2010 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-4650.05

2010 Federal Radionavigation Plan

The Federal Radionavigation Plan (FRP) is the official source of positioning, navigation, and timing (PNT) policy and planning for the Federal Government. It is required by the National Defense Authorization Act for Fiscal Year 1998, as published under Title 10 United States Code, Section 2281, paragraph (c) (10 USC 2281(c)). The FRP is prepared jointly by the Departments of Defense (DoD), Homeland Security (DHS), and Transportation (DOT), with the assistance of other government agencies. This 2010 edition of the FRP reflects the policy and planning for present and future federally provided PNT systems, covering common-use PNT 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 Instruction 6130.01D, the DoD Master Positioning, Navigation, and Timing Plan (MPNTP).

The FRP contains chapters covering Roles and Responsibilities, Policy, PNT User Requirements, Operating Plans, and the National PNT Architecture, as well as appendices covering System Parameters and Descriptions, PNT Information Services, and Geodetic Reference Systems and Datums. It is updated biennially, allowing more efficient and responsive updates of policy and planning information. Your suggestions for the improvement of future editions are welcomed.

Robert M. Gates Secretary of Defense	Ray LaHood Secretary of Transportation	Janet Napolitano Secretary of Homeland Security
Date: APR 15 2011	Date: December 20, 2010	Date: 3-29-11

Table of Contents

List of Figures

List of Tables

Executive Summary

The Federal Radionavigation Plan (FRP) reflects the official positioning, navigation, and timing (PNT) policy and planning for the Federal Government. The FRP covers both terrestrial- and space-based, common-use, federally operated PNT systems. Systems used exclusively by the military are covered in Chairman, Joint Chiefs of Staff Instruction 6130.01D, DoD Master Positioning, Navigation, and Timing Plan (MPNTP) (Ref. 1). 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 PNT systems:

- Global Positioning System (GPS)
- Augmentations to GPS
- Long Range Navigation (Loran)
- Instrument Landing System (ILS)
- Very High Frequency (VHF) Omnidirectional Range (VOR)
- Distance Measuring Equipment (DME)
- Tactical Air Navigation (TACAN)
- Aeronautical Nondirectional Radiobeacons (NDB)
- Microwave Landing System (MLS)
- Internet Time Service (ITS)
- Radio Station WWVB signal
- Two-Way Satellite Time Transfer (TWSTT)
- Network Time Protocol (NTP)

The Federal Government operates PNT 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. 2) for ensuring safe and efficient transportation. The Department of Defense (DoD) is responsible for maintaining aids to navigation required exclusively for national defense. DoD is also required by 10 USC § 2281 (Ref. 3), paragraph (b), 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 growth; and to eliminate unnecessary duplication of services. Selecting a future PNT 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 PNT systems will be considered for divestment to match the reduction in demand, provided those services are not a part of a backup PNT strategy for critical applications or safety-of-life services.

The Federal Government conducts research and development (R&D) activities relating to federally provided PNT 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 PNT system selection considerations.

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

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

Section 4 – PNT User Requirements: Summarizes context for performance requirements of federally provided PNT services that are available to civil users.

Section 5 – Operating Plans: Summarizes the plans of the Federal Government to provide PNT 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, DHS, DOT, and other Federal organizations.

Section 6 – National PNT Architecture: Summarizes the plans of the Federal Government to provide a National PNT Architecture for use by the civil and military sectors through the year 2025.

Appendix A – System Parameters and Descriptions

Appendix B – PNT Information Services

Appendix C – Geodetic Reference Systems and Datums

Appendix D – Acronyms

Appendix E – Glossary

References

1

Introduction to the Federal Radionavigation Plan

This section describes the background, purpose, scope, and objectives of the Federal Radionavigation Plan (FRP) while identifying the statutory authority to provide positioning, navigation, and timing (PNT) services as well as PNT system selection considerations. It summarizes the events leading to the preparation of this document, the national objectives for coordinating the planning of PNT services, and PNT authority and responsibility.

1.1 Background

A Federal Radionavigation Plan is required by Title 10 United States Code, Section 2281 [10 USC § 2281] (Ref. 3), paragraph (c). The first edition of the FRP was released in 1980 as part of a Presidential Report to Congress, prepared in response to Public Law (Pub. L.) 95-564, Page 92 Statute 2392 (92 Stat. 2392), *International Maritime Satellite (INMARSAT) Telecommunications Act of 1978* (Ref. 4). It marked the first time that a joint Department of Defense (DoD) and Department of Transportation (DOT) plan for PNT systems had been developed. With the transfer of the United States Coast Guard (USCG) from DOT to the Department of Homeland Security (DHS) through Pub. L. 107-296, 116 Stat. 2135, *Homeland Security Act of 2002* (Ref. 5), DHS has been added as a signatory to the FRP. The 2008 FRP updated and merged the 2005 FRP and 2001 Federal Radionavigation Systems (FRS) documents. This 2010 FRP reflects the policy and planning for present and future federally provided PNT systems.

The FRP was originally intended to address coordinated planning for federally provided radionavigation systems. Since that time, the Federal planning process has evolved to include other elements of navigation and timing, now referred to as PNT.

1.2 Purpose

The purpose of the FRP is to describe the U.S. Government's (USG) roles, responsibilities, and policies applicable to PNT systems. It describes PNT user requirements, operating plans, and a national architecture for USG provided PNT systems.

1.3 Scope

This plan covers federally provided systems and services used for PNT. PNT systems include radionavigation, timing, and other technologies that enable PNT services and applications. While the plan outlines the PNT performance requirements for various user groups, it is not a formal requirements document for the Federal Government. The plan does not include electronic systems that are used primarily for surveillance and communication (e.g., radar, cell phones). Additionally, Federal agencies participating in the National PNT Architecture effort determined that federally provided services will not satisfy the needs of all PNT users. Complementary technologies are evolving to meet those needs, and as these technologies become part of federally provided services, this plan will address them.

The systems and services addressed in this FRP are:

- Global Positioning System (GPS)
- Augmentations to GPS
- Long Range Navigation (Loran)
- Instrument Landing System (ILS)
- Very High Frequency (VHF) Omnidirectional Range (VOR)
- Distance Measuring Equipment (DME)
- Tactical Air Navigation (TACAN)
- Aeronautical Nondirectional Beacons (NDB)
- Microwave Landing System (MLS)
- Internet Time Service (ITS)
- Radio Station WWVB signal
- Two-Way Satellite Time Transfer (TWSTT)

- Network Time Protocol (NTP)

1.4 Objectives

The objectives of USG PNT system policy are to:

- strengthen and maintain national security;
- improve 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 PNT Services

Several departments and agencies provide PNT services. DOT is responsible under 49 USC § 101 (Ref. 2) for ensuring safe and efficient transportation. PNT systems play an important role in carrying out this responsibility. The two DOT elements that operate PNT systems are the Federal Aviation Administration (FAA) and St. Lawrence Seaway Development Corporation (SLSDC). Per Secretary of Transportation Memorandum dated August 1, 2007 (Ref. 6), the Administrator, Research and Innovative Technology Administration (RITA) is responsible for coordinating PNT planning within DOT and with other civil Federal elements.

FAA has the responsibility for the development and implementation of PNT systems to meet the needs for safe and efficient air navigation. 49 USC § 44505 (Ref. 7) 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 Pub. L. 105-66, 111 Stat. 1425, *Department of Transportation and Related Agencies Appropriations Act of 1998* (Ref. 8) § 346, 111 Stat. 1449, to implement the Nationwide Differential GPS (NDGPS) service in support of surface transportation and other terrestrial civil PNT missions. RITA is currently acting as the lead agency for this function; operations are provided by 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 PNT planning. These elements include the Federal Highway Administration (FHWA), the Federal Motor Carrier Safety Administration (FMCSA), the Federal Railroad Administration (FRA), the Federal Transit Administration (FTA), the 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 (Ref. 9), remain in full effect. USCG provides aids to navigation for safe and efficient marine navigation.

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 PNT capabilities.

DoD is required by 10 USC § 2281(Ref. 3), paragraph (b), 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.

Pub. L. 85-568, 72 Stat. 426, *National Aeronautics and Space Act of 1958*, as amended (Ref. 10), provides under sections 102 (d) and 103 for the National Aeronautics and Space Administration (NASA) to provide for the operations of space transportation systems and other activities required for the exploration of space, which in addition to space vehicles also includes related equipment, devices, components, and parts.

The Department of Commerce (DOC) is authorized through 33 USC § 883a-c. (Ref. 11) to conduct various types of surveys and disseminate the resulting data.

