11} (freq)*	-	Nationwide	99.7%	Continuous	N/A	Unlimited	N/A
Scientific Community	nanoseconds	10^{-16} (freq) after 30 days averaging	50 Picoseconds After 1 day averaging	Worldwide	99.7%	Continuous	N/A	Unlimited	N/A
Banking and Finance	seconds	-	-	-	TBD	TBD	TBD	-	TBD
Power Network Synchronization	microseconds	1ms**	-	North America	99.7%	1 second	Two	Unlimited	Resolvable with 99.9% confidence

* stratum 1 telecommunication requirement

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. For scientific applications, the IGS was established under the auspices of the International Association of Geodesy (IAG). The IGS operates a worldwide network of GPS reference stations. Data from these stations are used to produce high accuracy (5-10 cm) orbits and to define a worldwide reference coordinate system accurate at the 1 cm level. Currently, the highest accuracy orbits are produced on a weekly basis; however, daily, sub-daily and predicted orbits are also generated at somewhat reduced accuracies. In addition, Earth orientation, station and satellite clocks, tropospheric and ionospheric parameters are produced on a weekly to sub-daily basis.

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 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.

5

Operating Plans

This section summarizes the plans of the USG to provide radionavigation systems and services 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.

5.1 Operating Plans

5.1.1 Global Positioning System (GPS)

GPS is a multi-use, space-based radionavigation system owned by the USG, and operated by DoD, to meet defense and homeland security, civil, commercial, and scientific needs. The GPS provides two levels of service: SPS which uses the C/A code on the L1 frequency, and PPS which uses the P(Y) code on both the L1 and L2 frequencies. Access to the PPS is restricted to U.S. armed forces, U.S. Federal agencies, and select allied armed forces and governments. These restrictions are based on U.S. national security considerations. The SPS is available to all users on a continuous, worldwide basis, free of any direct user charge.

The specific capabilities provided by SPS are published in the *Global Positioning System Standard Positioning Service Performance Standard* (Ref. 9) available on the USCG Navigation Center website: http://www.navcen.uscg.gov.

NGA generates precise, post-fit GPS orbits for DoD as well as predictable orbits. NGA operates a global network of 11 GPS Monitor Stations geographically placed to complement the six USAF monitor stations. NGA stations are controlled with complete redundancy in key components and provide high quality data. The NGA data are also transmitted in near-real-time to the Air Force Space Command for incorporation their real-time GPS operations. The combined NGA-USAF GPS tracking network is used to define the WGS 84 reference frame, the standard geodetic reference system for GPS and for all DoD positioning, navigation, and geospatial products. GPS data and products from NGA can be found at http://earth-info.nga.mil/GandG/sathtml.

DoD will provide a 48-hour advance notice of changes in the constellation operational status that affect the service being provided to GPS SPS users in peacetime, other than planned GPS interference testing. The USG provides notification of changes in constellation operational status that affect the service being provided to GPS users or if a problem in meeting performance standards is anticipated. In the case of a scheduled event affecting service provided to GPS users, the USG will issue an appropriate Notice Advisory to Navstar Users (NANU) at least 48 hours prior to the event, in accordance with the *GPS Standard Positioning Service Performance Standard* (Ref. 9).

Coordination of planned interference testing activities nominally begins 60 days before testing events. Users are notified by the USCG as soon as an activity is approved, and by FAA typically not earlier than 72 hours before an activity begins. DoD notice will be given to the USCG Navigation Information Service (NIS) and the FAA Notice to Airmen (NOTAM) system. The NIS and NOTAM systems will announce unplanned system outages resulting from system malfunctions or unscheduled maintenance.

GPS will be the primary Federally provided radionavigation system for the foreseeable future. GPS will be augmented and improved to satisfy future military and civil requirements for accuracy, coverage, availability, continuity, and integrity. Current policy states that DoD will maintain a nominal 24-satellite constellation, and that replacement satellites will be launched on an anticipated need to maintain the constellation as satellites age and ultimately fail.

5.1.2 GPS Modernization

The GPS Modernization effort focuses on improving positioning and timing accuracy, availability, integrity monitoring support capability, and enhancement to the operational control segment. As these system enhancements are introduced, users will be able to continue to use existing IS-GPS-200 (Ref. 10) compliant receivers, as signal backward compatibility is a requirement for both the military and civil user communities. 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 existing user equipment or procure new user equipment in order to take full advantage of any new signal structure enhancements.

GPS modernization is a multi-phase effort to be executed over the next 15 or more years. The USG will add three additional coded civil signals to the existing civil signal, L1 C/A, to support future civil applications:

- L1C, frequency 1575.42 MHz, providing better performance than the current C/A signal being used by civilian receivers, and compatibility with the European Galileo system;
- L2C, frequency 1227.6 MHz; and
- L5, frequency 1176.45 MHz, to meet the needs of critical safety-of-life applications, such as civil aviation.

In addition, a secure and spectrally separated M-Code will be broadcast on the L1 and L2 frequencies. The first launch of an L2C capable satellite was in 2005, and the first launch of an L5 capable satellite is scheduled for 2009. Twenty-four L2C capable GPS satellites are projected to be on orbit by approximately 2016, and 24 GPS L5 capable satellites are projected to be on orbit by approximately 2018. Prior to declaration of FOC, not all performance parameters of the new civil signals will be met, and therefore the new signals will be available to users at their own risk.

As published in the Federal Register on September 23, 2008 (Volume 73, Number 185), the USG commits to maintaining the existing GPS L1 C/A, L1 P(Y), L2C and L2 P(Y) signal characteristics that enable codeless and semi-codeless GPS access until at least 31 December 2020. To enable an orderly and systematic transition, users of semi-codeless and codeless receiving equipment are expected to transition to using civil-coded signals by this date.

In May 2008, USAF awarded the development contract for the next generation of GPS satellites, known as GPS III. These satellites will improve the overall accuracy, availability, and integrity of the GPS constellation, as well as provide increased anti-jam performance to meet the future needs of civil and military users. The first GPS III launch is projected for 2014.

5.1.3 Augmentations to GPS

GPS SPS does not meet all the different user performance requirements for civil PNT applications.

Various differential techniques are used to augment the GPS to meet specific user performance requirements. However, it is important to note that civil differential systems and users of civil differential systems are dependent upon being able to receive the GPS civil signal in order to compute a position using differential techniques.

5.1.3.1 Maritime and Nationwide Differential GPS

USCG began development of the MDGPS system in the late 1980s to meet the needs of the Coastal and Harbor Entrance and Approach (HEA) phases of navigation and to enable automated buoy positioning. MDGPS service was certified fully operational in March 1999 after the network met the performance standards required for HEA navigation. PL 105-66, Title III, § 346 (111 Stat. 1449) authorizes the Secretary of Transportation to improve and expand the USCG's MDGPS into a Nationwide DGPS, or NDGPS, by adding an inland segment. RITA coordinates this inland program and is acting chair of the NDGPS Policy and Implementation Team. Today, multiple Federal agencies, several states, and scientific organizations are cooperating to provide the combined national DGPS utility, with plans to complete NDGPS system coverage throughout the lower 48 states.

Each NDGPS facility meets all operating parameters established to qualify a MDGPS facility for operational availability, as established by USCG. NDGPS was not designed to meet aviation integrity requirements.

In addition to providing a real-time broadcast of differential corrections, the U.S. DGPS services provide a robust operational backbone to the DOC's CORS application for post-processing survey applications and Web-enabled location solutions, the National Weather Service's Forecast Systems Laboratory for short-term precipitation forecasts, and the University NAVSTAR Consortium (UNAVCO) for plate tectonic monitoring. Where operational considerations allow, additional operational capability may be added, such as the broadcast of navigational or meteorological warnings and marine safety information (i.e., NAVTEX data) to support safe navigation at sea.

Currently 39 USCG and nine USACE broadcast sites provide service for maritime coverage CONUS, the Great Lakes, Puerto Rico, portions of Alaska and Hawaii, and portions of the Mississippi River Basin. The inland NDGPS segment complements the MDGPS segment and is planned to provide dual coverage of the CONUS and selected portions of Hawaii and Alaska as a combined national DGPS utility. There are currently 38 DOT sponsored sites in the NDGPS network providing 92 percent of the contiguous 48 states with single coverage and 65 percent with dual coverage. The combined DGPS service will provide uniform coverage of the CONUS and portions of Hawaii and Alaska, regardless of terrain, or man-made and other surface obstructions. This coverage is achieved by using a medium frequency broadcast optimized for surface applications. The broadcast has been demonstrated to be sufficiently robust to work throughout mountain ranges, difficult terrain and other obstructions. The combined DGPS service will provide a highly reliable GPS integrity function to users to meet the growing requirements of surface users (transportation, precision agriculture, natural resources and environmental management, emergency management and response, and surveying and construction communities).

As each new Nationwide site is added to the DGPS network, it is evaluated and tested to ensure that it meets the full operational capability specifications commensurate with a safety of life service. Once a site is declared fully operational, the site is monitored and maintained by the USCG to ensure support for safety applications. System coverage for a specific location can be obtained from the USCG Navigation Center (NAVCEN) website, http://www.navcen.uscg.gov

The two major deployment milestones have been established as nationwide single station coverage and nationwide dual station coverage (CONUS only). Under single station coverage, predicted to occur no earlier than 2010 (pending funding availability), users anywhere within CONUS will be able to receive at least one DGPS differential correction broadcast. The second major milestone is full coverage by at least two DGPS broadcasts, is expected to occur no earlier than 2012.

5.1.3.1.1 DGPS System Recapitalization

Because the original reference stations and integrity monitors are approaching the end of their useful life and have become unsupportable, USCG is implementing a recapitalization project for the maritime sites. This ongoing project will extend system life at least 15 years while also providing a substantial increase in performance (accuracy and integrity), flexibility, and maintainability. The improvements are centered on the major functional components of the system: the Reference Stations – used to calculate and transmit pseudorange corrections to properly equipped users; and the Integrity Monitors—used to check the validity of the transmitted corrections, ensuring users can depend on having the correct information. Another benefit of the recapitalized architecture is upgradeability. As new Satellite Navigation Systems become available, such as Galileo and other new GPS signals, USCG will be poised for “plug and play” receivers that manufacturers are currently developing, further enhancing the performance of the combined national DGPS utility.

DOT did not provide funding for recapitalization of NDGPS sites in FY08. DOT recently decided that recapitalization of NDGPS is a system priority and they are developing a funding plan to recapitalize as early as FY09.

5.1.3.1.2 High Accuracy NDGPS

The HA-NDGPS research program is sponsored by FHWA and FRA to enhance the performance of NDGPS. The first HA-NDGPS station began broadcasting in a test mode in 2001 with funding from the Interagency GPS Executive Board (IGEB). IGEB recognized the potential benefit to many Federal agencies, states, and the general public of having a nationwide high accuracy system. Two HA-NDGPS reference stations are currently operational and providing 10 to 15 cm accuracy throughout the coverage area. Further improvements to accuracy and the development of 1 to 2 second time-to-alarm integrity are anticipated. Once these improvements are complete, a HA-NDGPS standard will be developed.

To support this, several approaches are being investigated. They can be grouped into three general categories: improved ionosphere and troposphere prediction; increased data throughput to support broadcast of GPS observables; and the addition of pertinent data to the current broadcast. Each is discussed in the following sections.

5.1.3.1.2.1 Improved Ionosphere and Troposphere Prediction

Large errors and rapid changes in GPS positional accuracy can occur during significant space weather and tropospheric weather events. The only practical approach to mitigate this problem is to utilize space and lower atmospheric-weather models that assimilate all available observations to estimate and predict the magnitude of these events, and provide correctors for real-time high accuracy positioning and navigation applications.

NOAA developed and tested two atmospheric models to do this: U.S. Total Electron Content (US-TEC) for the ionosphere and NOAATrop, a real-time tropospheric signal delay model for the lower atmosphere. US-TEC is used operationally while NOAATrop is currently implemented experimentally. Both have been shown to provide atmospheric signal delay correctors with significantly improved accuracy and reliability. FHWA, in collaboration with USCG and NOAA, is evaluating the feasibility of using these weather models to create differential correction messages for broadcast, and use them to help resolve carrier phase ambiguities over arbitrarily long baselines.

5.1.3.1.2.2 Increased Data Throughput for Broadcast of GPS Observables

A second line of research is determining the feasibility of broadcasting navigation satellite observables. The focus of this effort has been the development of a low cost modification to existing NDGPS facilities in order to maximize the benefits of these facilities. The NDGPS site near Hagerstown, MD, was modified in April 2002 and a second site, Hawk Run, PA, was modified in July 2003. The effort has been divided into two phases.

Phase I was a proof of concept and implementation phase that determined the viability of modifying an NDGPS facility and examined the accuracy available from a single site. A broadcast data rate of 1000 bps was established as the maximum allowable. A second transmitter, transmission line, and diplexer were added to the Hagerstown NDGPS facility.

Testing began shortly after installation. Testing using this single site achieved a horizontal navigation solution of within 10 cm (95 percent) of truth at a range of approximately 250 km. This testing is documented in the Phase I final report available at: http://www.tfhrc.gov/its/ndgps/02110/index.htm.

5.1.3.1.2.3 Addition of Pertinent Data

With GPS SA set to zero by Presidential Direction in 2000, DGPS latency requirements for pseudorange correction data can be eased and range rate data may no longer be needed by users. Service providers are aggressively pursuing methods to leverage newly available data link capacity to enhance system performance. Methods being explored include:

- improved "post SA" reference station correction generation algorithms that increase accuracy,
- improved integrity monitoring processes that reduce user vulnerabilities,
- differential corrections that enable use of WAAS pseudo-ranges in DGPS position solutions,
- enhanced beacon almanacs that enable users to intelligently select the best beacon by signal specification,
- highly accurate atmospheric corrections generated by NOAA using wet/dry tropospheric and ionospheric data,
- network distribution of correction data between adjacent beacon sites, and
- distribution of precise orbit data over the DGPS data link.

5.1.3.2 Wide Area Augmentation System (WAAS)

WAAS, an SBAS operated by FAA, provides increased navigation accuracy, availability, and integrity for aircraft navigation during departure, en route, arrival, and approach operations. Although designed primarily for aviation applications, WAAS is widely available in receivers manufactured for navigation use by other communities.

FAA commissioned WAAS in 2003. WAAS service supports departure, en route, arrival, and approach operations, including nonprecision approaches and approach procedures with vertical guidance. The WAAS service may support additional capabilities such as advanced arrival and departure procedures (curved and segmented), more efficient en route navigation and parallel runway operations, runway incursion warnings, high-speed turnoff guidance, and airport surface operations.

WAAS will be modified to utilize the L5 signal provided by modernized GPS satellites, in lieu of the current semi-codeless L2 signal being utilized to determine ionospheric corrections. New dual-frequency WAAS avionics using L1 and L5 will improve the availability of LPV service.

5.1.3.3 Local Area Augmentation System (LAAS)

LAAS is a GBAS being developed by FAA. LAAS is expected to provide the required accuracy, availability, integrity, coverage, and continuity to initially support CAT-I precision approaches and eventually CAT-II and III precision approaches. Unlike current ILS, a single LAAS ground station may provide precision approach capability to all runway ends at an airport.

LAAS will augment GPS by providing local differential corrections to users via a VHF data broadcast. LAAS will allow suitably equipped aircraft to conduct precision approaches in the vicinity of LAAS-equipped airfields. LAAS will also allow suitably equipped aircraft to conduct curved approaches, segmented approaches, and more efficient parallel runway operations, runway incursion warnings, high-speed turnoff guidance, and airport surface operations.

CAT-I LAAS is being developed in cooperation with Airservices Australia, equipment manufacturers and users. The FAA plans to complete the first system design approval in 2008. The FAA is conducting research and development for a CAT-III LAAS prototype by 2010 followed by design approval in 2012.

5.1.3.4 Joint Precision Approach and Landing System (JPALS)

JPALS is a DoD landing system for all branches of the military service. For military secure users, JPALS will use secure Ultra High Frequency (UHF) data link communication to provide additional information to suitable aircraft to calculate guidance quality data (accuracy, integrity and continuity) for landing. The fixed-base JPALS will provide the same VHF data broadcast as LAAS.

5.1.3.5 The U.S. Continuously Operating Reference Station (CORS) System

NOAA's NGS, an element of DOC, has established a CORS system to support non-navigation post-processing applications of GPS, especially precise 3-dimensional positioning at the few centimeter level. More recently, the CORS network has also served the atmospheric science community as a troposphere and ionosphere monitoring network, and it has served the geophysics community as a crustal motion monitoring network. Additionally, the CORS system is being modernized to serve as the foundation for future applications that support real and near real-time positioning (that differ from navigation applications by the lack of redundancy and integrity monitoring required for safety-of-life applications). The CORS system provides code range and carrier phase data from a nationwide network of GPS stations for access by the Internet. As of June 2008, data were being provided from more than 1,200 stations.

The NGS manages and coordinates data contributions from GPS tracking stations established by more than 200 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 and DHS that support real-time navigation requirements (mostly WAAS and NDGPS augmentations). These real-time stations make up approximately 17 percent of all CORS stations. Other stations currently contributing data to CORS include stations operated by NOAA, NSF, and NASA in support of crustal motion activities; stations operated by state and local governments in support of surveying and mapping applications; and stations operated by NOAA's Earth Systems Research Laboratory, in support of meteorological applications. The breakdown of CORS partners is illustrated in Figure 5-1.

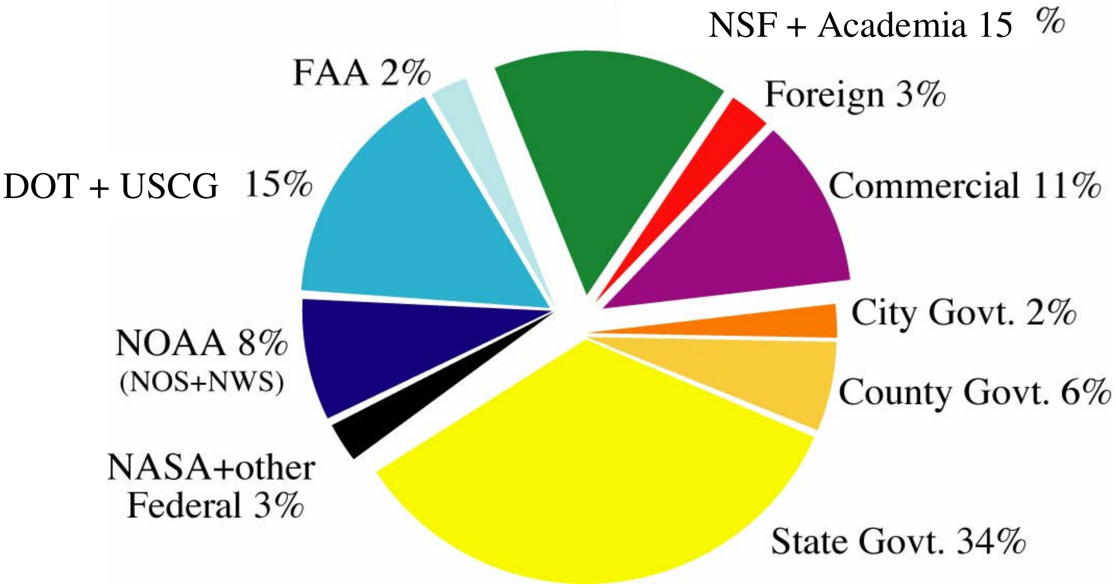

Figure 5-1. Partners in the Continuously Operating Reference Station System

The national CORS system is a GPS augmentation system managed by NOAA that archives and distributes GPS data for precision positioning and atmospheric modeling applications. It serves as the basis for the National Spatial Reference System, defining high accuracy coordinates for all Federal radionavigation systems. Historically, CORS served post-processing users of GPS, but is being modernized to support real-time users at a similar level of accuracy.

5.1.4 Loran

5.1.4.1 Loran-C

Today's Loran system, Loran-C, is a stand-alone, hyperbolic radionavigation system that was originally developed to provide military users with greater coverage and accuracy than its predecessor (Loran-A). It was subsequently selected as the radionavigation system for civil marine use in the U.S. coastal areas. It is approved by FAA as a supplemental system in the NAS for the en route and terminal phases of flight, and by the USCG as a means of maritime navigation in the coastal confluence zone. It is also available for use as either a primary or back-up precise frequency source to support precise timing applications. Loran-C provides horizontal coverage throughout the 48 conterminous states, their coastal areas, and most of Alaska south of the Brooks Range.

DHS continues to maintain and operate the Loran-C system in the short term while converting the Loran-C stations to a modernized Loran system referred to as *eLoran*, subject to the availability of funds as required by U.S. Law.

5.1.4.2 eLoran

eLoran is the next generation Loran system. Terrestrial-based, *eLoran* is an independent, dissimilar complement to the GPS. It will allow properly equipped users to retain PNT service in the event of GPS disruption. It has better accuracy, integrity, and continuity than Loran-C, while continuing to meet Loran-C's traditional availability requirements. *eLoran* also can provide precise time and frequency references needed by the telecommunications systems and other elements of critical infrastructure.

This improvement is realized through station equipment upgrades, the addition of a data channel on the signal-in-space, and all-in-view digital signal processing receivers. *eLoran* is designed to be backward compatible with Loran-C, however, users would require a new receiver in order to take full advantage of *eLoran* capabilities.

The combination of infrastructure and user equipment improvements will enable *eLoran* to meet the requirements for landing aircraft during an aviation non-precision instrument approach (0.3 nm horizontal), as well as the requirements for maritime harbor entrance and approach (10 to 20 m).

5.1.5 VOR and DME

VOR provides a bearing from an aircraft to the VOR transmitter. DME provides the slant-range distance from the aircraft to the DME transmitter. At many 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. Select VOR stations also broadcast weather information or air traffic communications.

FAA operates more than 1,000 VOR, VOR/DME, and VORTAC stations. DoD operates approximately 50 stations, located predominately on military installations in the U.S. and overseas, which are available to all users.

The current VOR services will be maintained at their current level until at least 2010 to enable aviation users to equip their aircraft with SATNAV avionics and to become familiar with the system. There is an FAA effort underway enabling a reduction in the VOR population, to begin in 2010, that will reduce VOR services by discontinuing facilities no longer needed. VOR services will be gradually discontinued in accordance with airway planning standard criteria after appropriate coordination. Service will be discontinued first at facilities where service is not needed or where satisfactory alternatives are available. VORs will remain in service throughout the transition to SATNAV to support IFR operations as needed, and serve as an independent navigation source in the NAS.

The FAA plans to sustain existing DME service to support en route navigation and to install additional low-power DME to support ILS precision approaches as recommended by the Commercial Aviation Safety Team. The FAA may also need to expand the DME network to provide an RNAV capability for terminal area operations at major airports and to provide continuous coverage for RNAV routes and operations at en route altitudes.

5.1.6 TACAN

TACAN is a tactical air navigation system for the military services ashore, afloat, and airborne. It is the military counterpart of civil VOR/DME. TACAN provides bearing and distance information through collocated azimuth and DME antennas. TACAN is primarily collocated with the civil VOR stations (VORTAC facilities) to enable military aircraft to operate in the NAS and to provide DME information to civil users.

FAA and DoD currently operate more than 100 “stand-alone” TACAN stations in support of military flight operations within the NAS. DoD also operates approximately 30 fixed TACAN stations that are located on military installations overseas, and maintains more than 90 mobile TACANs and two mobile VORTACs for worldwide deployment. FAA and DoD continue to review and update requirements in support of the planned transition from land-based to space-based primary navigation.

The DoD requirement for land-based TACAN will continue until military aircraft are properly equipped with GPS; GPS PPS receivers are certified for all operations in both national and international controlled airspace; and the GPS support infrastructure including published procedures, charting, etc., is in place. A phase down of TACAN systems is planned for a future date, yet to be determined. Sea-based TACAN will continue in use until a replacement system is successfully deployed. The USN, USCG, and Military Sealift Command (MSC) operate several hundred sea-based TACAN stations.

5.1.7 ILS

An ILS is a precision approach and landing system consisting of a localizer facility, a glide slope facility, and VHF marker beacons or low power DME (or both). A full precision approach also includes Runway Visual Range (RVR) and approach lighting systems. An ILS provides electronic vertical and lateral navigation (guidance) information during the approach and landing phase of flight and is associated with a specific airport runway end. Distance indication is provided by the marker beacons or DME. Depending on its configuration and the other systems installed on the airport and in the aircraft, an ILS can support CAT-I, II, and III approaches.

ILS is the standard precision approach system in the U.S. and abroad. FAA operates more than 1,200 ILS systems of which approximately 100 are CAT-II or CAT-III systems. In addition, DoD operates approximately 160 ILS facilities in the U.S. Non-Federal sponsors operate fewer than 200 ILS facilities in the U.S.

As the GPS-based augmentation systems (WAAS and LAAS) are integrated into the NAS, and user equipage and acceptance grows, the number of CAT-I ILS may be reduced. FAA does not anticipate phasing out any CAT-II or III ILS systems until LAAS is able to deliver equivalent service and GPS vulnerability concerns are addressed. A reduction in the number of CAT-II/III ILS may then be considered. Until LAAS systems are available, new and upgrade CAT-II and III precision approach requirements will continue to be met with ILS.

5.1.8 Nondirectional Beacons (NDB)

NDBs serve as nonprecision approach aids at some airports; as compass locators, generally collocated with the outer marker of an ILS to assist pilots in getting on the ILS course in a non-radar environment; and as en route navigation aids.

The NAS includes more than 1,300 NDBs. Fewer than 300 are owned by the Federal Government; the rest are non-Federal facilities owned predominately by state, municipal, and airport authorities.

FAA has begun decommissioning stand-alone NDBs as users equip with GPS. NDBs used as compass locators, or as other required fixes for ILS approaches (e.g., initial approach fix, missed approach holding), where no equivalent ground-based means are available, may need to be maintained until the underlying ILS is phased out. Most NDBs that define low-frequency airways in Alaska or serve international gateways and certain offshore areas like the Gulf of Mexico will be retained.

5.2 Navigation Information Services

5.2.1 USCG Navigation Information Service

The USCG 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, DoD, and other sources. The mission of the NIS is to gather, process and disseminate timely GPS, Loran, 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 list server; and
- collecting information from users in support of the CGSIC and the GPS managers and operators.

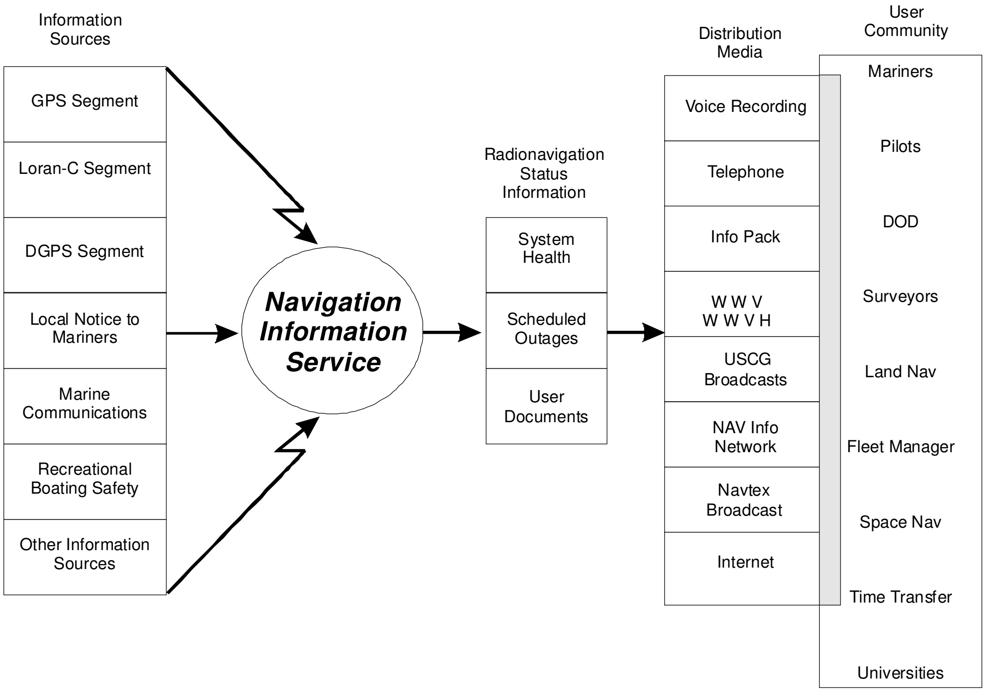

Figure 5-2. NIS Information Flow

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; and
- develop new user services as required.

Table 5-1. 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, NGA Data, FRP, and Miscellaneous Information	http://www.navcen.uscg.gov ftp://ftp.navcen.uscg.gov
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
NGA Broadcast Warnings	24 hours, broadcast upon receipt	Status Forecasts	(310) 227-3147 MCDWWNWS@nga.mil
NGA Weekly Notice to Mariners	On line Notices updated weekly	Status Forecasts Outages	(301) 227-3126 MCDNtM@nga.mil
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
RAIM Prediction	24 hours	User inquiry, status forecasts for RNAV Terminal, and En route RAIM	http://www.raimprediction.net

Information on GPS and USCG-operated radionavigation systems can be obtained from the USCG's NAVCEN, 7327 Telegraph Road, Alexandria, VA 22315-3998. Table 5-1 and Figure 5-2 show the services through which the NIS provides Operational Advisory Broadcasts. NAVCEN's 24-hour hotline: (703) 313-5900. NAVCEN's email address: webmaster@smtp.navcen.uscg.mil. and web-site: http://www.navcen.uscg.gov/.

5.2.2 GPS NOTAM/Aeronautical Information System

DoD provides notice of GPS satellite vehicle outages through the NOTAM system. These NOTAMs are reformatted NANUs provided by the 2nd Space Operations Squadron (2SOPS) at the GPS MCS. The outages are disseminated to the U.S. NOTAM Office, which is a joint DoD/FAA facility, at least 48 hours before they are scheduled to occur. Unexpected outages also are reported by the 2SOPS to the NOTAM Office as soon as possible.

Satellite NOTAMs are issued as both a domestic NOTAM under the KGPS identifier and as an international NOTAM under the KNMH identifier. This information is accessible by both civilian and military aviators. Unfortunately, the NOTAM is meaningless to a pilot unless there is a method to interpret the effects of a GPS satellite outage on the availability of the intended operation.

Use of GPS for IFR aerial navigation requires that the system have the ability to detect a satellite out-of-tolerance anomaly. This capability is currently provided by RAIM, an algorithm contained within the GPS receiver. All receivers certified for IFR navigation must have RAIM or an equivalent capability. WAAS avionics receive integrity information primarily from the WAAS message but also have a RAIM function for times when the aircraft is outside of SBAS coverage or when messages are not available.

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, 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 planned operations, particularly 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. Terminal and en route RNAV RAIM predictions to satisfy AC 90-100A preflight guidance may be obtained from www.raimprediction.net.