1.6 PNT System Selection Considerations

Many factors are considered in determining the optimum mix of federally provided PNT 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 usage. Certain 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 in place today were developed to meet different user requirements. This resulted in the proliferation of multiple PNT 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 National Security Presidential Directive-39 (NSPD-39), *U.S. Space-Based Position, Navigation, and Timing Policy*, December 8, 2004 (Ref. 12), dynamic PNT technology, changing user profiles, budget considerations, and international activities. *The National Space Policy of the United States of America*, June 28, 2010 (Ref. 13) provides amplifying information to previous policy. With the creation of DHS, DOT and DoD will maintain the current working relationship with USCG via MOA.

Starting with the 2010 edition of the FRP, the scope of user requirements has been broadened to identify PNT needs for space, aviation, surface, and subsurface applications. 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 PNT 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 World Geodetic System 1984 (WGS 84) 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 PNT 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, Joint Chiefs of Staff (CJCS) Instruction 6130.01D, *DoD Master Positioning, Navigation, and Timing Plan* (MPNTP) (Ref. 1).

1.6.1.2 Civil/Military Compatibility

Pub. L. 85-726, 72 Stat. 737, *Federal Aviation Act of 1958* (Ref. 14), requires 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." Appropriate PNT system standards are coordinated through the International Civil Aviation Organization (ICAO) and published for international aviation use, ensuring worldwide interoperability. Pub. L. 84-627, 84 Stat. 374, *National Interstate and Defense Highways Act of 1956* (Ref. 15), requires FHWA to develop a combined civil and military interstate highways systems. USCG is required to operate PNT 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), ICAO, USCG, or FAA specifications. PNT systems intended to support peacetime operations may not support combat operations. In those cases, DoD may need to develop additional PNT capability to combat wartime threats.

1.6.1.3 Review and Validation

The DoD PNT 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 PNT systems, there are a number of technical factors that must be considered:

- system accuracy;
- system precision;
- system integrity;
- system reliability
- system availability;
- communications security;
- spectrum availability;
- signal coverage;
- received signal strength;
- signal propagation;
- signal continuity;
- signal acquisition and tracking continuity;

- multipath effects;
- noise effects;
- susceptibility to natural or man-made disruption, e.g., radio frequency interference (RFI);
- environmental effects;
- platform dynamics;
- human factors engineering; and
- requirements for installation and operation (service provider and user equipment space, weight, and power considerations).

1.6.2.1 Vulnerability of GPS for Critical Infrastructure

The final report of the President's Commission on Critical Infrastructure Protection, *Critical Foundations, Protecting America's Infrastructures*, October 13, 1997 (Ref. 16) 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/NSC-63 *Critical Infrastructure Protection*, May 22, 1998, Annex B: Additional Taskings (Ref. 17) 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*, August 29, 2001 (Ref. 18), is available on the USCG 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 backup systems or procedures are available 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 backup 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.

NSPD-39 (Ref. 12) 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) *Critical Infrastructure Identification, Prioritization, and Protection*, December 17, 2003 (Ref. 19). It also defines responsibilities for locating and resolving interference. Additionally, *National Space Policy* (Ref. 13), states that the U.S. shall invest in domestic capabilities and support international activities to detect, mitigate, and increase resiliency to harmful interference to GPS, and identify and implement, as necessary and appropriate, redundant and backup systems or approaches for critical infrastructure, key resources, and mission-essential functions. The policy and plans for mitigation of disruptions to satellite-based PNT services is discussed in Sections 3.2.11 and 5.1.2, respectively, 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 interference, as well as intentional jamming/spoofing, 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 timely resolution and mitigation to quickly restore PNT services. DHS developed and published the *Positioning, Navigation, and Timing, Interference Detection and Mitigation (IDM) Plan*, August 20, 2007 (Ref. 20) and the *Interference Detection and Mitigation (IDM) Plan Implementation Strategy*, January 2008 (Ref. 21) to address these concerns. These documents provide a framework and guidance from which to execute the responsibilities required to fulfill the directives from NSPD-39 (Ref. 12).

Because of the unique safety requirements of aviation, FAA is implementing the Interference Monitoring Detection System (IMDS) to achieve an upgraded interference detection and locating capability. IMDS will help quickly reduce and mitigate the impacts of RFI on present and future National Airspace System (NAS) systems. New capabilities such as GPS and related augmentations, aeronautical data link systems, and Automatic Dependence Surveillance-Broadcast (ADS-B) ground and airborne segments, will require enhanced agency preparedness on radio frequency and electromagnetic interference detection capabilities. IMDS 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 end users benefit from the significant investments being made.

1.6.3 Economic Considerations

USG must continually review the costs and benefits of the PNT systems or capabilities it provides. This continuing analysis can be used both for setting priorities for investment in new systems, and for 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 or local government 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. FAA regulates and inspects air navigation facilities in accordance with Federal Aviation Regulations (FAR), Title 14 Part 171 of the Code of Federal Regulation (14 CFR 171) *Non-Federal Navigation Facilities* (Ref. 22), and FAA directives.

1.6.4 Institutional Considerations

1.6.4.1 Cost Recovery for PNT Services

In accordance with general policy and the User Fee Statute, 31 USC § 9701 (Ref. 23), the USG recovers the costs of federally provided services that provide benefits to specific user groups. The amount of use of present Federal PNT 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 PNT 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, NSPD-39 (Ref. 12) states that GPS civil services and GPS augmentations shall be provided free of direct user fees. For NDGPS, Pub. L. 105-66 (Ref. 8) § 346, 111 Stat. 1449, authorizes the Secretary of Transportation to manage and operate 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 PNT 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 PNT systems operated by 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 3212.03, *Performing Tests, Training, and Exercises Impacting the Global Positioning System (GPS) in the United States and Canada* (Ref. 24), per paragraph 7.14 of the NTIA *Manual of Regulations and Procedures for Federal Radio Frequency Management*, January 2008 (Ref. 25). DoD coordinates all interference testing and EA with other impacted Federal agencies, and FAA coordination and concurrence (through the Air Traffic Control (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 USG to support safety, security, and commerce. These services have supported air, land, and marine PNT 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 alternatives.

Air navigation facilities, owned and operated by non-Federal service providers, are regulated by FAA under 14 CFR 171 (Ref. 22). A non-Federal sponsor may coordinate with FAA to acquire, install, and turn a qualified air navigation facility over to 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 PNT 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 positioning for precise land and marine applications, e.g., agriculture and marine construction.

1.6.5 International Considerations

PNT 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 PNT systems. ICAO establishes standards for internationally used civil aviation PNT 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 PNT guidelines. The International Hydrographic Organization (IHO) and IMO cooperate in the operation of a worldwide marine navigation warning system, which includes warnings of PNT system outages. IMO reviews existing and proposed PNT systems to identify systems that could meet the requirements of, and be acceptable to, members of the international maritime community.

In planning U.S. PNT 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 PNT systems are sometimes used in combination with each other. These combined systems are often implemented to provide improved or complementary performance. USG encourages future interoperability with foreign space-based PNT systems for civil, commercial, and scientific uses worldwide. *National Space Policy* (Ref. 13) states that foreign PNT services may be used to augment and strengthen the resiliency of GPS. 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 (IRNSS). 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 PNT services. For example, the USG has concerns about PNT signal structures that could adversely impact the military and civil use of GPS. USG has also fostered the use of interoperable augmentations through its adherence to international standards for DGPS and space-based augmentation system (SBAS) services. These include NDGPS and the Wide Area Augmentation System (WAAS).

1.6.7 Radio Frequency Spectrum Considerations

PNT services use a significant amount of RF spectrum to provide the world with a safe and robust transportation system. PNT 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 PNT system policy, implementation, and operation.

In planning for PNT 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 PNT 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 OST Memo (Ref. 6), 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 PNT 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. This offers end users similar RF environments for their PNT equipment independent of where they operate.

Non-interference with PNT RF spectrum is crucial. All domestic and international PNT 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 PNT requirements, and considerable effort is put forth to ensure that PNT services are protected throughout WRC deliberations and other international discussions. The specific ITU band designations that define U.S. PNT services are listed below:

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

DoD, DHS, and DOT have responsibility for the certification of PNT applications pursuant to government responsibilities for national security and public safety. DoD, DHS, and DOT are Federal users of spectrum, as well as service providers and operators of PNT 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 PNT systems used on waterways.

Other DOT agencies (FHWA, FRA, FTA, NHTSA, and RITA) also work with the 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 PNT services.

2.1 Department of Defense (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 PNT capabilities.

DoD is required by 10 USC § 2281 (Ref. 3), paragraph (b), 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 PNT 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 PNT aids as part of the NAS when such activity is economically beneficial and specifically agreed to by the appropriate USG 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 SPS that will be available on a continuous, worldwide basis and 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 PNT 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 PNT 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. USN, through the USNO, serves as the official DoD timekeeper via its Master Clock in Washington, DC and Alternate Master Clock at Schriever AFB, Colorado.