GPS data are received via an antenna on the roof of the FAA Air Traffic Control System Command Center (ATCSCC). The almanac and satellite NOTAM 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. Both the military and FAA GPS RAIM outage reporting systems have been operational since 1995.

The military disseminates GPS NOTAMs through the Defense Internet NOTAM Service (DINS), a web-based distribution system. An example of GPS NOTAM is provided below:

A) KLAX
B) 0901081018
C) 0901081045
E) QXXXX GPS NON-PRECISION APPROACH NOT AVAILABLE

This NOTAM means that a GPS nonprecision approach at Los Angeles International Airport is unavailable on Jan. 8, 2009 from 10:18 to 10:45 UTC.

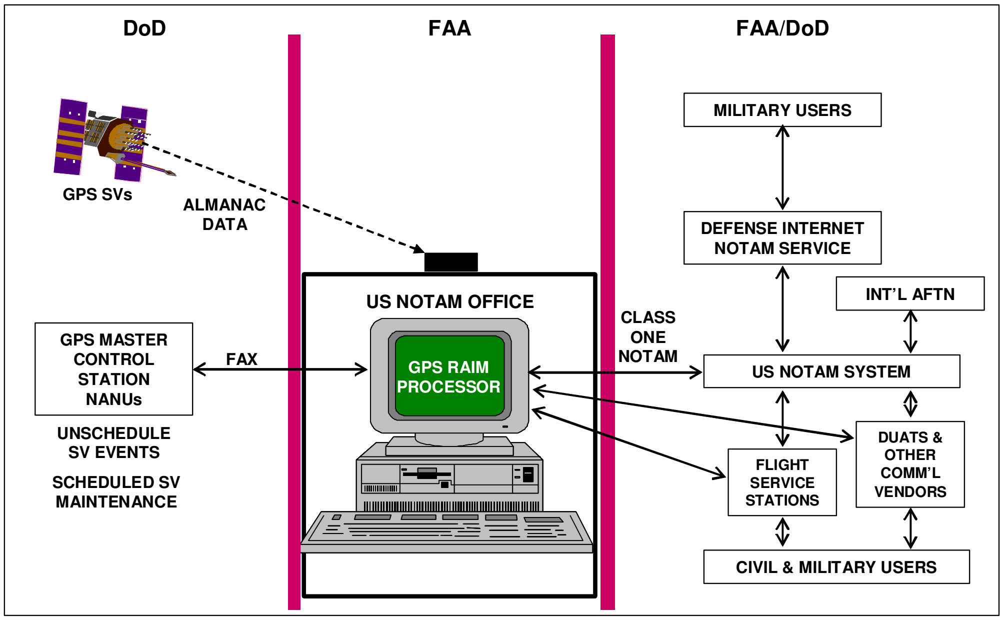

Figure 5-3. GPS NOTAM/Aeronautical Information Distribution System

FAA provides similar GPS outage information, not as a NOTAM, but in an aeronautical information format FAA uses the same GPS NOTAM generator as DoD to compute their aeronautical information, but it is distributed through Flight Service Stations (FSS), Direct User Access Terminal System (DUATS) vendors, and other commercial vendors as shown in Figure 5-3. The Lockheed Martin Flight Services FS-21 System in the lower 48 states plus Hawaii and Puerto Rico interfaces with a Volpe Center online RAIM prediction algorithm and provides a GPS/RAIM product to the flight service specialists. FAA Flight Services in Alaska receive GPS/RAIM information through a graphical overlay product produced by the Harris Corporation which is available on the Operational and Supportability Implementation System (OASIS) briefing system. GPS availability for a nonprecision approach at the destination airfield is provided to a pilot upon request from Flight Services. A pilot can request information for the estimated time of arrival or ask for the GPS availability over a window of up to 48 hours.

5.2.3 WAAS NOTAM/Aeronautical Information System

WAAS provides pilots with increased navigation capability throughout the NAS. The availability of WAAS is dependent on the operational status of the GPS constellation, WAAS assets (reference stations, master stations, ground uplink, geostationary satellites, and communications network), and ionospheric interference which is out the control of the FAA. Satellite navigation is different from ground-based navigation aids since the impact of satellites being out of service is not intuitively known and the area of degraded service is not stationary. Pilots need to know where and when WAAS is predicted to be unavailable. This requires a predictive service volume model (SVM) system that pilots and the FAA can rely on to forecast outages over a period of time for specific areas and airports. WAAS requires distribution of two types of NOTAMs: (1) event-driven notification of system degradation (e.g., satellite out of service) and (2) algorithmically derived predictions of the potential site-specific impact of system outages.

To generate WAAS Predictive NOTAMs, a model of WAAS determines service availability and areas expected to experience outages. The WAAS SVM currently in use was developed at the Volpe Center. The SVM relies on GPS satellite status from the GPS Master Control Station, received in the format of a NOTAM from the FAA; GPS almanac data from a GPS receiver with a backup source from Schriever Air Force Base; location information for airports with RNAV and GPS procedures from a listing provided by FAA Aviations System Standards that is converted into a database by the Volpe Center.

The SVM generates the WAAS service availability for a 30-hour period once every 24 hours. The data is processed at one-minute intervals over the 30-hour prediction window. Any predicted outages are formatted as NOTAMs and use the following criteria:

1. NOTAMs are based on airport reference-point coordinates.
2. NOTAMs are calculated at one-minute intervals/outages.
3. NOTAMs are published for a minimum of 15 minutes regardless of the outage duration.
    a. Three minutes are added to the beginning of the outage.
    b. Three minutes are added to the end of the outage.
4. Outages are based on a vertical alert limit of greater than 50 m or a horizontal alert limit of greater than 40 m.
5. Outages separated by less than 15 minutes are combined into a single outage.

Outages are based on WAAS service unavailability for LNAV, LNAV/VNAV, and LPV approaches, and also are designed to provide outage information for en route operations. If WAAS service is unavailable, the algorithm reverts to determining availability for horizontal guidance based on TSO C145/146 RAIM) with Fault Detection and Exclusion (FDE) and SA set to zero.

Airfield-specific NOTAMs are sent to FSS. NOTAMs are formatted in the U.S. domestic NOTAM format. Airfields that have been determined not to have a high enough availability 98 percent or an average of one outage per day or more) are marked with an “inverse W” (W) to indicate that WAAS NOTAM information is not provided. Certain flight-planning restrictions apply to those airfields.

The WAAS NOTAM generation function resides on the FAA Military Operations System (MILOPS) operating environment. The WAAS NOTAM system receives outages formatted as NOTAMs from the WAAS SVM, parses the NOTAM text to determine the responsible FSS for the locations involved, and then transmits the NOTAM text via a Service B message to the Automated Flight Service Station (AFSS). Specialists at the FSS review the NOTAM text and transmit it to the US NOTAM System (USNS) for processing. Once processed, USNS sends a response back to the originating FSS with the USNS NOTAM number.

Predicted outages are based on airport status versus runway end for each procedure. The term UNRELIABLE is used in conjunction with GPS and WAAS NOTAMs as an advisory to pilots indicating that the expected level of WAAS service (LNAV/VNAV, LPV) may not be available. WAAS UNRELIABLE NOTAMs are predictive in nature and are published for flight planning purposes. Upon commencing an approach at locations NOTAM’d as WAAS UNRELIABLE, if the WAAS avionics indicate LNAV/VNAV or LPV service is available, the vertical guidance may be used to complete the approach using the displayed level of service. Should an outage occur during the approach, reversion to LNAV minima may be required. Area-wide WAAS UNAVAILABLE NOTAMs indicate loss or malfunction of the WAAS system.

The WAAS NOTAM System is under evaluation for improvements and changes that will automate the process and provide more timely and accurate updates as the system status changes. Consideration is being given to criteria and outage classification changes.

5.2.4 Maritime Information Systems

USCG provides coastal maritime safety broadcasts through VHF Marine Radio Broadcasts on VHF simplex channel 22A and Global Maritime Distress and Safety System (GMDSS) NAVTEX text broadcasts on 518 kHz.

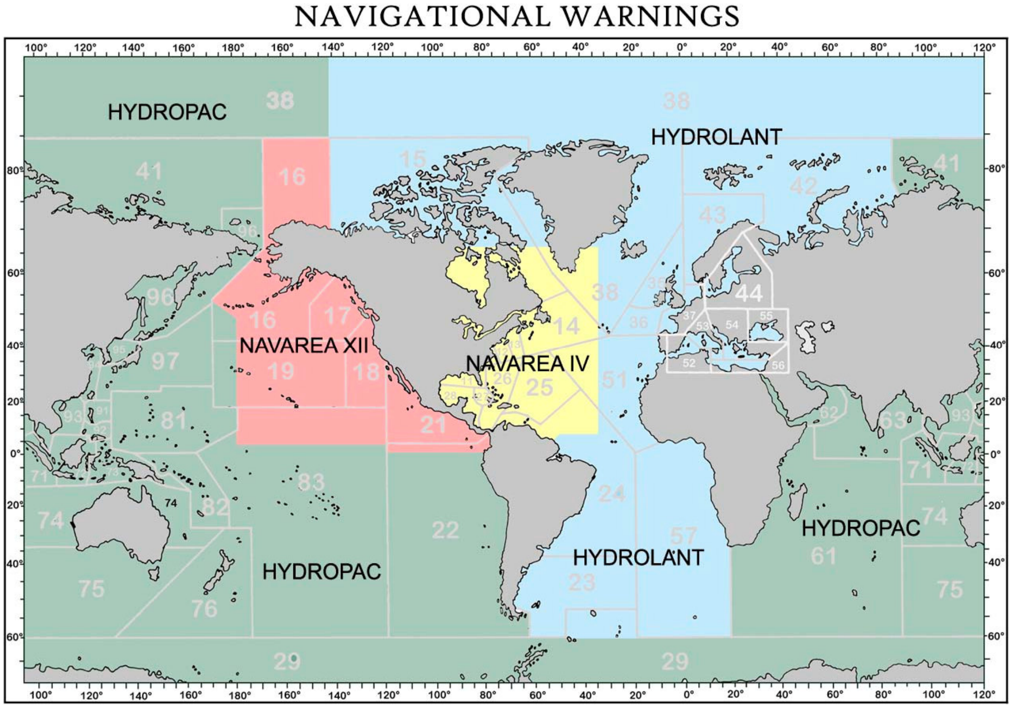

Figure 5-4. NGA Maritime Broadcast Warnings Cover NAVAREAs IV & XII

The NGA Office of Global Navigation is the Area Coordinator for issuance of marine navigation warnings for two of the sixteen NAVAREAs (areas in the IHO and IMO established World-Wide Navigational Warning Service) providing coverage of North America, see Figure 5-4. The NAVAREA Coordinators assimilate information from coastal nations within each NAVAREA and are required to promulgate information that includes failure of and/or changes to major navigational aids, including GPS; newly discovered wrecks, obstructions or natural hazards; military operations; search and rescue; cable laying; movement of offshore drilling units; scientific research and various other underway activities. NAVAREA messages are promulgated to one of four Inmarsat-C satellites depending on the ocean region covered, see Figure 5-5. All merchant vessels over 300 gross tons are required to carry an Inmarsat-C transceiver. The Inmarsat-C transceivers have a built-in GPS receiver which is used by the transceiver to automatically determine the NAVAREA where the vessel is sailing so as to provide the relevant messages. This is a part of the GMDSS and provides offshore coverage beyond national coastal broadcasts or provides coverage should a coastal station become inoperable, e.g., as occurred during hurricane Katrina. NGA provides global broadcast service through issuance of HYDROLANT and HYDROPAC messages which are principally directed to the USN and vessels involved in international deep sea navigation.

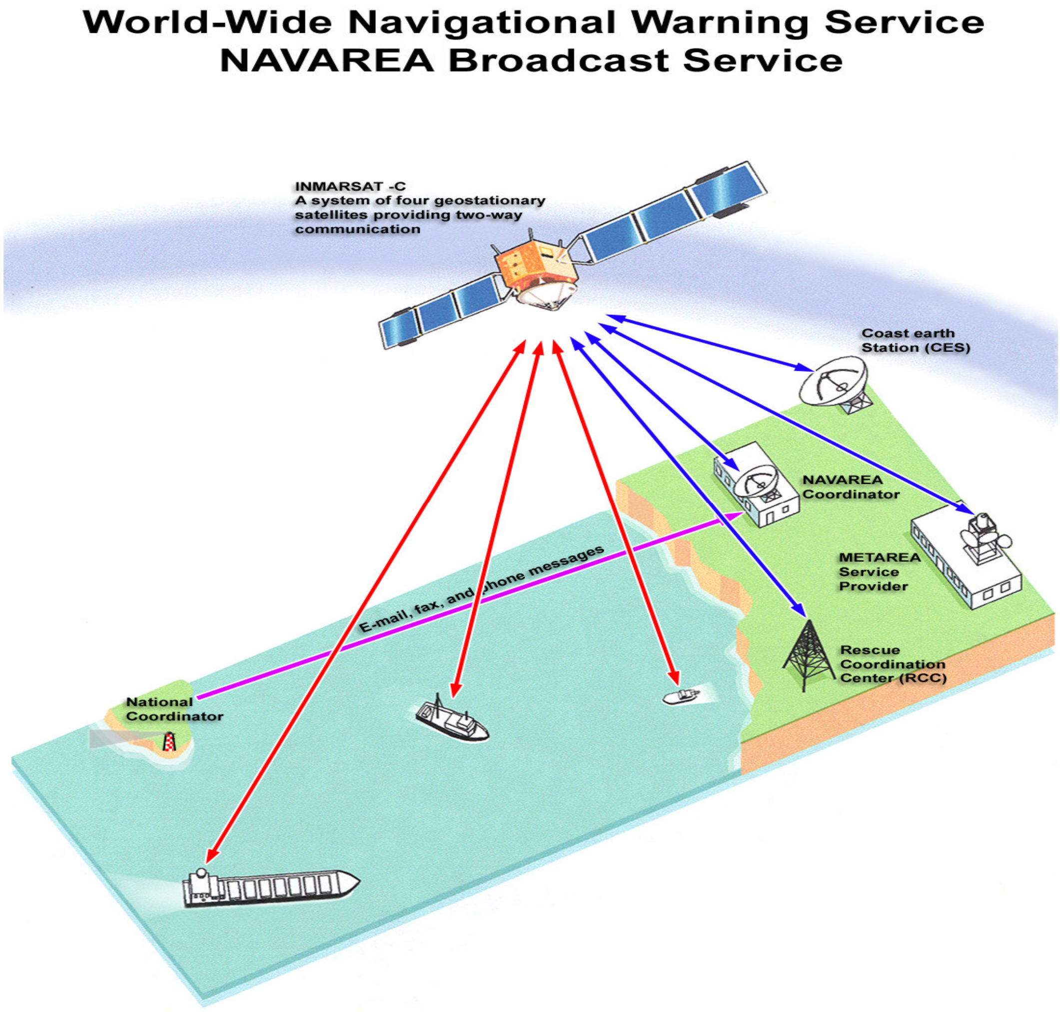

Figure 5-5. IHO/IMO World-Wide Navigational Warning Service, NAVAREA Broadcast Service

The NGA Office of Global Navigation further provides on-line Notices to Mariners which include notice of GPS outages. NGA also provides an on-line brochure for marine navigators, “Using Nautical Charts with Global Positioning System.”

5.3 NASA GPS Data and Space-User Services

5.3.1 International GNSS Service (IGS)

The International GNSS Service, formerly known as International GPS Service, was formally recognized in 1993 by the International Association of Geodesy and began operations on January 1, 1994. It is recognized as an international scientific service, and it advocates an open data, and equal access, policy. NASA funds the IGS Central Bureau, which is located at Jet Propulsion Laboratory (JPL), and a global data center located at the NASA Goddard Space Flight Center. For more than 10 years, IGS has expanded to a coordinated network of over 350 GPS monitoring stations from 200 contributing organizations in 80 countries. Other contributing U.S. agencies and organizations include, among others, the NOAA's NGS, USNO, NGA, and NSF. The IGS mission is to provide the highest quality data and products as the standard for GNSS's in support of Earth science research, multidisciplinary applications, and education, as well as to facilitate other applications benefiting society. Approximately 100 IGS stations report with a latency of one hour. This data, and other information, may be obtained from the IGS website at: http://igscb.jpl.nasa.gov.

5.3.2 Space-Based Range (SBR) and GPS Metric Tracking (GPS MT)

Space-based navigation, GPS, and space-based range (SBR) safety technologies are key components of the next generation launch and test range architecture being developed by NASA with assistance from DoD and FAA. A space-based range provides a more cost-effective launch and range safety infrastructure while augmenting range flexibility, safety, and operability to better accommodate more diverse and dispersed (multiple launch ranges) space operations in the future. A memorandum was signed on November 2006 for GPS-MT by January 1, 2011 for all DoD, NASA, and commercial vehicles launched at the Eastern and Western ranges. Development is underway for using GPS-based tracking via NASA's Tracking Data Relay Satellite Service (TDRSS) as a primary means of launch vehicle tracking. Also in the future, reusable launch vehicles (RLV) are expected to be part of the mix of aviation and space traffic.

5.3.3 Global Differential GPS and TDRSS Augmentation Service for Satellites (TASS)

The Global Differential GPS (GDGPS) System is a high accuracy GPS augmentation system, developed by Caltech's Jet Propulsion Laboratory (JPL), to support the real-time positioning, timing, and orbit determination requirements of NASA's science missions. The Global Differential GPS network consists of 100+ dual-frequency, real-time GPS reference stations operational since 2000. Its real-time products are also used for GPS situational assessment, natural hazard monitoring, emergency geolocation (E911), and other civil and defense applications. Future NASA plans include developing the TDRSS Augmentation Service Satellites (TASS) to disseminate the GDGPS real-time differential correction message to Earth satellites and enable precise autonomous orbit determination, science processing, and the planning of operations in Earth orbit. The TASS signal will be transmitted on S-band from NASA's TDRSS satellites and will also provide ranging signal synchronized with GPS. A demonstration TASS signal has continued to be broadcast to space users since 2006.

5.4 The Future – A National Positioning, Navigation, and Timing Architecture

Although radionavigation systems like GPS will remain the cornerstone of the Nation's PNT Architecture, addressing current and future capability gaps will require innovative thinking. In an effort to fully understand capability gaps and chart a course to achieve efficient and effective solutions, an interagency team co-sponsored by DoD (ASD/NII) and DOT (RITA) undertook a National PNT Enterprise Architecture Study focused on the 2025 timeframe—the team's recommendations were presented to and accepted by DoD and DOT leadership in June 2008.

The study team identified the following gaps as being of primary concern:

- assured and real-time PNT in physically impeded environments;
- assured and real-time PNT in electromagnetically impeded environments, to include operations during spoofing, jamming and unintentional interference;
- higher accuracy with integrity needed (especially for future highway and rail applications);
- timely notification (as short as 1 second in some situations) when PNT information is degraded or misleading, especially for safety-of-life applications or to avoid collateral damage;
- high-altitude/space position and orientation, to include real-time high-accuracy position and orientation (<10 milliarcseconds) information;
- user access to timely geospatial information for successful navigation; and
- PNT modeling capabilities in impeded conditions to determine impacts, more timely modeling capabilities, and a capability to predict impacts in urban environments

Addressing these gaps will present significant challenges for the PNT community and USG radionavigation systems. The path offered by the architecture study team included a vision for USG-provided PNT services and an overarching strategy supported by four vectors and a series of recommendations. A key objective of the effort was to serve as the basis for making informed recommendations on DoD, civil, and commercial PNT program plans, requirements, budgets, schedules, international partnerships, science and technology (S&T) investments, and policies. The top-level elements of the architecture are outlined below.

5.4.1 Vision – US Leadership in Global PNT

The National PNT Architecture's vision is for "US Leadership in Global PNT," based on the policy foundation set by the National Space-Based PNT Policy. The U.S. can lead by efficiently developing and fielding PNT capabilities and avoiding unnecessarily redundant government services as determined by the responsible government agencies to meet their requirements. Additionally, the U.S. should issue and adhere to stable policies, building credibility both domestically and internationally, enabling the commercial sector to innovate and advance PNT through competitive practices. Furthermore, USG agencies should provide PNT capabilities in a coordinated manner, share information, and present a more unified view of U.S. objectives by promoting inter-agency cooperation across the full scope of PNT.

5.4.2 Strategy – Greater Common Denominator

The National PNT Architecture seeks to fulfill the architectural vision by promoting a "Greater Common Denominator" strategy. In this architecture, users are predominantly dependent upon external sources of PNT information, like radionavigation, where "greater" capabilities meet the needs of a larger, more "common" segment of the user base. In that vein, U.S. GNSS modernization is vital to providing significantly more capability on a global scale to an unlimited number of users.

In addition to users being dependent on external sources, the architecture is also centrally focused on wide adoption of low-burden (e.g., size, weight, power and cost) autonomous features to overcome physical and electromagnetic impedances. The Architecture also acknowledges that specialized solutions will continue to exist where it is either inefficient or inappropriate to provide the required capability more commonly, to ensure robustness for certain applications, or to meet agency regulatory responsibilities. Lastly, the U.S. must continue to balance the need for a national security advantage in light of providing greater capabilities at a common level.

5.4.3 Vector – Multiple Phenomenologies

The National PNT Architecture promotes the use of multiple phenomenologies to ensure robust availability and address gaps in the ability to operate in physically and electromagnetically impeded environments. "Multiple phenomenologies" refers to diverse physical phenomena such as radio frequencies and inertial sensors as well as diverse sources and data paths using those physical phenomena (e.g., multiple radio frequencies) to provide interchangeable solutions to the user. The Multiple Phenomenology Vector includes issues related to standards, criteria of use (especially when incorporating foreign data sources), and mixing ground-, air-, space-based and internal data sources for a single solution.

5.4.4 Vector – Interchangeable Solutions

The National PNT Architecture promotes the interchangeability of solutions to enhance efficiency and exploit source diversity. Interchangeable solutions have a degree of compatibility and interoperability that allows the combination of diverse sources to obtain a superior PNT solution. In accordance with national policy, the U.S. should promote interchangeability and user acceptance thereof, by refining PNT-related policy goals and objectives to include interchangeability, and through U.S. involvement and leadership in international forums.

5.4.5 Vector – Fusion of PNT with Communications

The National PNT Architecture leverages users' increasing connectivity to communications networks for use as sources of PNT, not merely as data channels for PNT aiding and augmentation data. This vector promotes the fusion of PNT features with new and evolving communications capabilities, resulting in increased robustness by offering services outside of traditional radionavigation spectrum.

5.4.6 Vector – Cooperative Organizational Structures

The National PNT Architecture promotes a coordination process, building on existing organizations where appropriate, to facilitate cooperation and information sharing. This coordination is important both to review and assess progress towards this architecture's goals and to review and assess the contribution of the architecture to national goals and interests as contained in Presidential policy and in legislation. This vector also promotes identification and leverage of Centers of Excellence for phenomenologies and applications should across the community.

5.4.7 The Way Ahead for PNT

The National PNT Architecture's Guiding Principles seek to provide more effective and efficient PNT capabilities by identifying an evolutionary path for government provided systems and services through 2025. This enterprise-level architecture will help guide future PNT system-of-systems investment and implementation decisions while recognizing the critical importance of meeting users' needs. Future transition and implementation planning, along with the appropriate investments, will enable the evolution to a system-of-systems architecture achievable in the 2025 timeframe.

Appendix A

Geodetic Datums and Reference Systems

A.1 Datums

As a general definition, a datum is any quantity or set of quantities that may serve as a referent or basis for calculation of other quantities. This broad characterization, in turn, leads to two related definitions of geodetic datum:

- a geodetic datum is a set of constants specifying the coordinate system used for geodetic control; and
- a geodetic datum is defined above, together with the coordinate system and the set of all points and lines whose coordinates, lengths, and directions have been determined by measurement and calculation.

The first definition is realized, for example, by specification of an ellipsoid and associated origin and orientation information. The second definition, which is prevalent in mapping and charting, is realized, for example, by specification of ellipsoid, origin, and orientation in combination with a self-consistent set of observed reference coordinates. The first definition represents an idealization of a geodetic datum, and the second definition expresses the realization of a geodetic datum.

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 have been defined using a reference ellipsoid and six topocentric parameters expressing origin and orientation. One example is North American Datum 1927 (NAD 27). Due to the constraints and requirements of the times, horizontal datums were non-geocentric in definition.

Vertical datums are expressed in some form of orthometric height, and can be clustered into two categories: those generally based on Mean Sea Level (MSL), and those based on some tidally-derived surface of an averaged high or low water. Examples of the former is the North American Vertical Datum 1988 (NAVD 88), and the example of the latter is Mean Lower Low Water (MLLW). Vertical datums depend upon two elements, the approximation or realization of Mean Sea Level, and the approximation or realization of orthometric height. For example, NAVD 88 is based on an adopted elevation at Point Rimouski (Father's Point), and it uses Helmert orthometric heights as an approximation to true orthometric heights. By contrast, the National Geodetic Vertical Datum 1929 (NGVD 29) was fixed to a set of reference tide gauges, without correction for local sea surface topography departures, and it used normal orthometric heights as an approximation to true orthometric heights.

Three dimensional datums are defined using a reference ellipsoid and six geocentric parameters expressing origin and orientation. Unlike horizontal datum, a three dimensional datum provides the foundation for accurate determination of ellipsoid heights. Examples of three dimensional datums are NAD 1983 (NAD 83) and WGS 1984 (WGS 84).

NAD 83 was affirmed as the official horizontal datum for the U.S. by a notice in the Federal Register (Vol. 54, No. 113 page 25318) on June 14, 1989.

NAVD 88 was affirmed as the official vertical datum for the U.S. by a notice in the Federal Register (Vol. 58, No. 120 page 34325) on June 24, 1993.

A.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. Because of this methodology, it became possible to establish positions of high accuracy in a rectangular reference frame without specification of an ellipsoid. An example of such a reference frame is the International Terrestrial Reference Frame 1997 (ITRF 97). A geodetic reference system is the combination of a reference frame and an ellipsoid. As seen above, a geodetic reference system is a synonym for a three dimensional datum. Examples of geodetic reference systems are NAD 83 and WGS 84.

The geodetic reference system used by unaugmented GPS is the *Department of Defense World Geodetic System 1984, Its Definition and Relationships with Local Geodetic Systems* (Ref. 11). The details of the models, the parameters, their uncertainties, and relationships to other systems are given in the reference. The most recent WGS 84 reference frame and the ITRF 94 system are in agreement to better than 5 cm. NAD 83 differs from WGS 84 and ITRF 94 by over 2 m.

The geodetic reference system used by deployed GPS augmentations is the NAD 83. MDGPS and NDGPS augmentations are described in Section 5.1.3.1. The DGPS corrections provided by these augmentations are referenced to NAD 83, thus allowing DGPS receivers to easily provide NAD 83 coordinates. The national CORS system, described in Section 5.1.3.5, includes coordinate databases in both the NAD 83 geodetic reference system, and in the ITRF 2000 (ITRF 00) reference frame combined with the Geodedic Reference System 1980 (GRS 80) ellipsoid.

A.3 Geoid

The geoid is a specified equipotential surface, defined in the Earth's gravity field, which best fits, in a least square sense, global mean sea level. It should be noted that due to effects such as atmospheric pressure, temperature, prevailing winds and currents, and salinity variations, MSL will depart from an equipotential surface by a meter or more.

The geoid is a complex, physically-based surface, and while it can vary by up to 100 meters in height from a geocentric ellipsoid, its deviations from MSL rarely exceed 2 meters. Many national regional vertical datums are tied to a local mean sea level (LMSL), which may differ significantly from global MSL due to local effects such as river run off and extremes in coastal tidal effects. Thus, national and regional vertical datums around the world, which are tied to LMSL, will differ from one another significantly when considered on a global basis. In addition, due to the realization and orthometric height approximations of various vertical datums, other departures at the meter level or more will be found when comparing elevations to a global geoid reference.

For the U.S., the GEOID03 geoid model has been developed to directly relate ellipsoid heights from the NAD 83 three-dimensional datum to the NAVD 88 vertical datum. Comparisons with GPS ellipsoid heights on leveled benchmarks show this conversion can generally be accomplished in the conterminous United States to about 2.5 cm (1 sigma).

On a global basis, the Earth Gravity Model 1996 (EGM96) was developed to produce an improved global geoid. WGS 84 (EGM96) Geoid is accurate to better than a meter in gravity surveyed areas.

A.4 Land Maps

As discussed earlier, the NAD 83 and the NGVD 88 datums were adopted by Congress as datums for the U.S. Depending upon the scale of mapping and the spacing of contour intervals, the older NAD 27 and NGVD 29 datums may be adequate to represent the National Spatial Data Accuracy

Standard. Except for the largest map scales, the horizontal components of WGS 84 and NAD 83 are equivalent. Datum transformations are available which relate the NAD 27 and NAD 83 datums, and which relate the NGVD 29 and NAVD 88 datums.

A.5 Nautical Charts

As discussed earlier, the NAD 83 and NAVD 88 datums were adopted by Congress as datums for the U.S. On a global basis, International IHO designated the use of the WGS 84 as the universal datum. Since then, the horizontal features have been based on WGS 84 or in other geodetic reference systems that are compatible, such as NAD 83.

All vertical features and depths are still defined with respect to tidal surfaces, which may differ in definition from chart to chart. The IHO has agreed to Lowest Astronomical Tide and Highest Astronomical Tide as the preferred tidal datums for use in nautical charting.

A.6 Aeronautical Charts

As discussed earlier, the NAD 83 and the NAVD 88 datums were adopted by Congress as datums for the U.S. On a global basis, ICAO designated the use of the WGS 84 as the universal datum. Since then, the horizontal features have been used on WGS 84 or in other geodetic reference systems which are compatible, such as the NAD 83 or the ITRF combined with the GRS 80 ellipsoid.

All vertical features and elevations are still determined relative to the local vertical datums, which may vary by a meter or more from a global geoid reference (e.g., WGS 84 (EGM96) geoid).

A.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. With the transition to electronic charts, the inaccuracies of manual plotting by cartographers are avoided in that the accurate position of features can be included within the electronic chart data.

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 from a map or chart.

Appendix B

System Parameters and Descriptions

B.1 System Parameters

Systems described in Section B.2 are defined below 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
  Fix Rate
- Accuracy
  Reliability
- Availability
  Spectrum
- Coverage
- Fix Dimensions
- System Capacity
- Ambiguity
- Integrity

B.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.

B.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 navigation system accuracy 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 user. 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 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.

With the latest publication of the GPS SPS and PPS Performance Standards, DoD has changed its specification of horizontal accuracy to 2 drms or 95 percent. In the past, DoD had specified 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.

- Repeatable accuracy: The accuracy with which a user can return to a position whose coordinates has 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.

B.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.

B.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 that affect signal availability.

B.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.

B.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.

B.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.

B.1.8 System Capacity

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

B.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.