DoD carries out its responsibilities for PNT coordination through the internal management structure shown in Figure 2-1. The figure shows the administrative process used to consider and resolve PNT issues. The operational control of DoD PNT systems is not shown here, but is described in the CJCSI 6130.01D (Ref. 1) and other DoD documents.

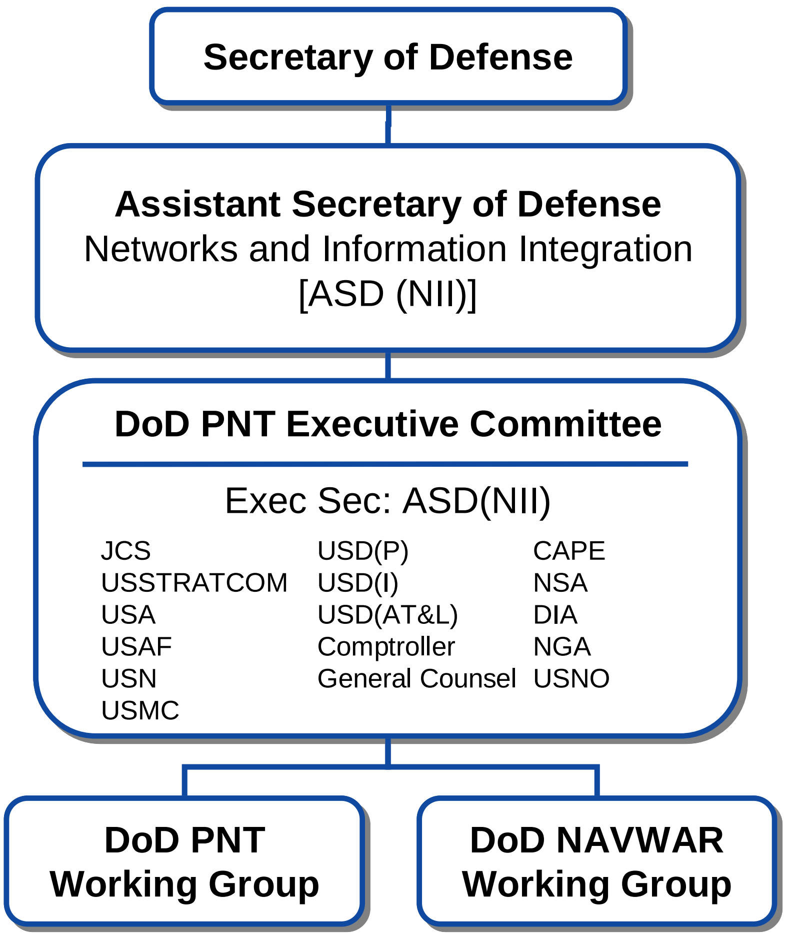

Figure 2-1 DoD PNT Management Structure

2.1.1 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 the combatant commands and military departments in the preparation of their respective detailed PNT plans. The JCS are aware of operational PNT requirements and capabilities of the Unified Commands and the Services, and are responsible for the development, approval, and dissemination of the CJCSI 6130.01D (Ref. 1).

CJCSI 6130.01D (Ref. 1) is the official PNT policy and planning document of the CJCS, which addresses operational defense requirements.

The following organizations also perform PNT management functions:

2.1.1.1 Joint Staff (J-3)

Joint Staff (J-3) oversees CJCSM 3212.03 (Ref. 24) which implements guidance to request and gain approval to conduct EA tests, training and exercises (TT&Es) that affect GPS with the U.S., Mexico, and Canada. Joint Staff (J-3) reviews all EA TT&E packages, coordinates first with the Joint Spectrum Center for quality assurance, and then coordinates the final package with DoD and Interagency stakeholders (e.g., FAA, USCG, etc.).

2.1.1.2 Joint Staff (J-6)

The Directorate for Command, Control, Communications, and Computer Systems Support, Joint Staff (J-6), is responsible for analysis, evaluation, and monitoring of PNT system planning and operations; general joint warfighter PNT matters; authoring and publishing the CJCSI 6130.01D (Ref. 1), and chairs the Netcentric Functional Capabilities Board (NC FCB) (first level of the Joint Capabilities Integration and Development System (JCIDS) review for DoD and Interagency PNT requirements).

2.1.1.3 Joint Staff (J-8)

Joint Staff (J-8) acts as the gatekeeper for JCB and Joint Requirements Oversight Council (JROC) review of DoD and Interagency PNT requirements that are approved by the NC FCB. Joint Staff (J-8) also (in coordination with various DoD and Interagency partners) establishes guidance for the Interagency Requirements Process (IRP).

2.1.1.4 Commanders of the Unified Commands

The Commanders of the Unified Commands perform PNT functions similar to those of the JCS. They develop PNT requirements as necessary for contingency plans and JCS exercises that require PNT resources external to that command. They are also responsible for review and compliance with the CJCSI 6130.01D (Ref. 1).

2.1.2 Administrative Management

Four permanent organizations provide PNT planning and management support to ASD (NII). These organizations are the DoD PNT Executive Committee, the DoD PNT Working Group, the DoD Navigation Warfare (NAVWAR) Working Group, and the Military Departments and Combatant Commands. Brief descriptions are provided below.

2.1.2.1 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 Positioning/Navigation (POS/NAV) Executive Committee.

2.1.2.2 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.

2.1.2.3 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.

2.1.2.4 Military Departments and Combatant Commands

The Military Departments and Combatant Commands are responsible for participating in the development, dissemination and implementation of the CJCSI 6130.01D (Ref. 1) and for managing the development, deployment, operation, and support of designated PNT systems.

2.2 Department of Transportation (DOT) Responsibilities

DOT is responsible under 49 USC § 101 (Ref. 2) for ensuring safe and efficient transportation. PNT systems play an important role in carrying out this responsibility. The two elements within DOT that operate PNT systems are FAA and SLSDC. The RITA Administrator is responsible for coordinating PNT 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 PNT 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 (Ref. 19).

DOT carries out its responsibilities for civil PNT systems planning through the internal management structure shown in Figure 2-2. The structure was originally established by DOT Order 1120.32, April 27, 1979 (Ref. 26) and revised by DOT Order 1120.32C, October 06, 1994 (Ref. 27).

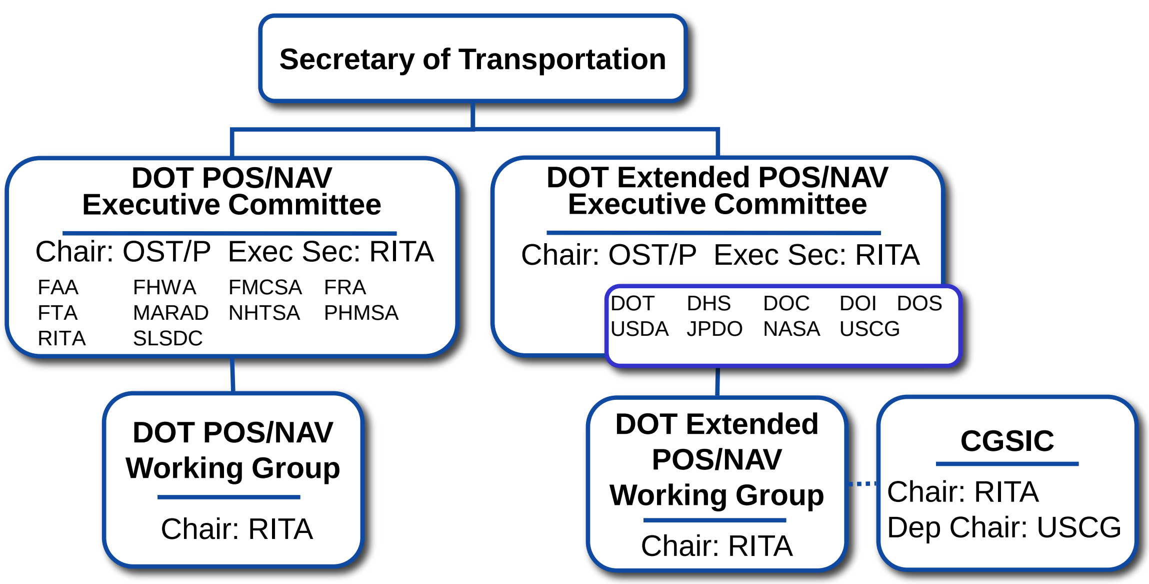

Figure 2-2 DOT Navigation Management Structure

The Secretary of Transportation, under 49 USC § 301 (Ref. 28), has overall leadership responsibility for navigation matters within DOT and promulgates PNT plans. RITA coordinates PNT issues and planning that 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 PNT systems.