B.1.10 Integrity

Integrity is the measure of the trust that can be placed in the correctness of the information supplied by a navigation system. Integrity includes the ability of the system to provide timely warnings to users when the system should not be used for navigation.

B.1.11 Spectrum

FAA, DoD, and USCG require spectrum as providers and operators of radionavigation systems.

B.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 B.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.

B.2.1 GPS

GPS is a space-based dual use radionavigation system that is operated for the USG by the USAF. The USG provides two types of GPS service. PPS is available to authorized users and SPS is available to all civil users. As GPS continues to modernize with the implementation of new civil signals, civil GPS capability becomes comparable to PPS.

The GPS has three major segments: space, control, and user. The GPS Space Segment consists of a nominal constellation of 24 satellites in six orbital planes. The satellites operate in circular Medium Earth Orbit (MEO), approximately 20,200 km (10,900 nm), and at an inclination angle of 55 degrees and with a 12-hour period.

The GPS Control Segment has a network of monitor stations and four dedicated ground antennas with uplink capabilities. The monitor station network uses GPS receivers 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 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 satellite 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 B-1. Further details on the performance of GPS SPS may be found in the GPS SPS PS (Ref. 9).

A. Signal Characteristics

Each satellite transmits four spread 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 and L2C, which broadcasts a signal that is currently utilized by users to reduce the ionosphere error on the L1 C/A signal from the same satellite. The Precise code is denoted as P(Y) to signify that this PRN code can be transmitted in either a clear unencrypted "P" or an encrypted "Y" code configuration. The 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. Modernized satellites will broadcast additional signals as descried in Section 3.2.7.

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 -158.5 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 use by single frequency (SPS) 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 sec. As long as a satellite indicates a healthy status, a receiver can continue to operate using these data for the validity period 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.

Conceptually, 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.

Table B-1. GPS/SPS Characteristics

SPS ACCURACY (METERS) 95%*	SERVICE AVAILABILITY*	COVERAGE	SERVICE RELIABILITY**	FIX RATE	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE							
Horz ≤ 9 Vert ≤ 15 Time ≤ 40ns	99%	Terrestrial Service Volume	1-1x10^{-5}/hr/SIS	1-20 per second	3D + Time	Unlimited	None

* Accuracy and availability percentages are computed using 24-hour measurement intervals. Statistics are representative for an average location within the global service volume. Predictable horizontal 95% error can be as large as 17 m and predicted vertical 95% error as large as 37 m at the worst-case location in the terrestrial service volume. Accuracy statistics do not include contributions from the single-frequency ionospheric model, troposphere, or receiver noise. Availability statistic applies for worst-case location predicted 95% horizontal or vertical position error values.

** Reliability threshold is ± 4.42 times the upper bound on the URA value corresponding to the URA index "N" currently broadcast by the satellite.

B. Accuracy

SPS is the standard specified level of positioning, velocity and timing accuracy that is available, without restrictions, to any user on a continuous worldwide basis. SPS provides a global average predictable positioning accuracy of 9 m (95 percent) horizontally and 15 m (95 percent) vertically and time transfer accuracy within 40 ns (95 percent) of UTC. For more detail, refer to the *Global Positioning System Standard Positioning Service Performance Standard* (Ref. 9).

C. Availability

The SPS provides a global average availability of 99 percent. Service availability is based upon the expected horizontal error being less than 17 m (95 percent) and the expected vertical error being less than 37 m (95 percent). The expected positioning error is a predictive statistic, and is based on a combination of position solution geometry and predicted satellite ranging signal errors.

D. Coverage

GPS coverage is worldwide. The coverage of the GPS SPS service is described in terms of a terrestrial service volume, which covers from the surface of the earth up to an altitude of 3,000 km.

E. Reliability

The probability that the SPS signal-in-space (SIS) user range error (URE) from a healthy satellite will not exceed ± 4.42 times the upper bound on the User Range Accuracy (URA) value corresponding to the URA index "N" currently broadcast by the satellite without a timely alert is > 1-1x10-5/hr.

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 effective user 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 and time when only three satellites are available.

H. System Capacity

The capacity is unlimited.

I. Ambiguity

There is no ambiguity.

J. Integrity

The GPS system architecture incorporates many features including redundant hardware, robust software, and rigorous operator training to minimize integrity anomalies. Resolution of an unanticipated satellite integrity anomaly may take up to 6 hours. Even the best response time may be on the order of several minutes, which is insufficient for certain applications. For such applications, augmentations such as RAIM (a built-in receiver algorithm) may be required to achieve the requisite timely alert.

K. Spectrum

GPS satellites broadcast at two L-Band frequencies: L1 in the 1559-1620 MHz aeronautical radionavigation/satellite service band and L2 in the 1215-1260 MHz band. The planned third civil signal, L5, is to be centered at 1176.45 MHz in the 1164-1215 MHz aeronautical radionavigation satellite service band.

B.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.

GPS must be augmented to meet current aviation, land, and marine accuracy and integrity requirements. DGPS is one method to satisfy these 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 pseudorange corrections based on its measurements. 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 to better than 7 m (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 method 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 a fixed 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 MDGPS Service, the NDGPS service, and the FAA LAAS.

The above method is incorporated in the FAA 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 are processed to yield highly accurate ephemeris, ionospheric and tropospheric calibration maps, and DGPS corrections for the broadcast spacecraft ephemeris and clock offsets. In the WAAS, these GPS corrections and system integrity messages are relayed to civil users via a dedicated package on geostationary satellites. This relay technique also supports 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 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 code phase range data. The national 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.

B.2.2.1 Maritime and Nationwide DGPS

The combined national DGPS utility augments the U.S. GPS by providing increased accuracy and integrity of the GPS using land-based reference stations to transmit correction messages over radiobeacon frequencies from local beacons. The service has been implemented through agreements between multiple Federal agencies including the USCG, DOT, and USACE.

Today, 39 USCG and nine USACE broadcast sites provide service for maritime coverage of the continental U.S. (CONUS), the Great Lakes, Puerto Rico, portions of Alaska and Hawaii, and portions of the Mississippi River Basin. DOT sponsors the Nationwide DGPS (NDGPS) program to provide signal coverage over inland surface areas of the U.S. to meet the growing requirements of surface users. There are currently 39 DOT sponsored sites in the NDGPS network providing 92 percent of the contiguous 48 states with single coverage and 65 percent with dual coverage by differential corrections. NDGPS currently meets all of the USCG DGPS performance requirements and both systems are monitored and operated as a combined national DGPS utility by the USCG from one of three independent control stations.

Figure B-1 shows the DGPS architecture using pseudorange corrections. The reference station's and other user's pseudorange calculations are strongly correlated. Pseudorange corrections computed by the reference station, when transmitted to the user in a timely manner, can be directly applied to the user's pseudorange computation to dramatically increase the resultant accuracy of the pseudorange measurement before it is applied within the user's navigation solution.

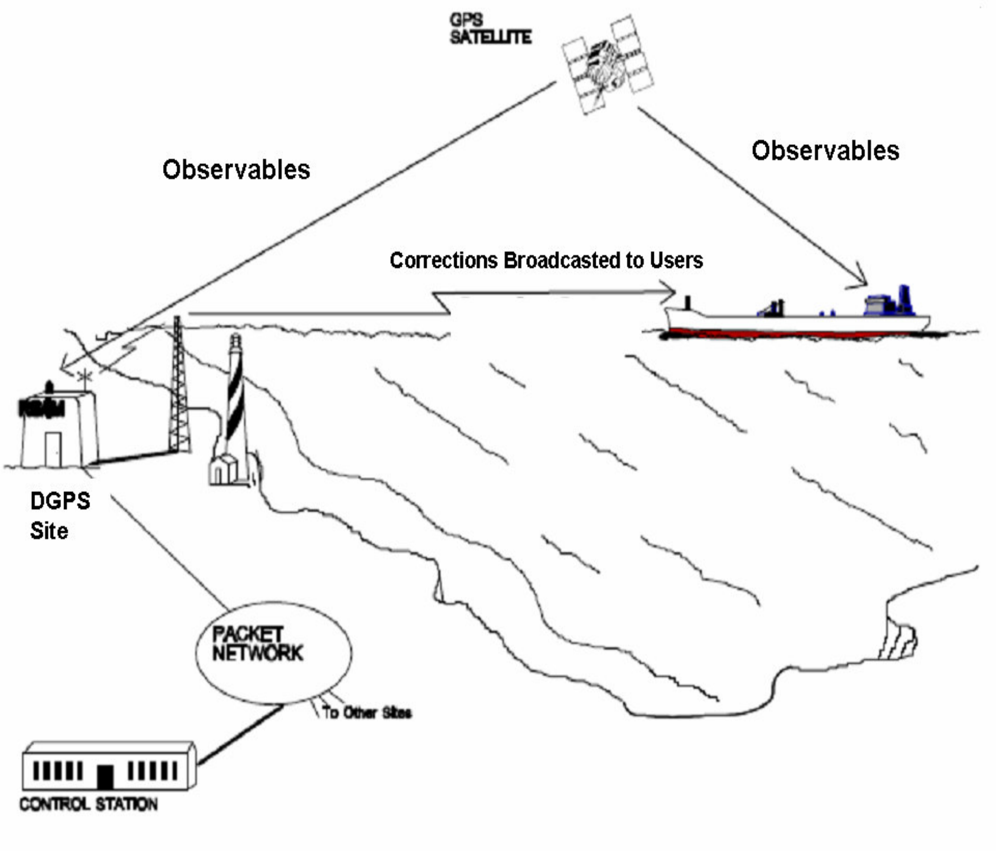

Figure B-1. Maritime DGPS Architecture

A. Signal Characteristics

The datalinks for DGPS corrections are broadcast sites transmitting between 285 and 325 kHz using minimum shift keying (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. These DGPS Services do not use data encryption. The characteristics of the Maritime DGPS (MDGPS) Service are summarized in Table B-2.

Table B-2. MDGPS and NDGPS 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	Continental U.S. including coastal areas, selected areas of HI, AK, and PR	< 500 outages/1,000,000 hours	1-20 per second	3D	Unlimited	None	On-site integrity monitor and 24-hour DGPS control center

B. Accuracy

The predictable accuracy of the DGPS Service within all established coverage areas is specified 10 m (2 drms) or better. The DGPS Service accuracy at each broadcast site is carefully controlled and is consistently 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 interference and propagation distortions. Typical user equipment is able to achieve 1-2 meter horizontal accuracies in real time, throughout the coverage area. High-end user equipment routinely achieves accuracies better than 1 meter, throughout the coverage area, by compensating for the various degrading factors.

C. Availability

Current availability calculations have been modified to be user-centric. The previous method used signal-on-air at the various broadcast sites and average them together. While this is provides a good metric for how well an individual site is operating, it does not give a true sense of signal availability from the user's perspective. This is particularly true for users that have coverage from alternate sites in the event a site is taken off-air due to maintenance or equipment failure. Coverage is now based on service areas, typically a 3 nm square, and the availability of a signal averaged across all those areas. While the calculation has changed, the standards to be met have not. 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

The combined U.S. DGPS Service is operated by the USCG and is deployed in three distinct segments. Figure B-2 illustrates the signal coverage for the combined system.

(1) In accordance with the USCG's DGPS Broadcast Standard (COMDTINST M16577.1), the MDGPS 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 (see Figure B-3).

(2) Much of this inland waterway portion is provided by the USACE (see Figure B-4).

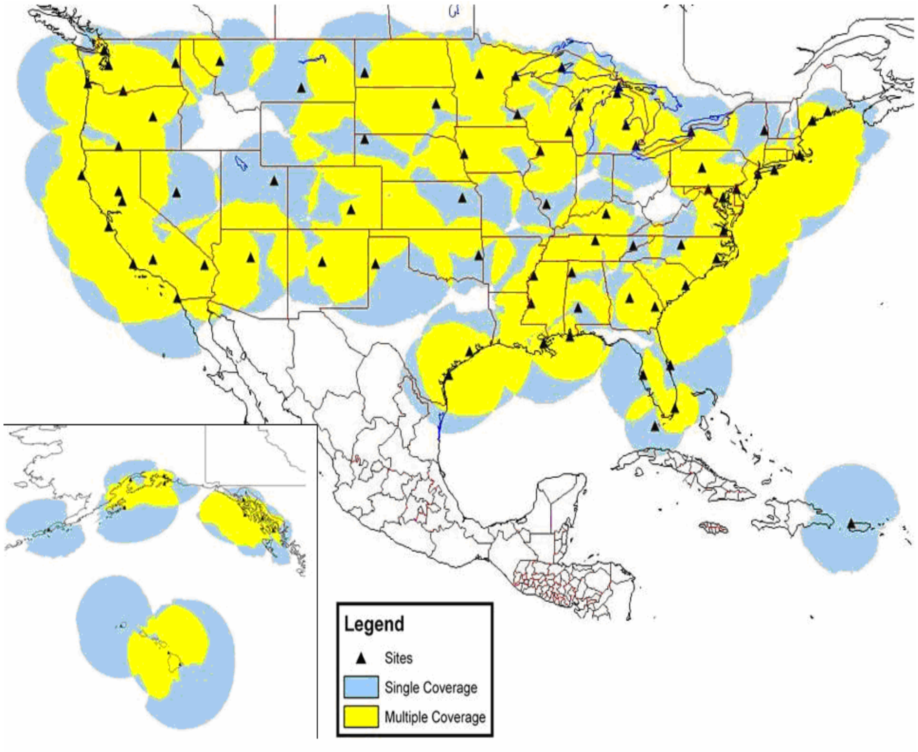

Figure B-2. Combined DGPS Signal Coverage

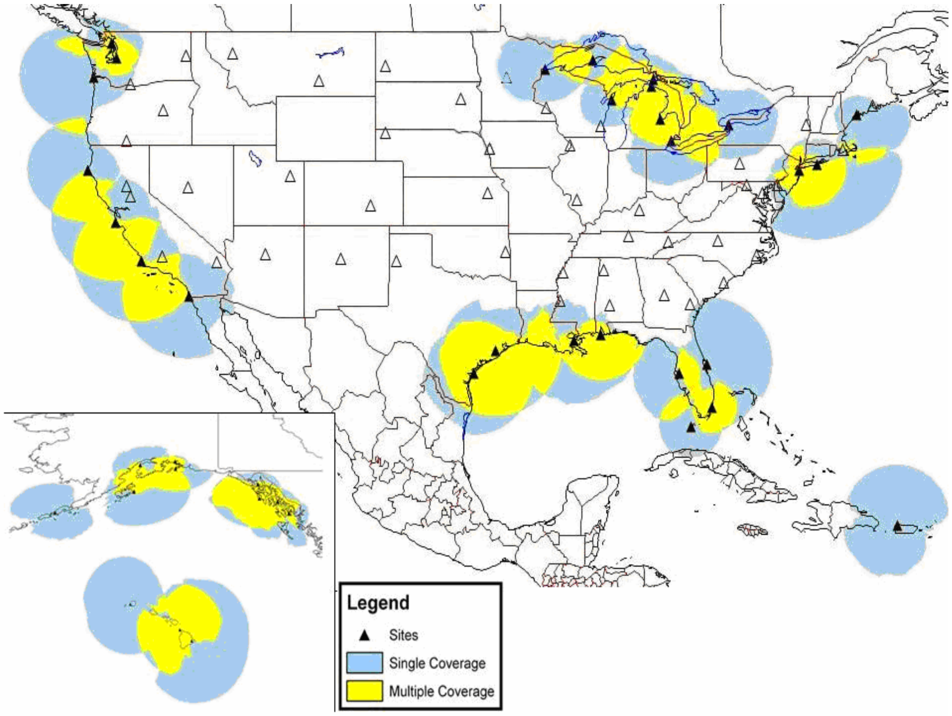

Figure B-3. MDGPS Coverage

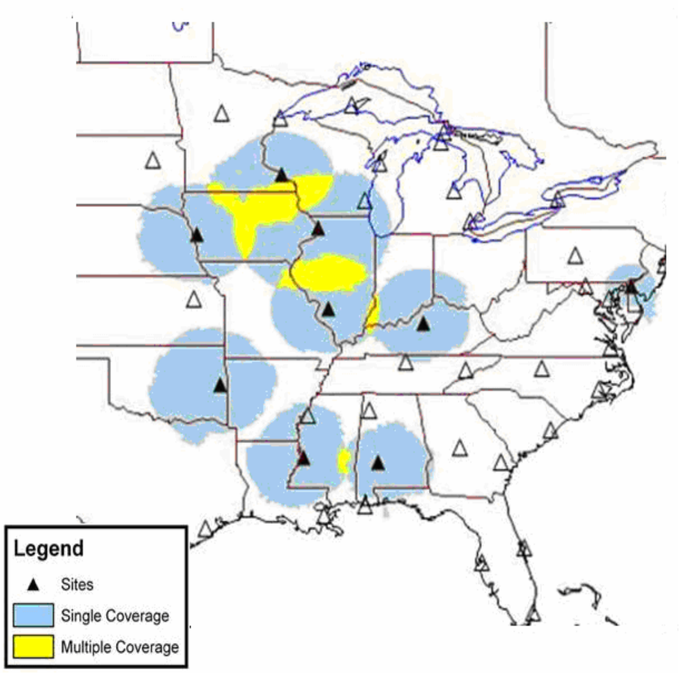

Figure B-4. USACE Inland Waterway Coverage

(3) The inland NDGPS segment is planned to complement the USCG and USACE provided segments and provide dual coverage of the continental U.S. and selected portions of Hawaii and Alaska. See Figure B-5.

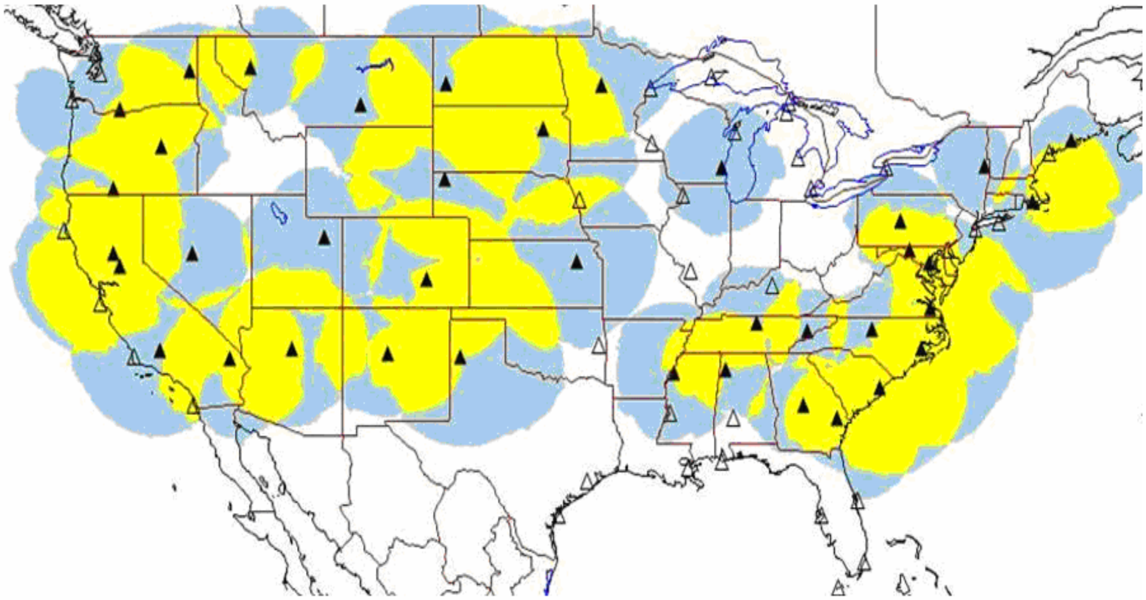

Figure B-5. Inland NDGPS Coverage

It is important to note that the coverage indicated is provided regardless of terrain, and man-made and other surface obstructions. This is achieved by use of the medium frequency broadcast optimized for surface applications.

E. Reliability

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

F. Fix Rate

DGPS Broadcast sites transmit a set of data every 2.5 sec or better. Each set of data points includes pseudorange 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. System Capacity

Unlimited.

H. Ambiguity

None.

I. Integrity

Integrity of the DGPS Service 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 are notified of an out-of-tolerance condition within 6 sec.

In addition to the post-broadcast integrity check, a pre-broadcast integrity check capability is being added as the sites are recapitalized. Pre-broadcast integrity ensures that a bad correction is not sent out.

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

J. Spectrum

The DGPS Service broadcasts GPS pseudorange corrections in the 285-325 kHz maritime radiobeacon band.

B.2.2.2 Nationwide DGPS

The Nationwide DGPS (NDGPS) is based on the architecture of the MDGPS Service. Figure B-6 shows the NDGPS architecture using pseudo-range corrections. Figure B-6 and the following discussion describe the characteristics of the NDGPS system.

A. Signal Characteristics

The data-links 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 m (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 interference and propagation distortions. High-end user equipment may achieve accuracies better than 1 meter, throughout the coverage area, by compensating for the various degrading factors.

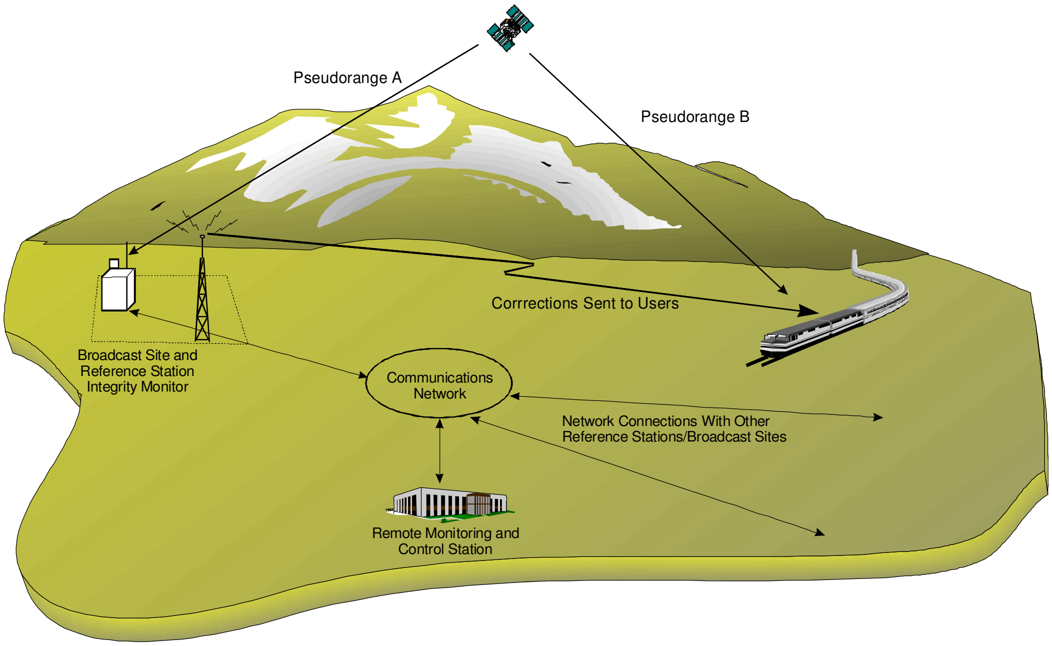

Figure B-6. NDGPS Navigation Service

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.

D. Coverage

When complete, the NDGPS Service will provide uniform differential GPS coverage of the continental U.S. and selected portions of Hawaii and Alaska regardless of terrain, man made, and other surface obstructions. This is achieved by using a terrain-penetrating medium frequency signal optimized for surface application. This service, along with MDGPS, provides a highly reliable GPS integrity function to terrestrial and maritime users.

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 sec 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.

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 sec.

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 will direct the navigator to ignore an erroneous GPS signal or may, under certain circumstances, extend the use of unhealthy GPS satellites by providing accurate corrections.

K. Spectrum

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

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

The WAAS consists of equipment and software that augments the DoD-provided GPS SPS (see Figure B-7). The signal-in-space provides three services: (1) integrity data on GPS and GEO satellites, (2) wide area differential corrections for GPS satellites, and (3) an additional ranging capability. WAAS currently supports aviation navigation for en route through approaches equivalent to CAT-I and RNAV guided departures. WAAS achieved its full level performance build in 2008 to meet service availability requirements.

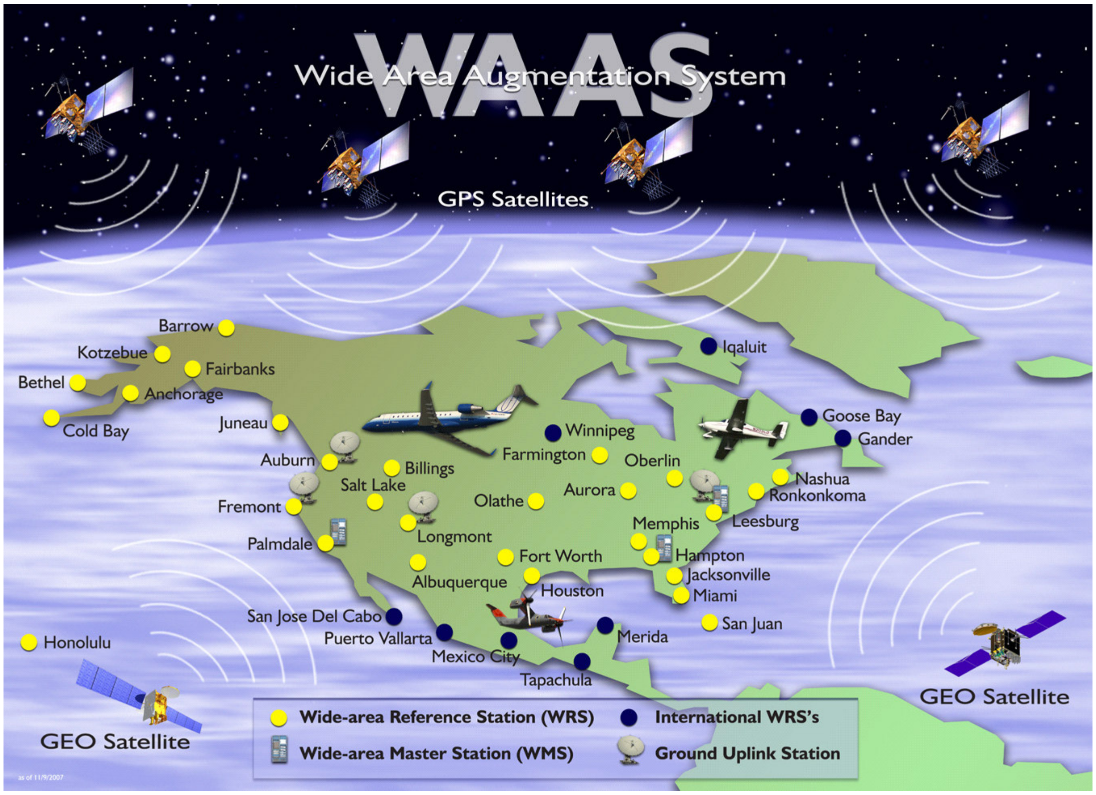

Figure B-7. WAAS Architecture

The GPS satellites' data are 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 sent to a Ground Earth Station (GES) and uplinked along with the GEO navigation message to GEO satellites. These GEO satellites then downlink these data on the GPS Link 1 (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 Airway Facilities personnel.

The WAAS user receiver processes: (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.

A. Signal Characteristics

The WAAS collects raw data from all GPS and WAAS GEO satellites that support the navigation service. WAAS ground equipment develops messages on ranging signals and signal quality parameters of the GPS and GEO satellites. The GEO satellites broadcast the WAAS messages to the users and provide ranging sources on the GPS L1 frequency using GPS-type modulation, including a C/A PRN code. The code-phase timing is synchronized to GPS time to provide a ranging capability.

B. Accuracy

WAAS is delivering horizontal and vertical accuracy of better than 2 m (95 percent) throughout CONUS. The accuracy requirements are based on aviation operations. For the en route through nonprecision approach phases of flight, unaugmented GPS accuracy is sufficient. For LPV-200[*], the horizontal and vertical requirement is 4 m (95 percent).

C. Availability

The WAAS availability for en route through nonprecision approach operations is at least 0.99999. For approach with vertical guidance operations, the availability is at least 0.99.

D. Coverage

The WAAS full service volume is defined from the surface up to 100,000 ft 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).

---

[*] LPV-200 does not meet the technical definition of Category I precision approach; however, it can provide a 200-foot decision height, equivalent to Category I.

E. Reliability

The WAAS provides 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 approaches 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.

WAAS integrity is specified by three parameters: probability of hazardously misleading information (PHMI), time to alert, and the alert limit. For the en route through nonprecision approach phases of flight, where integrity is derived from RAIM with FDE, the performance values are:

PHMI	10^{-7} per hour
Time to Alert	8 sec
Alert Limit	Protection limits specified for each phase of flight

For LPV approach operations, where integrity is provided by WAAS, the performance values are:

PHMI	10^{-7} per approach
Time to Alert	6.2 sec
Alert Limit*	Horizontal 40m/Vertical 50m
Alert Limit**	Horizontal 40m/Vertical 35m

---

* for approaches with ceiling and visibility minimums as low as 250 ft and ¾ mile

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

K. Spectrum

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

B.2.2.4 Aeronautical 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 SPS 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 CAT-III precision approach, including autoland. The LAAS signal-in-space will provide: (1) local area differential corrections for GPS satellites and for WAAS GEOs used as ranging sources[***]; (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 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 possesses 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 point descriptions for each runway end being served are broadcast to aircraft operating in the local terminal area via a LAAS VHF data broadcast transmission.

Airborne LAAS receivers apply the differential correction to their own satellite 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 range data from all available range sources that support the navigation service.

The LAAS ground facility (LGF) will generate differential correction messages as well as pseudorange correction error parameters for each of

---

[**] for approaches with ceiling and visibility minimums as low as 200 ft and ½ mile

[***] Corrections to WAAS GEO ranging sources are optional for LAAS equipment.

the ranging measurements. The LAAS VHF data broadcast transmitter will then broadcast the LAAS DGPS data to users. The VHF ARNS band, 108-117.975 MHz, is used for the LAAS VHF data broadcast.

B. Accuracy

LAAS accuracy has been derived from ILS accuracy requirements. For CAT-I precision approach, the lateral accuracy requirement is 16.0 m, 95 percent. The LAAS CAT-I vertical accuracy requirement is 4.0 m, 95 percent.

C. Availability

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

D. Coverage

The LAAS minimum service volume is defined as:

- Vertically: Beginning at the runway datum point out to 20 nm above 0.9 degrees and below 10,000 ft.
- Horizontally: 450 ft. either side of the runway beginning at the runway datum point and projecting out 35 degrees either side of the approach path out to 20 nm (per the non-Federal LAAS specification).

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 for systems intended to support CAT-I operations is specified for two separate parameters: PHMI and Time to Alert. The PHMI is 1×10^{-7} and the time to alert is 6 sec. Requirements to support CAT-III operations are under development and are intended to fit within the operational framework of ILS CAT-III operations.