2.2.1 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 Under Secretary for Policy (OST/P) and consists of policy-level representatives from the General Counsel's Office (OST/C), Budget and Programs (OST/B), the Administration (OST/M), FAA, FHWA, FMCSA, FRA, FTA, MARAD, NHTSA, PHMSA, RITA, and SLSDC.

2.2.1.1 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, 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.

2.2.2 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 PNT systems. It is chaired by OST/P and consists of policy-level representatives from DOT, DHS, DOC, Department of the Interior (DOI), the Joint Planning and Development Office (JPDO), NASA, DOS, USCG, and the U.S. Department of Agriculture (USDA).

2.2.2.1 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 PNT systems. It is chaired by RITA and 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.

2.2.2.2 Civil GPS Service Interface Committee (CGSIC)

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

2.2.3 DOT Agencies

2.2.3.1 Federal Aviation Administration (FAA)

FAA has responsibility for development and implementation of PNT 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 (Ref. 7), paragraph (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."

2.2.3.2 Saint Lawrence Seaway Development Corporation (SLSDC)

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.

2.2.3.3 Maritime Administration (MARAD)

MARAD is the agency within DOT dealing with waterborne transportation. Its programs promote the use of waterborne transportation and its integration with other segments of the transportation system, and the viability of the U.S. merchant marine. MARAD works in many areas involving ships and shipping, shipbuilding, port operations, vessel operations, national security, environment, and safety. MARAD is also charged with maintaining the health of the merchant marine, since commercial mariners, vessels, and intermodal facilities are vital for supporting national security. MARAD provides support and information for current mariners along with extensive support for educating future mariners. MARAD also maintains a fleet of cargo ships in reserve known as the Ready Reserve Force to provide surge sealift during war and national emergencies, and is responsible for disposing of ships in that fleet, as well as other non-combatant Government ships, as they become obsolete.

2.2.3.4 Other DOT Agencies

FHWA, FMCSA, FRA, FTA, NHTSA, and RITA have 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.

2.3 Department of Homeland Security (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. The DHS PNT management structure is shown in Figure 2-3.

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 that:

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

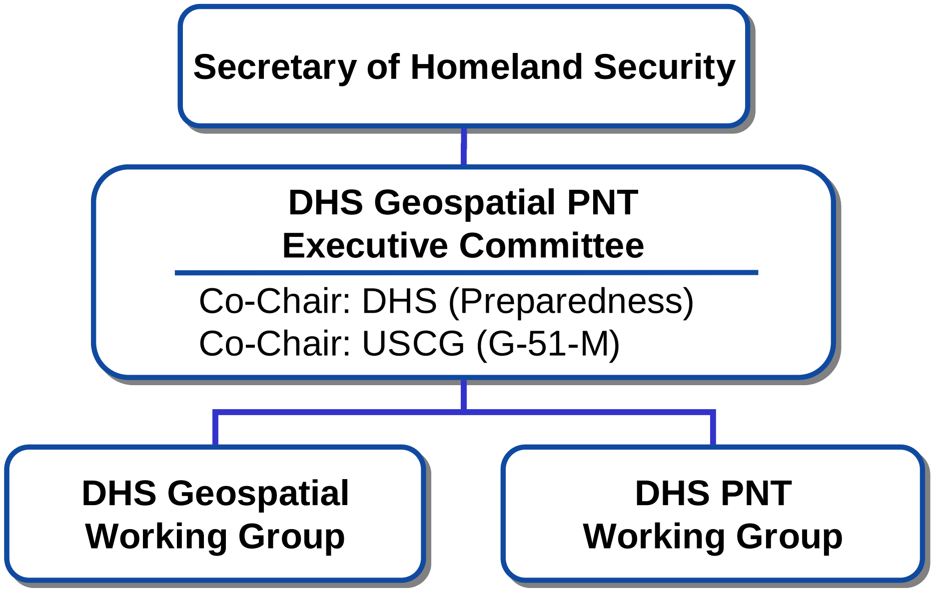

Figure 2-3 DHS PNT Management Structure

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 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.

2.3.1 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 (Ref. 9) 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 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 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."

2.4 Other Government Organizations Responsibilities

2.4.1 National Executive Committee for Space-Based PNT

NSPD-39 (Ref. 12) 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 Executive Committee for Space-Based PNT. 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 GPS, its augmentations, security for these services, and relationships with foreign PNT services. The National Executive Committee is co-chaired by the Deputy Secretaries of Defense and Transportation. The National Executive Committee management structure is shown in Figure 2-4.

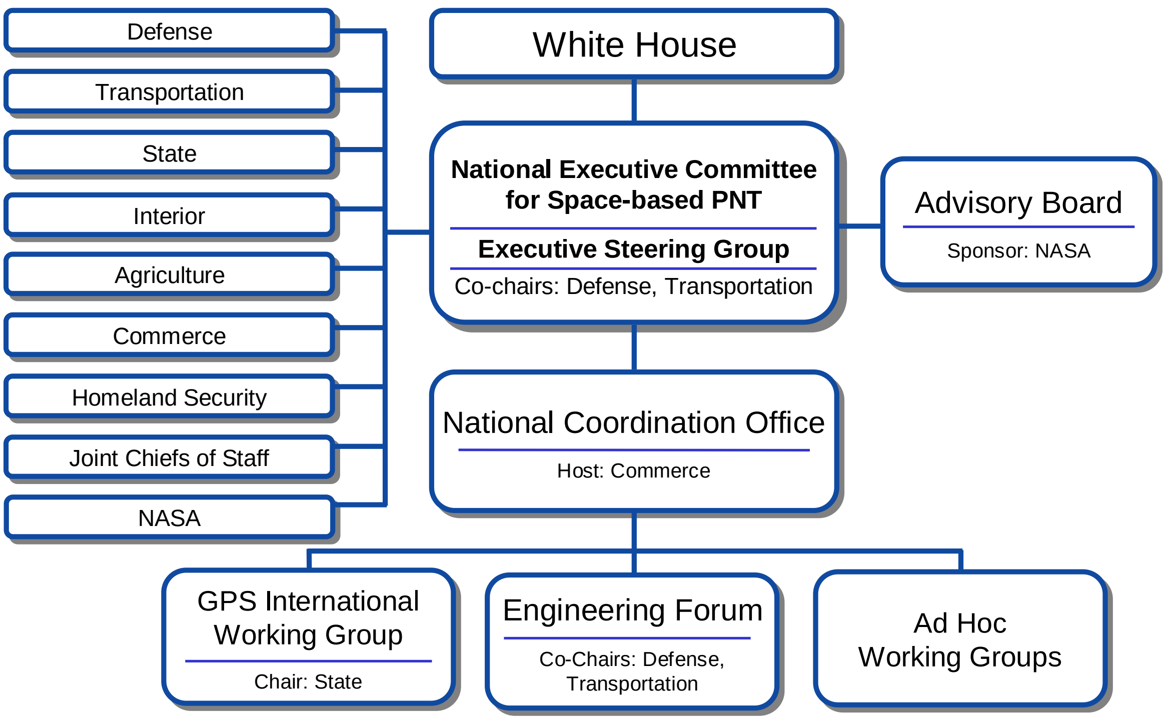

Figure 2-4 National Space-Based PNT Management Structure

NSPD-39 (Ref. 12) established the National Executive Committee for Space-Based PNT to provide top-level guidance on matters concerning space-based PNT. The National Executive Committee is chaired jointly by the Deputy Secretaries of Defense and Transportation. Its membership includes equivalent-level officials from DOS, DOI, USDA, DOC, and DHS, as well as JCS 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.

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 GPS 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 (NCO) 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 composed 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.

2.4.2 Department of Commerce (DOC)

NSPD-39 (Ref. 12) 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 Executive Committee for Space-Based PNT and NCO, providing office space, staffing, support services, and other resources. Through the National Geodetic Survey (NGS) of the National Oceanic and Atmospheric Administration (NOAA), DOC is responsible for defining, maintaining, and providing access to the National Spatial Reference System (NSRS). The NSRS is a consistent coordinate system that defines latitude, longitude, height, scale, gravity, and orientation throughout the U.S. and is designed to meet the Nation's economic, social, and environmental needs. NGS disseminates the NSRS to the public through its Online Positioning User Service (OPUS), which is based on its network of Continuously Operating Reference Stations (CORS). NOAA also serves as the current Analysis Center Coordinator for the International Global Navigation Satellite System (GNSS) Service (IGS).

The Secretary of Commerce, in coordination with the Secretary of the Navy, has authority to interpret and modify UTC for application as Standard Time in the U.S. 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 and provides an official time scale through various dissemination services.

2.4.3 Department of State (DOS)

DOS responsibilities are included in NSPD-39 (Ref. 12). The Policy directs that "The Secretary of State shall:

- 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; and

  - 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 Director of Central Intelligence, and the NASA Administrator, the Sensitive Technology List created by U.S. Commercial Remote Sensing Space Policy, dated April 25, 2003 (Ref. 29). In particular, include sensitive technology items and/or information related to PNT applications."

2.4.4 National Aeronautics and Space Administration (NASA)

In support of the provisions under Pub. L. 85-568 (Ref. 10), the operation of space activities includes providing PNT services via national assets such as the NASA ground and space communication and tracking networks, including the broadcast of navigation signals, and the development and operation of equipment supporting PNT in NASA missions.

The NASA mission also includes pioneering the future in space exploration, scientific discovery, and aeronautics research, which includes a number of GPS application areas in the space, aeronautics, and terrestrial environments. Finally, NSPD-39 (Ref. 12) 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.

2.4.5 Joint Planning and Development Office (JPDO)

In December, 2003, Congress passed Pub. L. 108-176, 117 Stat. 2490, *Vision 100--Century of Aviation Reauthorization Act* (Ref. 30) that created the Next Generation Air Transportation System (NextGen) initiative, JPDO, and the Senior Policy Committee. The legislation set broad goals for the NextGen Initiative with a 2025 horizon. The goals called for improvement across a set of transportation metrics, including safety, security, efficiency, quality, affordability, and environment, however, the goals also set clear expectations for a modernized communications, navigation, and surveillance (CNS) infrastructure; net-centric information sharing (NCIS) among system components; accommodation of a wide range of public, private, and commercial users and aircraft types; scalability to meet growing demand; and the leveraging of investments from across the government.

The JPDO roles and responsibilities were called out under the general thrust of “creating and carrying out an integrated plan for a Next Generation Air Transportation System.” This responsibility was further defined to include transition planning, oversight of research and development, and the coordination of goals, research programs, and technology transfer among agencies. The legislation also called for JPDO to “consult with the public and ensure the participation of experts from the private sector.” The legislation, however, did not call out any specific implementation authority, and it has been interpreted that JPDO is to coordinate across multi-agency mission planning and implementation authorities. Finally, the legislation created the Senior Policy Committee (SPC), chaired by the Secretary of Transportation, to work with JPDO. The SPC, in addition to the Secretary of Transportation, is composed of the Secretary or Administrator (or their designee) of each JPDO partner agency. Those agencies include FAA, NASA, DoD, DHS, DOC, and OST/P. The SPC was tasked to provide policy leadership to the initiative, including recommendations for the required funding and legislation.

3

Policy

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

3.1 General

The Federal Government operates PNT 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 PNT services to the public in the most cost-effective manner possible.

By statute [10 USC § 2281 (Ref. 3), paragraph (b)], DoD is required 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.

By statute [49 USC § 44505 (Ref. 7)], 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 (Ref. 9)], 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."

These PNT services have historically been provided from ground based systems. As the full civil potential of GPS services and its augmentations are implemented, the demand for services provided by other federally provided PNT systems is expected to decrease. The USG will reduce non-GPS-based PNT 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 backup 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 PNT system, it is Federal policy to provide redundant PNT service where required. Backups to GPS for safety-of-life navigation applications, or other critical applications, can be other PNT 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 PNT 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 PNT 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 PNT services provided by the Federal Government to ensure interoperability with international users.

PNT 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 PNT systems.

The U.S. National Policy is that all PNT 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 PNT 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.

3.1.1 Timing Policy

In 1975, the 15th Conférence Générale des Poids et Mesures (CGPM, composed of representatives of signatory nations to the Treaty of the Meter, including the U.S.) “strongly endorsed” the use of UTC, Coordinated Universal Time, as the basis of civil time throughout the world. In 2007, the United States formally adopted this recommendation. Congress passed Pub. L. 110-69, 121 Stat. 572, *America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (COMPETES) Act* (Ref. 31), which among many other things redefined Standard Time in the United States to be UTC with appropriate hour offsets for the various U.S. time zones. (121 Stat. 598–599) *The COMPETES Act* went on to define UTC in the U.S. as, “the time scale maintained through the [CGPM] and interpreted or modified for the United States by the Secretary of Commerce in coordination with the Secretary of the Navy.” NIST and USNO provide advice and technical support to these secretaries, respectively, and act on delegated authority to maintain and disseminate UTC as official U.S. time. NIST and USNO have a Memorandum of Agreement that coordinates their programs. In general, USNO focuses on meeting requirements of DOD systems and associated non-military systems, while NIST provides services to the private sector. Nonetheless, both organizations agree that their realizations of UTC are equivalent to within 100 nanoseconds at all measurement intervals longer than 1 second. Military and civil users with timing requirements tighter than 100 nanoseconds are advised to contact USNO and NIST respectively for technical support if needed.

3.2 Space-Based PNT Policy

3.2.1 Executive Policy

On June 28, 2010, the President issued the new *National Space Policy* (Ref. 13) that provides high-level guidance regarding space-based PNT. The policy calls for continued U.S. leadership in the service, provision, and use of GNSS. It reaffirms existing U.S. commitments to: provide continuous, worldwide access to civil GPS, free of direct user fees; pursue international GNSS cooperation; operate and maintain GPS to meet published standards; and take steps to detect and mitigate GPS interference. *National Space Policy* (Ref. 13) augments and does not supersede NSPD-39 (Ref. 12).

With NSPD-39 (Ref. 12), 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 *Statement by the President Regarding the United States' Decision to Stop Degrading Global Positioning System Accuracy* of May 1, 2000 (Ref. 32), 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.

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, in order to meet growing national, homeland, and economic security requirements, civil requirements, and commercial and scientific demands.

The U.S. will continue to maintain space-based PNT services, and augmentation, backup, and service denial capabilities that: (1) provide uninterrupted availability of PNT services; (2) meet growing national, homeland, and economic security requirements, civil requirements, and commercial and scientific 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) retain 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 (Ref. 19);

- 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 GPS Service

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 commitment in IMO Assembly Resolution A.953(23), *World-wide Radionavigation System*, 5 December 2003 (Ref. 33). The aviation community has documented this commitment 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 GPS SPS Performance Standard (PS) (Ref. 34) of September 2008. 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 authorized U.S. users, and authorized allied military users.

3.2.3 Navigation Warfare (NAVWAR)

With NSPD-39 (Ref. 12), the President directed that the Secretary of Defense shall develop, acquire, operate, realistically test, evaluate, and maintain NAVWAR capabilities.

NAVWAR is defined as deliberate military operations to gain and maintain a PNT information advantage. Desired effects are generated through the coordinated employment of components within information operations, space operations, and cyberspace operations, including electronic warfare, space control, space force enhancement, and computer network operations.

The DoD NAVWAR program exists to ensure that the U.S. retains a military advantage in the area of conflict by: protecting authorized use of GPS; preventing the hostile use of GPS, its augmentations, or any other PNT service; and preserving peaceful civil GPS use outside an area of military operations. The NAVWAR program requires occasional testing, which may impact the civil use of GPS.

NAVWAR Electronic Attack (EA) Test, Training, and Exercises (TT&E) activities that could impact GPS within the U.S., Mexico and Canada must be coordinated within the DoD and Interagency. CJCSM 3212.03 (Ref. 24) gives guidance on how to request and gain approval to conduct these EA TT&E activities.

3.2.4 GPS Backup for Critical Infrastructure

The USG recognizes the benefits of providing a backup capability to GPS to mitigate the safety, security, or economic effects of a disruption of GPS service. In accordance with NSPD-39 (Ref. 12), 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 (Ref. 19).

In March 2007, the DOT POS/NAV Executive Committee and the DHS Geospatial/PNT Executive Committee accepted the findings of the Institute for Defense Analyses' Independent Assessment Team and agreed 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 Executive Committee for Space-Based PNT supported this approach and tasked DOT and DHS with completing an action plan that included identifying an executive agent, developing a transition plan to address funding and operations, and requesting approval by DOT and DHS Secretaries resulting in a final decision. DoD had not approved *eLoran* as a GPS backup for military applications.

In March 2008, the National Executive Committee for Space-Based PNT endorsed the DOT/DHS decision to transition the Loran system to *eLoran*. Pub. L. 111-83, 123 Stat. 2142, *Department of Homeland Security (DHS) Appropriations Act for Fiscal Year 2010* (Ref. 35), however, allowed for termination of the Loran-C signal on January 4, 2010. Accordingly, USCG terminated the transmission of all U.S. Loran-C signals effective 2000Z, 08 Feb 2010.

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 indicated wide variance in backup system requirements. Therefore, DHS is working with Federal partners to clarify the operational requirements.

3.2.5 GPS 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 Station (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 these precise timing data. Details about obtaining calibration of GPS timing receivers and traceability to UTC can be found at http://tycho.usno.navy.mil.