K. Spectrum

LAAS broadcasts in the 108-117.975 MHz ARNS frequency band, currently populated by VORs and ILSs, either on channels interstitial to the current VOR/ILS, or after VOR and ILS have been partially decommissioned.

B.2.2.5 National Continuously Operating Reference Stations (CORS)

The national CORS system is a GPS augmentation being established by NOAA's NGS to spport precision, non-navigation applications as described in Section 2.6. The CORS system provides code range and carrier phase data from a nationwide network of GPS stations for access through the Internet. In addition, high accuracy reference coordinates are computed to support components of the Federal Navigation System. As of June 2008, data were being provided from 1200 CORS stations. NGS has implemented CORS by making use of stations established by other groups, rather than by building an independent network of reference stations. About 15 percent of the stations now providing data for the CORS system are from the USCG MDGPS Service and the NDGPS, described in Sections B.2.2.1 and B.2.2.2, as well as the NDGPS stations being established by DOT to support land navigation. Other stations contributing data to the CORS system include those operated by the 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 Earth Systems Research Laboratory (ESRL) in support of meteorological applications.

The CORS system takes data to a Central Data 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 placed in files on the Internet. 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 tropospheric and ionospheric refraction models, to improve the accuracy of the CORS data.

B.2.3 Loran

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.

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.

A. Signal Characteristics

Loran-C is a pulsed, hyperbolic system operating in the 90 to 110 kHz frequency band. The system is based upon measurement of the difference in time of arrival of pulses of RF energy radiated by a chain of synchronized transmitters 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 B-3.

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

ACCURACY (2 drms)								
PREDICTABLE	REPEATABLE	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
0.25nm (460m)	N/A	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.*

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. 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 interoperable 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.

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 (SNR) limit of 1:3 SNR. Current Loran-C coverage is shown in Figure B-8. Expansion of the Loran-C system into the Caribbean Sea and the North Slope of Alaska has been investigated.

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 ns 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.

Figure B-8. Coverage Provided by U.S. or Supported Loran-C Station

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 Lines of Position (LOP) 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.

B.2.4 VOR, DME, and TACAN

Historically, VOR, DME, and TACAN have comprised the basic infrastructure for aviation en route and terminal navigation and nonprecision approaches in the United States, but will cede their preeminence as augmented satellite-based navigation becomes more widely implemented. Information provided to the pilot by VOR is the magnetic azimuth relative to the VOR ground station. DME provides a measurement of the slant rage 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 similar to VOR/DME and is used primarily by military aircraft. When TACAN is collocated with VOR, it is designated as a VORTAC facility. DME and the distance measuring function of TACAN are functionally the same.

B.2.4.1 VOR

A. Signal Characteristics

The signal characteristics of VOR are summarized in Table B-4. VORs are assigned frequencies in the 108 to 117.975 MHz (VHF) 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 B-4. VOR and DME System Characteristics (Signal-in-Space)

ACCURACY* (2 Sigma)						FIX	FIX	SYSTEM	AMBIGUITY
PREDICTABLE	REPEATABLE	RELATIVE	AVAILABILITY	COVERAGE	RELIABILITY	RATE	DIMENSIONS	CAPACITY	POTENTIAL
VOR: 90m (±1.4°)* *	23m (±0.35°)** *	--	Approaches 99% to 99.99%	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	

* VOR and DME accuracy do not include survey error as they would apply to RNAV applications.

** *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.*

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 (FTE), 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) that is ±2.3 degrees.

C. Availability

VOR availability is typically 99 percent to 99.99 percent.

D. Coverage

Most aeronautical radionavigation aids that provide positive course guidance have a designated standard service volume (SSV) that defines the unrestricted reception limits usable for random or unpublished route navigation. Within the SSV, the NAVAID signal is frequency protected and is available at the altitudes and radial distances indicated in Table B-5. In addition to these SSVs, it is possible to define a non-standard service volume if siting constraints result in different coverage. SSV limitations do not apply to published IFR routes or procedures.

Reception below 1,000 ft above ground level is governed by line-of-sight considerations, and is described in Section 1-1-8 of the FAA Aeronautical Information Manual (AIM). Complete functional and performance characteristics are described in FAA Order 9840.1, U.S. National Aviation Standard for the VOR/DME/TACAN Systems.

Reception within the SSV is restricted by vertical angle coverage limitations. Distance information from DME and TACAN, and azimuth information from VOR, is normally usable from the radio horizon to elevation angles of at least 60 degrees. Azimuth information from TACAN is normally usable from the radio horizon to elevation angles of at least 40 degrees. At higher elevation angles — within the so-called cone of ambiguity — the NAVAID information may not be usable.

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.

Table B-5. VOR/DME/TACAN Standard Service Volumes (SSV)

SSV Class Designator	Altitude and Range Boundaries
T (Terminal)	From 1,000 ft above ground level (AGL) up to and including 12,000 ft AGL at radial distances out to 25 nm.
L (Low Altitude)	From 1,000 ft AGL up to and including 18,000 ft AGL at radial distances out to 40 nm.
H (High Altitude)	From 1,000 ft AGL up to and including 14,500 ft AGL at radial distances out to 40 nm. From 14,500 AGL up to and including 60,000 ft at radial distances out to 100 nm. From 18,000 ft AGL up to and including 45,000 ft AGL at radial distances out to 130 nm.

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 10 sec of an out-of-tolerance condition detected by an independent monitor.

K. 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 decommissioned. One of those future applications is LAAS, either on channels interstitial to the current VOR/ILS, or after VOR and ILS have been partially decommissioned.

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.

B.2.4.2 DME

A. Signal Characteristics

The signal characteristics of DME are summarized in Table B-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 (UHF) 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 DME 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 DME are identified by a wider interrogation pulse-pair time spacing of 0.036 msec versus X-channel DME 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 coverage is described in the preceding section on VOR and in Table B-5. Because of facility placement, almost all of the airways have coverage and most of the CONUS has dual coverage, permitting DME/DME 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 10 sec of an out-of-tolerance condition detected by an independent monitor.

K. Spectrum

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 will use 978 MHz in the DME ARNS band to enable ADS-B services for segments of the aviation community not equipped with the 1090 MHz Mode-S extended squitter. ADS-B is a function in which aircraft transmit four dimensional (4-D) position and intent data derived from onboard navigation systems to other aircraft and to the ground Air Navigation Service Provider (ANSP) network.

The FAA plans to increase the number of DME transmitters to provide service necessary for RNAV routes and terminal procedures. Continued use of a substantial portion of the 960-1215 MHz ARNS band will be required to support DME.

B.2.4.3 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 B-6.

Table B-6. TACAN System Characteristics (Signal-in-Space)

ACCURACY (2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE							
Azimuth ±1° (± 63m at 3.75km)	Azimuth ±1° (± 63m at 3.75km)	Azimuth ±1° (±63m at 3.75km)	98%	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°
DME: 185m (±0.1nm)	DME: 185m (±0.1nm)	DME: 185m (±0.1nm)							

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 coverage is described in the preceding section on VOR and in Table B-5.

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 10 sec of an out-of-tolerance condition detected by an independent monitor.

K. 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 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 JTIDS/MIDS also operates in this band on a non-interference basis.

B.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 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 B-7.

Table B-7. ILS Characteristics (Signal-in-Space)

ACCURACY AT MINIMUM APPLICABLE DECISION HEIGHT (Meters - 2 Sigma)						FIX	FIX	SYSTEM	AMBIGUITY
CATEGORY	AZIMUTH	ELEVATION	AVAILABILITY	COVERAGE	RELIABILITY	RATE*	DIMENSION	CAPACITY	POTENTIAL
1	± 9.1	±4.1	Approaches 99%	Normal limits from center of localizer ±10° out to 18nm and ±35° out to 10nm	98.6% with positive indication when the system is out of tolerance	Continuous	Heading and deviation in degrees	Limited only by aircraft separation requirements	None
2	TBD**	TBD**							
3	TBD**	TBD**							

* *Signal availability in the coverage volume.*

** *Accuracy characteristics are specified by characteristics unique to ILS (e.g., beam bend tolerances, glide path alignment). Studies are underway to derive a*
total source accuracy (in meters).

A. *Signal Characteristics*

The localizer facility and antenna are typically located 1,000 ft 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 ft from the approach end of the runway and provides a UHF (328.6 to 335.4 MHz ARNS band) signal. Marker beacons are located ILS 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 ILS: 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 ft plus or minus 250 ft 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 CAT-I ILS approaches. An inner marker, located approximately 1,000 ft from the threshold, is normally associated with CAT-II and III ILS approaches.

B. *Accuracy*

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

---

[*] Marker beacons are no longer required for ILS approaches, if a substitute can be provided. Existing beacons are being allowed to attrit and may be taken out of service, given an acceptable substitute.

C. Availability

ILS-based procedures are typically available between 98 and 99 percent of the time.

D. Coverage

Coverage for individual systems is as follows:

- Localizer: ±35° centered about course line out to 10nm and ±10° out to 18nm.
- Glide Slope: from 0.45 to 1.75 times the glide slope angle out to 10nm.
- Marker Beacons: ±40° (approximately) on minor axis (along approach path) ±85° (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 interference.

In some cases, using localizers with aperture antenna arrays and two-frequency systems resolves ILS siting problems. For the glide slope, using wide aperture, capture effect image arrays and single-frequency arrays provides 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 B-8.

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.

Table B-8. 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

I. Ambiguity

Any potential ambiguities are resolved by imposing system limitations as described in Section 3.2.5.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

K. 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 unless ILS is phased out.

ILS localizers share the 108-111.975 MHz portion of the 108-117.975 MHz ARNS band with VOR. As noted in Section 3.2.4, 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 decommissioned. One of those future applications is LAAS, either on channels interstitial to the current VOR/ILS, or after VOR and ILS have been partially decommissioned. 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 CAT-II and III localizers even after many CAT-I ILSs have been decommissioned.

ILS glide slope subsystems operate in the 328-335.4 MHz band. 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 Traffic Information Service (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 CAT-II and III ILS glide slope subsystems even after CAT-I ILS have been decommissioned.

B.2.6 MLS

The U.S. plans to use augmented GPS systems to satisfy the requirements originally earmarked for the Microwave Landing System (MLS). Accordingly, the FAA has terminated all activity associated with MLS. NASA, however, continues to use MLS for space shuttle operations, and the DoD has limited use as well. The system characteristics of MLS are summarized in Table B-9.

Table B-9. 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.*

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 ft (+4.0 m) at the runway threshold approach reference datum and the elevation accuracy is ±2.0 ft (+0.6 m). The lower surface of the MLS beam crosses the threshold at 8 ft (2.4 m) above the runway centerline. The flare guidance accuracy is ±1.2 ft throughout the touchdown zone and the DME accuracy is ±100 ft for the precision mode and ±1,600 ft 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

Azimuthal coverage typically extends ±40^{o} on either side of the runway centerline, and elevation coverage from 0o to a minimum of 15^{o} over the azimuthal coverage area, and out to 20 nm. Some systems 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.

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 interference 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.

K. Spectrum

MLS originally operated in the frequency band 5000 – 5250 MHz. However its operational band is now limited to the 5030 – 5150 MHz frequency band. The 5030 – 5090 MHz band is channelized by ICAO for MLS, and the band 5090 – 5150 MHz is termed the MLS extension band.. Other services have not yet attempted to utilize the 5030 – 5090 MHz band due to the safety of life aspects of the MLS function. FAA and the rest of the civil aviation community are investigating potential aeronautical applications of the band 5090 – 5250 MHz for implementation because it is estimated by many that this portion of the band will not be needed for future MLS assignments. 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; and
- Airport Local Area Network, called the Airport Network and Location Equipment (ANLE) is an surface network for communications at airports between ground based and aircraft systems on the ground. It supports short range communications and location functions on the ground at airports.
- Also, the MLS band is also being considered for future Unmanned Aircraft System (UAS) functions.

B.2.7 Aeronautical Nondirectional Radiobeacons (NDB)

Radiobeacons are nondirectional radio transmitting stations that operate in the low- and medium-frequency bands to provide ground wave signals to a receiver. Aircraft nondirectional beacons are used to supplement VOR-DME for transition from en route to airport precision approach facilities and as a nonprecision approach aid at many airports. 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 B-10.

Table B-10 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					

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 amplitude modulation (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 sec of an out-of-tolerance condition.

K. 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 NDB system has been decommissioned throughout the rest of the NAS.

B.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. These marine radiobeacons have been phased out.

Appendix C

List of Acronyms

The following is a listing of abbreviations for organization names and technical terms used in this plan:

AAM	Automated Asset Mapping (4-27)
ABAS	Aircraft-Based Augmentation System (3-13)
ADF	Automatic Direction Finder (B-38)
ADS	Automatic Dependent Surveillance (4-8)
ADS-B	Automatic Dependent Surveillance-Broadcast (1-9)
ADS-C	Automatic Dependent Surveillance-Contract (4-11)
AFSS	Automated Flight Service Stations (5-18)
A/G	Air/Ground (B-29)
AGL	Above Ground Level (B-28)
AIM	Aeronautical Information Manual (B-27)
AIS	Automatic Identification System (3-10)
AM	Amplitude Modulation (B-39)
ANLE	Airport Network and Location Equipment (B-38)
ANSP	Air Navigation Service Provider (B-31)
ARNS	Aeronautical Radionavigation Service (1-14)
ASD (NII)	Assistant Secretary of Defense for Networks and Information Integration (1-13)

ASR	Airport Surveillance Radar (4-7)
ATC	Air Traffic Control (4-4)
ATCSCC	Air Traffic Control System Command Center (5-16)
BIPM	Bureau of Weights and Measures (3-6)
BTS	Bureau of Transportation Statistics (2-9)
C/A	Coarse/Acquisition (3-7)
CCW	Coded Continuous Wave (B-39)
CEP	Circular Error Probable (B-2)
CFR	Code of Federal Regulations (1-10)
CGS	Civil GPS Service (5-13)
CGSIC	Civil GPS Service Interface Committee (2-10)
CJCS	Chairman, Joint Chiefs of Staff (1-6)
CNS	Communication, Navigation and Surveillance (4-3)
CONUS	Conterminous United States (4-12)
CORS	Continuously Operating Reference Stations (2-13)
CPDLC	Controller Pilot Data Link Communications (4-8)
COSMIC	Constellation Observing System for Meteorology, Ionosphere and Climate (D-2)
CRAF	Civil Reserve Air Fleet (3-8)
DGPS	Differential Global Positioning System (3-10)
DHS	Department of Homeland Security (1-1)
DIA	Defense Intelligence Agency (2-6)
DINS	Defense Internet NOTAM Service (5-16)
DME	Distance Measuring Equipment (1-2)
DNI	Director of National Intelligence (2-5)
DOC	Department of Commerce (1-4)
DoD	Department of Defense (1-1)
DOI	Department of Interior (2-10)
DOS	Department of State (1-12)