3.2.6 GPS Signal Monitoring

USG does not currently monitor and assess SPS performance in real-time. USG does continuously monitor PPS signal-in-space (SIS) user range errors (URE) for all satellites in view of Operational Control System (OCS) and NGA monitor stations in near-real-time, to ensure they are meeting performance objectives. The GPS control segment maintains six monitor stations, which are combined with 11 stations provided by the NGA. NGA generates precise, post-fit GPS orbits, as well as predicted orbits, for DoD. 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 United States Air Force (USAF) Space Command (AFSPC) 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 https://www1.nga.mil/ProductsServices/Pages/default.aspx.

3.2.7 Modernized GPS Signals

3.2.7.1 Civil Signals

In addition to the L1 Coarse/Acquisition (C/A) signal, the USG is introducing three additional coded signals (L1C, L2C, and L5) to support future civil applications.

The performance specifications in the current SPS PS apply to users of the L1 C/A (1575.42 MHz) signal. Performance standards are being developed to incorporate the modernized civil signals and future editions will be published as operational capability is achieved.

3.2.7.2 Military Signals

Currently, authorized users with keyed GPS receivers are provided access to PPS (i.e., P(Y) code) on L1 and L2. These will be supplanted in the future by 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 separated from civilian signals and other radionavigation satellite service signals, thereby enabling U.S. NAVWAR operations. NAVWAR involves protecting U.S. and allied use of GPS while simultaneously preventing hostile forces access to GPS, its augmentations, or any other PNT service, and preserving peaceful civil GPS use outside an area of military operations. M-Code will permit higher power operation than that of the present signal design and will facilitate localized tactical denial of GPS civil signals. 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 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 their augmentation systems, with the exception of the Army validated WAAS requirement documented in the Global Air Traffic Management (GATM) Operational Requirements Document (ORD) (Ref. 36). 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 our international allies to seek approval for use of these receivers in foreign airspace.

3.2.9 Discontinuation of Codeless and Semi-Codeless GPS Access

As published in the Federal Register, Volume 73, Number 185, September 23, 2008, Page 54792, *Preservation of Continuity for Semi-Codeless GPS Applications* (Ref. 37), 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 modernized civil-coded signals by this date.

3.2.10 GPS Augmentation

USCG is mandated by 14 USC § 81(Ref. 9) to implement, maintain, and operate electronic navigation aids that meet maritime needs of the U.S. armed forces and/or U.S. commerce.

PL 105-66 (Ref. 8) § 346, 111 Stat. 1449 authorizes the Secretary of Transportation to improve and expand the USCG Maritime Differential GPS (MDGPS) into the NDGPS, by adding an inland segment. RITA coordinates the inland program and is acting chair of the NDGPS Policy and Implementation Team.

3.2.11 Mitigating Disruptions to GPS

DOT, in conjunction with other governmental agencies, is developing and implementing mitigation plans in response to the recommendations of the Volpe Report (Ref. 18), as well as other USG critical infrastructure protection initiatives. In addition, NSPD-39 (Ref. 12) directs DOT, in coordination with DHS, to develop, acquire, operate, and maintain backup PNT capabilities for critical civil and commercial applications within the U.S., in the event of a disruption to GPS or its augmentations.

3.2.12 The Future of GPS

GPS will be the primary federally provided PNT 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.

4

PNT User Requirements

The FRP is not intended to be a requirements document. The purpose of this section is to provide context for the PNT systems provided by the USG. 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 manner. Agencies must consider the needs of civil and military users to which they provide services within their enabling statutes. DoD users need to operate worldwide with civil and NATO PNT systems while simultaneously maintaining the capability to use military PNT signals.

The requirements of civil and military users for PNT 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.

4.1 General PNT User Requirements

PNT 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 a Federal agency, 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 PNT system users.

The provisioning of Government provided PNT services is conditioned on the receipt of sufficient annual appropriations.

4.2 Space PNT User Requirements

4.2.1 Space PNT Requirements

The Space Communications and Navigation (SCaN) office operates as a central organization within the Space Operations Mission Directorate (SOMD) and its responsibilities include the management of existing space network and the implementation of any improvements and upgrades to those systems and networks. NASA has agreements with other U.S. agencies on support of the NASA communication and tracking networks to non-NASA customers.

Measurements from the tracking networks, and on-board observables, are sent to the NASA Flight Dynamics Facility (FDF) to generate navigation products, such as trajectory analysis and orbit determination, for the missions. Individual missions may choose to include GPS measurements as an observable. As such, NASA's mission to pioneer the future in space exploration, scientific discovery and aeronautics research, includes a number of GPS application areas in the space, aeronautics, and terrestrial environments.

This section provides examples of current, and future, GPS needs for supporting spacecraft navigation and NASA’s science mission, which are summarized in Table 4-1. These reflect the GPS capabilities available throughout the GPS Terrestrial Service Volume (surface to 3000 km altitude) as enabled by the GPS signal parameters (power, availability, etc.) defined in current Interface Specifications and assumption of phase and delay stability among the various signals.

Table 4-1 Space User Requirements

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS					
	ACCURACY	AVAILABILITY	CONTINUITY	INTEGRITY	TIME TO ALERT	COVERAGE
On-Board Autonomous Navigation (1 σ) [A]						
	3D Position: Error not to exceed 1m (post-processed)	N/A	N/A	N/A	N/A	Space Service Volume Low Earth Orbit
	3D Velocity: Error not to exceed 0.1 m/s (post-processed)					
	Attitude Determination: Error not to exceed 0.01º per axis (post-processed)					
Science Applications **(1 σ)**						
Earth Observation Satellites	3D Position: 10 cm (real-time)[B] 2-5 cm (post-processed)[B]	N/A	N/A	N/A	N/A	Space Service Volume Low Earth Orbit
	3D Velocity: N/A (real-time and post-processed)					
	Attitude Determination: N/A (real-time and post-processed):					
	Time: Real-Time: N/A Post-Processed: Time transfer stable to 0.15 ηs					
Altimetry Missions	3D Position: 3mm in altitude (post-processed)[B]	N/A	N/A	N/A	N/A	Space Service Volume Low Earth Orbit
	3D Velocity: N/A					
	Attitude Determination: N/A					
	Time: Time transfer stable to 0.15 ηs					
Occultation Measurements	3D Position: 10 cm level (post-processed)[C]	N/A	N/A	N/A	N/A	Space Service Volume Low Earth Orbit
	3D Velocity: 0.05 mm/sec (post-processed)[C]					
	Attitude Determination: N/A					
	Time: N/A					

[A] The primary navigation function for NASA missions is performed through communication channel tracking by NASA's Ground and Space Networks, and ground-based trajectory analysis of observables. Individual missions may opt for autonomous navigation capabilities through on-board processing of inertial measurements, celestial measurements, and radiometric signals including GPS. The accuracy requirements described here for on-board autonomous navigation result from filtered GPS data and do not represent instantaneous solution requirements.

[B] Real-time positioning using dual frequency GPS measurements combined with differential corrections from NASA's Global Differential GPS (GDGPS) network of 100+ dual frequency ground monitoring stations. Post processing analysis incorporates additional algorithms and models.

[C] Positioning and velocity requirement for accurate measurement of occultation refraction of the GPS signals as they pass through the atmosphere.

4.2.1.1 Spacecraft Navigation

Onboard spacecraft vehicle navigation support is provided by multiple sources, including GPS and augmentation systems, ground-based and space-based communication channel tracking, and inertial navigation systems. GPS and GPS augmentations are 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/s (1 sigma),
- attitude determination error not to exceed 0.01 deg in each axis (1 sigma), and
- clock offset between UTC (USNO) and the GPS time scale not to exceed 1 µs (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 continuing work with USAF to further define the performance parameters to support navigation services in the GPS space service volume, which covers the region in space between 3,000 km and Geostationary Earth Orbit (GEO) altitude (~36,000 km).

4.2.1.2 Scientific Support

GPS scientific support describes analysis of data 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 and time transfer stable to 0.15 ns. However, 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 measurements with sub-mm precision in order to accurately measure the refraction of the GPS signals as they pass through the atmosphere.

4.2.1.3 Geodetic Reference Frame

NASA supports the International Laser Ranging Service in the tracking and orbital analysis of laser retroreflector-equipped GNSS satellites, as well as a large number of Earth observation satellites, to support the maintenance and improvement of the International Terrestrial Reference Frame and the advancement of Earth science relating to climate change and geohazards. NASA has undertaken the task of coordinating efforts among Federal agencies to identify the geodetic requirements to meet future PNT requirements.

4.2.2 Space User Community

NASA currently uses 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, it is expected that other government agencies will 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.

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 provides 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 Johnson Space Center is involved in research and development (R&D) efforts of GPS receivers for human spaceflight. The latest generation of NASA GPS space-borne receivers are software programmable units.

Standard GPS receivers are inadequate for certain space applications above LEO due to reduced signal power level and availability. 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. This research requires precise satellite positioning at the 10 cm (1 sigma) level in real-time, and centimeter-level (1 sigma) positioning with post-processed data. This capability will enable numerous scientific measurements that are not available today to support research in areas such as oceanography and geodesy.

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.

4.3 Aviation PNT User Requirements

Aircraft navigation 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 Instrument Flight Rules (IFR).

Aircraft separation criteria, established by FAA, take into account limitations of CNS, and ATC Automation 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 PNT system will remain within a specified error budget.

The following are basic requirements for aviation navigation systems (see Table 4-2 for specific requirements). "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% 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 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 Area Navigation (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, and DME/DME/IRU (Inertial Reference Unit) (where there is adequate infrastructure), 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.

4.3.1 Air Navigation User Requirements and Phases of Flight

Current user requirements are a function of legacy navigation system capabilities. User requirements are evolving toward performance based requirements as described in section 4.3.2.

The four phases of aerial navigation are en route (including oceanic/remote areas), terminal, takeoff and approach-to-landing, and surface.

4.3.1.1 En Route Phase

This phase is the portion of flight after departure and prior to the transition to approach. The general requirements in Section 4.3 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.

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 wind 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.

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

4.3.1.2 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 and 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 access, operational efficiency, and environmental effects within these areas.

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.

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

4.3.1.3 Takeoff and Approach-to-Landing Phases

The general requirements of Section 4.3 apply to the takeoff and approach-to-landing phases. In addition, specific procedures and clearance zone requirements are specified in FAA Order 8620.3B, *United States Standard for Terminal Instrument Procedures (TERPS)* (Ref. 38).

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

Takeoff Phase

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

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.
- Precision Approach Procedure: A standard instrument approach procedure where an electronic glide slope is provided to tighter tolerances than an Approach with Vertical Guidance.

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

Nonprecision and Lateral Navigation (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 s 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.

Approach with Vertical Guidance (LNAV/VNAV, LPV, and RNP)

Lateral Navigation/Vertical Navigation (LNAV/VNAV) and Localizer Performance with Vertical Guidance (LPV) are RNAV approach procedures that provide lateral and vertical guidance for the approach with operational ceiling and visibility minimums as low as 250 ft and ¾ mi. Some flight management systems (FMS) provide LNAV/VNAV capability by incorporating lateral RNAV guidance information with barometric-generated vertical guidance information. Baro-generated VNAV accuracy, however, is affected by both cold and hot weather, requiring operational limitations on using it for LNAV/VNAV operations. WAAS-based LNAV/VNAV and LPV operations are not affected by temperature variations. RNP approach procedures are three-dimensional procedures with lateral and vertical path deviation guidance provided with specified navigation capabilities.

Precision Approach-to-Landing

A precision approach is a standard instrument approach procedure in which an electronic glideslope/glidepath is provided. 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.

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. Ground-Based Augmenation System (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 a 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 mi visibility minimum similar to the lowest CAT I minimums. ICAO is amending the definition of CAT I to include LPV-200. Precision approach and landing systems must automatically remove hazardously misleading signals from service within 6 s for CAT I, and 2 s for CAT II and III.

4.3.1.4 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 NextGen.

4.3.2 Evolving Aviation Navigation Requirements

The Required Navigation Performance and Special Operational Requirements Study Group (RNPSORSG) (renamed Performance Based Navigation Study Group) 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* (Ref. 39). This manual supersedes the manual on RNP (Doc 9613, Second Edition). Consequently, this affects a number of ICAO documents, including:

- Annex 11, *Air Traffic Services* (Ref. 40)
- *Procedures for Air Navigation Services, Air Traffic Management* (PANS-ATM, Doc. 4444 ATM/501) (Ref. 41)
- *Procedures for Air Navigation Services, Aircraft Operations* Volumes I & II (PANS-OPS, Doc 8168) (Ref. 42)
- *Regional Supplementary Procedures* (Doc 7030) (Ref. 43)
- *Air Traffic Services Planning Manual* (Doc. 9426 AN/924) (Ref. 44)

- *Manual on Airspace Planning Methodology for the Determination of Separation Minima* (Doc 9689) (Ref. 45)

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.

Table 4-2 depicts the RNAV signal-in-space performance requirements established by ICAO. Demonstrating system compliance with the signal-in-space requirements depicted below requires rigorous safety management system and safety risk management documentation processes. The following paragraphs characterize flight operations in the various phases of flight.

4.3.2.1 En Route Phase

In the United States, an RNAV 2 application supports an En Route continental Airspace Concept. With the publication of FAA Advisory Circular (AC) 90-100A, *U.S. Terminal and En Route Area Navigation (RNAV) Operations* (Ref. 47), 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).

Table 4-2 Aviation Performance-Based Navigation Requirements *

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS						
	ACCURACY		AVAILABILITY	CONTINUITY	INTEGRITY	TIME TO ALERT	COVERAGE **
	Horizontal	Vertical					
Oceanic	10 or 4 nmi	N/A	0.99 – 0.99999		$1\text{-}1\text{x}10^{-7}$//hr	NA	NA
Enroute	2 nmi	N/A	0.99 – 0.99999	$1\text{-}1\text{x}10^{-4}$/hr to $1\text{-}1\text{x}10^{-8}$/hr	$1\text{-}1\text{x}10^{-7}$/hr	5 min	NA
Terminal	1 nmi	N/A	0.99 – 0.99999	$1\text{-}1\text{x}10^{-4}$/hr to $1\text{-}1\text{x}10^{-8}$/hr	$1\text{-}1\text{x}10^{-7}$/hr	15 s	NA
Non Precision Approach	220 m	N/A	0.99 – 0.99999	$1\text{-}1\text{x}10^{-4}$/hr to $1\text{-}1\text{x}10^{-8}$/hr	$1\text{-}1\text{x}10^{-7}$/hr	10 s	NA
APV-I	16 m	20 m	0.99 – 0.99999	$1\text{-}8\text{x}10^{-6}$/15 s	$1\text{-}2\text{x}10^{-7}$ in any approach	10 s	NA
APV-II	16 m	8 m	0.99 – 0.99999	$1\text{-}8\text{x}10^{-6}$/15 s	$1\text{-}2\text{x}10^{-7}$ in any approach	6 s	NA
CAT I	16 m	6 – 4 m	0.99 – 0.99999	$1\text{-}8\text{x}10^{-6}$/15 s	$1\text{-}2\text{x}10^{-7}$ in any approach	6 s	NA

* From ICAO Annex 10 Vol 1 (Ref. 46) Table 3.7.2.4-1. ICAO is in the process of changing approach definitions of the APV classification and including LPV-200 as a precision approach.

** Not Specified by ICAO, Annex 10, Vol. 1, Table 3.7.2.4-1, Signal-in-Space Performance Requirements

4.3.2.2 Oceanic En Route

Oceanic and remote continental Airspace Concepts are currently served by two navigation specifications, RNP 10 and RNP 4. Both of these navigation specifications support the navigation element of the Airspace Concept. In the case of RNP 10, when 50 nmi longitudinal separation is applied, ADS-C surveillance is required. In the case of RNP 4, when 30 nmi lateral or 30 nmi longitudinal separation is applied, ADS-C surveillance is required.

4.3.2.3 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) as listed in AC 90-100A (Ref. 47).

4.3.2.4 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.

Near-Precision and Performance Based Approaches

With the advent of WAAS it is possible to have an LPV approach anywhere in the U.S. where airspace and geography permit, 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% under optimum conditions. LPV approaches outnumber ILS approaches in the U.S., providing more service to aviation users. Airports with appropriate infrastructure within the signal-in-space coverage area are eligible for LPV-200 approaches.

Precision Approach-to-Landing

Approach concepts cover all segments of the instrument approach, i.e., initial, intermediate, final, and missed approach. 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. RNP specifications requiring a navigation accuracy of 0.1 nmi will increasingly be used in these environments. The potential exists for lower RNP values to support advanced NextGen capabilities.

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

4.3.2.5 Aviation 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.

4.3.3 Aviation Positioning Requirements

A final rule was published in 2010 to amend FAA regulations, Title 14 CFR Part 91, *General Operating and Flight Rules* (Ref. 48), §91.225 and §91.227, by adding equipage requirements and performance standards for ADS–B Out avionics on aircraft operating in Classes A, B, and C airspace, as well as certain other specified classes of airspace within the NAS. ADS-B Out broadcasts information about an aircraft through the use of an onboard positioning source and transmitter to a ground receiver. Use of ADS-B Out will move air traffic control from a radar-based system to a satellite-derived aircraft location system. This rule will facilitate the use of ADS-B for aircraft surveillance by FAA and DoD air traffic controllers to safely and efficiently accommodate aircraft operations and the expected increase in demand for air transportation. This rule also provides aircraft operators with a platform for additional flight applications and services. The compliance date for this final rule is January 1, 2020.