DOT	Department of Transportation (1-1)
DUATS	Direct User Access Terminal System (5-17)
EA	Electronic Attack (1-10)
EFVS	Enhanced Flight Vision System (4-7)
EGM	Earth Gravity Model (A-3)
eLoran	Enhanced Loran (3-5)
ESRL	Earth Systems Research Laboratory (B-22)
ExComm	Executive Committee (2-1)
FAA	Federal Aviation Administration (1-3)
FAF	Final Approach Fix (4-8)
FAR	Federal Aviation Regulation (1-10)
FCC	Federal Communications Commission (1-13)
FDE	Fault Detection and Exclusion (5-18)
FHWA	Federal Highway Administration (1-4)
FL	Flight Level (4-3)
FMCSA	Federal Motor Carrier Safety Administration (1-3)
FMS	Fight Management Systems (4-10)
FOC	Full Operational Capability (4-28)
FRA	Federal Railroad Administration (1-3)
FRP	Federal Radionavigation Plan (1-1)
FRS	Federal Radionavigation Systems (1-1)
FSS	Flight Service Station (5-17)
FTA	Federal Transit Administration (1-4)
FTE	Flight Technical Error (B-27)
GATM	Global Air Traffic Management (3-8)
GBAS	Ground-Based Augmentation Systems (3-13)
GDGPS	Global Differential GPS (5-21)
GDOP	Geometric Dilution of Precision (B-23)

GEO	Geosynchronous Earth Orbit (4-24)
GES	Ground Earth Station (B-17)
GIS	Geographic Information Systems (4-30)
GLONASS	Global Navigation Satellite System (Russian Federation) (1-12)
GMDSS	Global Maritime Distress and Safety System (5-19)
GNSS	Global Navigation Satellite System (3-7)
GPS	Global Positioning System (1-2)
GPS-MT	Global Positioning System – Metric Tracking (5-21)
GRACE	Gravity Recovery and Climate Experiment (D-3)
GRS	Geodedic Reference System (A-3)
HA-NDGPS	High Accuracy Nationwide Differential Global Positioning System (4-29)
HEA	Harbor Entrance and Approach (5-4)
HSPD-7	Homeland Security Presidential Directive – 7 (1-8)
HUD	Head-up Display (4-7)
IAG	International Association of Geodesy (4-33)
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities (1-12)
IC	Intelligence Community (2-5)
ICAO	International Civil Aviation Organization (1-6)
IDM	Interference Detection and Mitigation (1-9)
IFR	Instrument Flight Rules (3-10)
IGEB	Interagency GPS Executive Board (5-5)
IGS	International GNSS Service (2-13)
IHO	International Hydrographic Organization (1-12)
ILS	Instrument Landing System (1-2)
IMO	International Maritime Organization (1-6)
INMARSAT	International Maritime Satellite Organization (1-1)
INS	Inertial Navigation System (3-13)

INU	Inertial Navigation Unit (3-12)
IOC	Initial Operational Capability (3-7)
IRAC	Interdepartment Radio Advisory Committee (1-13)
ITRF	International Terrestrial Reference Frame (A-2)
ITS	Intelligent Transportation Systems (1-14)
ITS-JPO	Intelligent Transportation Systems Joint Program Office (2-9)
ITU	International Telecommunication Union (1-12)
JCS	Joint Chiefs of Staff (2-6)
JPALS	Joint Precision Approach and Landing System (5-8)
JPL	Jet Propulsion Laboratory (5-21)
JPO	Joint Program Office (2-9)
JTIDS	Joint Tactical Information Distribution System (B-30)
LAAS	Local Area Augmentation System (3-13)
LEO	Low Earth Orbit (4-23)
LGF	LAAS Ground Facility (B-20)
LNAV	Lateral Navigation (4-9)
LOP	Line of Position (B-25)
Loran	Long Range Navigation (1-2)
LPV	Localizer Performance with Vertical Guidance (3-9)
MARAD	Maritime Administration (1-4)
MCS	Master Control Station (3-6)
MCW	Modulated Continuous Wave (B-39)
MDGPS	Maritime Differential GPS Service (4-30)
MEO	Medium Earth Orbit (B-4)
MIDS	Multi-function Information Distribution System (B-30)
MILOPS	Military Operations System (5-18)
MLLW	Mean Lower Low Water (A-2)
MLS	Microwave Landing System (1-2)

MNPS	Minimum Navigation Performance Specification (4-8)
MOA	Memorandum of Agreement (1-3)
MPNTP	Master Positioning, Navigation, and Timing Plan (2-5)
MSC	Military Sealift Command (5-11)
MSK	Minimum Shift Keying (B-10)
MSL	Mean Sea Level (A-2)
NAD	North American Datum (A-1)
NANU	Notice Advisories to Navstar Users (5-2)
NAS	National Airspace System (1-9)
NASA	National Aeronautics and Space Administration (1-4)
NATO	North Atlantic Treaty Organization (1-12)
NAVAID	Navigation Aid (3-9)
NAVCEN	USCG Navigation Center (5-5)
NAVD	North American Vertical Datum (A-2)
NAVTEX	See Appendix D (5-4)
Navwar	Navigation Warfare (2-7)
NCO	National Coordination Office (2-13)
NDB	Nondirectional Beacon (1-2)
NDGPS	Nationwide Differential Global Positioning Service (1-3)
NextGen	Next Generation Air Transportation System (4-10)
NGA	National Geospatial-Intelligence Agency (2-5)
NGS	National Geodetic Survey (1-4)
NGVD	National Geodetic Vertical Datum (A-2)
NHTSA	National Highway Traffic Safety Administration (1-4)
NII	Networks and Information Integration (1-13)
NIS	Navigation Information Service (5-2)
NIST	National Institute of Standards and Technology (2-13)
NOAA	National Oceanic and Atmospheric Administration (1-4)

NOTAM	Notice to Airmen (5-2)
NPA	Nonprecision Approach (D-4)
NRL	Naval Research Laboratory (4-24)
NSA	National Security Agency (2-6)
NSF	National Science Foundation (4-32)
NSRS	National Spatial Reference System (4-30)
NTIA	National Telecommunications and Information Administration (1-10)
OAB	Operational Advisory Broadcast (5-13)
OASIS	Operational and Supportability Implementation System (5-17)
OPUS	Online Positioning User Service (2-13)
ORD	Operational Requirements Document (3-8)
OST	Office of the Secretary of Transportation (2-9)
OST/B	Assistant Secretary for Budget Programs (2-9)
OST/C	General Counsel's Office (2-9)
OST/M	Assistant Secretary for Administration (2-9)
OST/P	Assistant Secretary for Transportation Policy (2-9)
PBN	Performance Based Navigation (4-11)
PDD	Presidential Decision Directive (1-7)
PHMI	Probability of Hazardously Misleading Information (B-19)
PHMSA	Pipeline and Hazardous Materials Safety Administration (1-4)
PL	Public Law (1-1)
PNT	Positioning, Navigation, and Timing (1-2)
POS/NAV	Positioning and Navigation (2-7)
PPS	Precise Positioning Service (1-4)
PRN	Pseudo-Random Noise (B-5)
PS	Performance Standard (3-5)

PTC	Positive Train Control (1-14)
QZSS	Quasi Zenith Satellite System (1-12)
RAIM	Receiver Autonomous Integrity Monitoring (3-13)
R&D	Research & Development (4-23)
RDF	Radio Direction Finder (4-19)
RF	Radio Frequency (1-11)
RFI	Radio Frequency Interference (1-7)
RITA	Research and Innovative Technology Administration (1-3)
RLV	Reusable Launch Vehicle (5-21)
RNAV	Area Navigation (3-14)
RNP	Required Navigation Performance (4-8)
RNPSORSG	Required Navigation Performance and Special Operational Requirements Study Group (4-11)
RNS	Radionavigation Service (1-14)
RNSS	Regional Navigation Satellite System (India) (1-12)
RNSS	Radionavigation Satellite Service (1-14)
RSS	Root Sum Square (B-27)
RTCM	Radio Technical Commission for Maritime Services (B-10)
SA	Selective Availability (3-3)
SAR	Search and Rescue (4-15)
SATNAV	Satellite-Based Navigation (3-9)
SBAS	Space-Based Augmentation System (3-13)
SBR	Space-based Range (5-21)
SID	Standard Instrument Departure (4-7)
SIS	Signal-In-Space (B-7)
SLSDC	Saint Lawrence Seaway Development Corporation (1-3)
SNR	Signal-to-Noise (B-24)
SPS	Standard Positioning Service (1-4)

SSV	Space Service Volume (4-24)
STAR	Standard Terminal Arrival Route (4-7)
SVM	Service Volume Model (5-17)
S&T	Science and Technology (5-23)
TACAN	Tactical Air Navigation (1-2)
TASS	TDRSS Augmentation Service Satellites (5-21)
TD	Time Difference (B-23)
TDL	Track Defect Location (4-27)
TDRSS	Tracking and Data Relay Satellite System (5-21)
TDWR	Terminal Doppler Weather Radio (B-38)
TERPS	Terminal Instrument Procedures (4-9)
TIS	Traffic Information Services (B-36)
TRSB	Time Reference Scanning Beam (B-36)
TSO	Technical Standard Order (5-15)
UAS	Unmanned Aircraft System (B-38)
UHF	Ultra High Frequency (5-8)
UN	United Nations (1-13)
UNAVCO	University NAVSTAR Consortium (5-4)
URA	User Range Accuracy (B-7)
URE	User Range Error (B-7)
USACE	U.S. Army Corps of Engineers (4-30)
USAF	United States Air Force (3-6)
USC	United States Code (1-1)
USCG	United States Coast Guard (1-1)
USDA	U.S. Department of Agriculture (2-9)
USG	United States Government (1-1)
USN	United States Navy (2-5)
USNO	United States Naval Observatory (1-5)

USNS	United States NOTAM System (5-18)
UTC	Coordinated Universal Time (1-5)
US-TEC	United States Total Electron Content (5-6)
VFR	Visual Flight Rules (4-3)
VHF	Very High Frequency (1-2)
VNAV	Vertical Navigation (4-9)
VOR	Very High Frequency Omnidirectional Range (1-2)
VORTAC	Collocated VOR and TACAN (4-7)
VTS	Vessel Traffic Services (3-10)
WAAS	Wide Area Augmentation System (3-8)
WGS	World Geodetic System (1-5)
WMS	Wide Area Master Station (B-17)
WRC	World Radiocommunication Conference (1-13)
WRS	Wide Area Reference Stations (B-17)
WWV/WWVH	Call Signs for the NIST Radio Stations (1-2)
2SOPS	2nd Space Operations Squadron (5-15)
4-D	Four Dimensional (B-31)

The following is a listing of units used throughout this plan:

cm	centimeter
dBW	Decibel watt (decibels relative to one watt)
drms	distance root mean squared
ft	feet
GHz	Gigahertz
Hz	Hertz (cycles per second)
kHz	kilohertz
km	kilometer
m	meter
MHz	Megahertz
mm	millimeter
ms	millisecond
nm	nautical mile
ns	nanosecond
sec	second

Appendix D

Glossary

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.
- 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.

Area Navigation (RNAV) – A method of navigation which permits aircraft operation on any desired flight path within the coverage of station referenced navigation aids or within the limits of capability of self-contained aids, or a combination of these.

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.

Coastal Confluence Zone (CCZ) - Harbor entrance to 50 nm offshore or the edge of the continental shelf (100 fathom curve), whichever is greater.

Codeless or Semicodeless Processing - Techniques to obtain L2 Y code pseudorange and carrier -phase measurements without the cryptographic knowledge for full access to this signal. Codeless techniques only utilize the known 10.23 MHz chip rate of the Y code signal and the fact that the same Y code signal is broadcast on both L1 and L2. Semicodeless techniques use some known features of the Y code.

Common-use Systems - Systems used by both civil and military sectors.

Conterminous U.S. (CONUS) - 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.

Coordinated Universal Time (UTC) - An atomic time scale, and the basis for civil time. UTC 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 sec.

COSMIC – The Constellation Observing System for Meteorology, Ionosphere and Climate was launched in December 2005 and consists of six microsatellites each carrying three instruments: a GPS radio occultation receiver, an ionospheric photometer, and a tri-band beacon. These satellites will initially be placed in an initial orbit 400 km above the Earth and over the first year will be gradually boosted to a final orbit approximately 700 km above the Earth. During this time geodetic gravity experiments will be conducted.

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

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

Divestment – The transfer of a radionavigation facility to a non-Federal service provider when it no longer meets criteria for sustainment as a Federal service. If a radionavigation facility cannot be transferred, the service is discontinued and the facility is decommissioned.

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.

Full Operational Capability (FOC) - A system dependent state that occurs when the particular system is able to provide all of the services for which it was designed.

Global Navigation Satellite System (GNSS) – GNSS refers collectively to the world-wide positioning, navigation, and timing (PNT) determination capability available from one or more satellite constellations, such as the United States' Global Positioning System (GPS) and the Russian Federation's Global Navigation Satellite System (GLONASS). Each GNSS system employs a constellation of satellites operating in conjunction with a network of ground stations.

GRACE – The Gravity Recover and Climate Experiment consists of two identical satellites launched in March 2002 and flying approximately 220 km apart in a polar orbit 500 km above the Earth. Its primary mission is to conduct gravity field measurements. Each spacecraft carries a Blackjack GPS receiver which, in addition, acquires GPS occultation measurements.

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

Integrity - Integrity is the measure of the trust that can be placed in the correctness of the information supplied by a navigation system. Integrity includes the ability of the 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.

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

Jason – An oceanography satellite launched December 2001 and flying in a 66° inclined orbit 1300 km above the Earth. Its mission is to monitor global ocean circulation, study the ties between the oceans and atmosphere, improved global climate forecasts and predictions, and monitor events such as El Nino conditions and ocean eddies. It is designed to directly measure climate change through very precise millimeter-per-year measurements or global sea-level changes. On-board instrumentation includes a GPS receiver and a laser retoreflector.

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 and digital navigation data; 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.

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

NAVTEX – A system designated by IMO as the primary means for transmitting coastal urgent marine safety information to ships worldwide. The NAVTEX system broadcasts Marine Safety Information such as Radio Navigational Warnings, Storm/Gale Warnings, Meteorological Forecasts, Piracy Warnings, and Distress Alerts. Full details of the system can be found in IMO Publication IMO-951E – The NAVTEX Manual.

Nonprecision Approach (NPA) – An instrument approach procedure based on a lateral path and no vertical guide path. The procedure is flown with a navigation system that provides lateral (but not vertical) path deviation guidance.

Precise Time - A time requirement accurate to within 10 ms.

Precision Approach – An instrument approach procedure, based on a lateral path and a vertical glide path, that meets specific requirements established for vertical navigation performance and airport infrastructure.

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

Radiolocation - Radiodetermination used for purposes other than those of radionavigation.

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

Reliability – The probability of performing a specified function without failure under given conditions for a specified period of time.

Required Navigation Performance (RNP) - 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.

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.

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.

References

1. Title 49 United States Code Section 101.
2. Title 10 United States Code Section 2281.
3. *U.S. Space-Based Positioning, Navigation, and Timing Policy,* December 8, 2004.
4. *2007 CJCS Master Positioning, Navigation, and Timing Master Plan,* Chairman Joint Chiefs of Staff Instruction 6130.01D, 13 April 2007.
5. U.S. Department of Transportation, Volpe Center, *Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System*, September 2001.
6. *United States Standard for Terminal Instrument Procedures* (TERPS), FAA Handbook 8260.3B, July 1976.
7. *Air Force Space Command/Air Combat Command Operational Requirements Document (ORD) AFSPC/ACC 003-92-I/II/III for Global Positioning System (U)*, 18 February 2000.
8. Federal Railroad Administration, *"Differential GPS: An Aid To Positive Train Control,"* Report to the Committees on Appropriations, June 1995.
9. U.S. Department of Defense, *Global Positioning System Standard Positioning Service Performance Standard,* September 2008.
10. *Navstar GPS Space Segment/Navigation User Interfaces*, Interface Specification IS-GPS-200D, March 7, 2006.
11. National Imagery and Mapping Agency, *"Department of Defense World Geodetic System 1984, Its Definition and Relationships with Local Geodetic Systems,"* Third Edition, July 4, 1997.