The required performance of the positioning source used for ADS-B Out is represented by the navigation accuracy category for position (NAC_p), the navigation accuracy category for velocity (NAC_v), the navigation integrity category (NIC), the system design assurance (SDA), and the source integrity level (SIL) parameters, as described in 14 CFR 91 (Ref. 48), §91.227, *Automatic Dependent Surveillance-Broadcast (ADS–B) Out Equipment Performance Requirements*, effective January 1, 2020. The required positioning source performance for ADS-B Out is as follows:

- NAC_p must be less than 0.05 nmi
- NAC_v must be less than 10 m/s
- NIC must be less than 0.2 nmi
- SDA must be less than or equal to 1×10^{-5} per hr
- SIL must be less than 1×10^{-7} per hr or per sample

4.4 Surface PNT User Requirements

4.4.1 Maritime User Requirements

4.4.1.1 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.

4.4.1.1.1 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.

4.4.1.1.2 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.

4.4.1.1.3 Coastal Navigation

Coastal navigation is that phase in which a ship is within 50 nmi 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 nmi wide, if a one-way path, or two nmi 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 nmi 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.

4.4.1.1.4 Ocean Navigation

Ocean navigation is that phase in which a ship is beyond the continental shelf (200 m in depth), and more than 50 nmi 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.

4.4.1.2 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 4-3, 4-4, 4-5, and 4-6 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.

4.4.1.2.1 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 PNT 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 4-3.

Table 4-3 Maritime User Requirements for Purposes of System Planning and Development - Inland Waterway Phase

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS					
	ACCURACY (meters, 2 drms)	AVAILABILITY	CONTINUITY	INTEGRITY	TIME TO ALERT	COVERAGE
Safety of Navigation (All Ships and Tows)	2-5	99.9%	*	TBD	TBD	US Inland Waterway Systems
Safety of Navigation (Recreational Boats and Smaller Vessels)	5-10	99.9%	*	TBD	TBD	US Inland Waterway Systems
River Engineering and Construction Vessels	0.1**-5	99%	*	TBD	TBD	US Inland Waterway Systems

* Dependent upon mission time.
** Vertical dimension.

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.

4.4.1.2.2 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 4-4 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 PNT information that is presented at less than 10 sec intervals on a moving vessel, some form of an automatic display is required. Technology is available which presents PNT information along with other data.

Table 4-4 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, 2 drms)	AVAILABILITY	CONTINUITY	INTEGRITY	TIME TO ALERT	COVERAGE
Safety of Navigation (Large Ships & Tows)	8 – 20***	99.7%	**	TBD	TBD	US harbor entrance and approach
Safety of Navigation (Smaller Ships)	8 – 20	99.9%	**	TBD	TBD	US harbor entrance and approach
Resource Exploration	1 – 5*	99%	**	TBD	TBD	US harbor entrance and approach
Engineering and Construction Vessels Harbor Phase	0.1****-5	99%	**	TBD	TBD	Entrance channel & jetties, etc.

(b)

BENEFITS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET BENEFITS					
	ACCURACY (meters, 2drms)	AVAILABILITY	CONTINUITY	INTEGRITY	TIME TO ALERT	COVERAGE
Fishing, Recreational and Other Small Vessels	8 – 20	99.7%	**	TBD	TBD	US harbor entrance and approach

* Based on stated user need.
** Dependent upon mission time.
*** Varies from one harbor to another. Specific requirements are being reviewed by the USCG.
**** Vertical dimension.

Minimum Performance Criteria: The PNT 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 PNT requirements for various-sized vessels while operating in such restricted confines. PNT user conferences have indicated that for many mariners, the PNT system becomes a secondary tool to visual and audio aids to navigation, radar, and intership communications when entering the harbor entrance and approach environment. Continuing efforts are being directed toward verifying user requirements and desires for PNT 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 the Vessel Traffic Service (VTS) along with the Automatic Information Service (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, Puerto Rico, 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 m for each 150 km distance from the broadcast site.

4.4.1.2.3 Coastal Phase

There is a need for continuous, all-weather PNT 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 4-5. Furthermore, the total navigation service in the coastal area must provide service of useful quality and be within the economic reach of all classes of mariners.

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

- the need for larger vessels to navigate within the designated one-way traffic lanes at the approaches to many major ports, in fairways established through offshore oil fields, and at safe distances from shallow water; 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 nmi will satisfy the minimum safety requirements if a fix can be obtained at least every 15 min. As indicated in Table 4-5, 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 PNT. Navigation service for operation within the coastal area is provided by GPS and NDGPS.

Table 4-5 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, 2 drms)	AVAILABILITY	CONTINUITY	INTEGRITY	TIME TO ALERT	COVERAGE
Safety of Navigation (All Ships)	0.25 nmi (460 m)	99.7%	**	TBD	TBD	US coastal waters
Safety of Navigation (Recreation Boats and Other Small Vessels)	0.25 – 2 nmi (460 – 3,700 m)	99%	**	TBD	TBD	US coastal waters

(b)

BENEFITS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET BENEFITS					
	ACCURACY (meters, 2 drms)	AVAILABILITY	CONTINUITY	INTEGRITY	TIME TO ALERT	COVERAGE
Commercial Fishing (Include Commercial Sport Fishing)	0.25 nmi (460 m)	99%	**	TBD	TBD	US coastal/Fisheries areas
Resource Exploration	1.0 – 100 m*	99%	**	TBD	TBD	US coastal areas
Search Operations, Law Enforcement	0.25 nmi (460 m)	99.7%	**	TBD	TBD	US coastal/Fisheries areas
Recreational Sports Fishing	0.25 nmi (460 m)	99%	**	TBD	TBD	US coastal areas

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

4.4.1.2.4 Ocean Phase

The requirements for safety of navigation in the ocean phase for all ships are given in Table 4-6. 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 nmi coupled with a maximum fix interval of 2 hr 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 nmi and a fix interval of 15 min or less. The navigation signal should be available 95% of the time. Further, in any 12-hour period, the probability of obtaining a fix from the system should be at least 99%.

Table 4-6 Maritime User Requirements/Benefits for Purposes of System Planning and Development - Ocean Phase

(a)

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS					
	ACCURACY (meters, 2 drms)	AVAILABILITY	CONTINUITY	INTEGRITY	TIME TO ALERT	COVERAGE
Safety of Navigation (All Craft)	2-4 nmi (3.7 – 7.4 km) minimum 1-2 nmi (1.8 – 3.7 km) desirable	Worldwide	**	TBD	TBD	99% fix at least every 12 hr

(b)

BENEFITS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET BENEFITS					
	ACCURACY (meters, 2 drms)	AVAILABILITY	CONTINUITY	INTEGRITY	TIME TO ALERT	COVERAGE
Large Ships Maximum Efficiency	0.1 – 0.25 nmi* (185 – 460 m)	99%	**	TBD	TBD	Worldwide, except polar regions
Resource Exploration	10 – 100 m*	99%	**	TBD	TBD	Worldwide
Search Operations	0.1 – 0.25 nmi (185 – 460 m)	99%	**	TBD	TBD	National Maritime SAR regions

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

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 PNT 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 4-6. The predictable accuracy benefits may be as stringent as 10 m for special maritime activities, and may range to 0.25 nmi for large, economically efficient vessels, including search operations. Search operations must also have a repeatable accuracy of at least 0.25 nmi.

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 practicable.

4.4.1.3 Future Marine PNT Requirements

The marine PNT 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 PNT 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 PNT systems capabilities.

4.4.1.3.1 Safety

4.4.1.3.1.1 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 PNT systems.

4.4.1.3.1.2 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 PNT performance is needed.

4.4.1.3.1.3 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. PNT 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.

4.4.1.3.2 Economics

4.4.1.3.2.1 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 PNT systems can contribute to better productivity and decreased delay in transit.

4.4.1.3.2.2 All Weather Operations

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

4.4.1.3.3 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 PNT services of higher quality and for broadened geographic coverage in order to allow environmentally sound development of resources.

4.4.1.3.4 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 PNT systems.

4.4.2 Land User Requirements

4.4.2.1 Land Transportation Requirements

Requirements for use of PNT systems for land vehicle applications continue to evolve. Many civil land applications that use PNT 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* (Ref. 49). 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 PNT 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 a Report to the Committees on Appropriations, *Differential GPS: An Aid to Positive Train Control (*Ref. 50) 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 s, 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 s 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%. The availability requirement for rail is estimated as 99.9%.

Whilst USG has no statutory responsibility to provide PNT services for land PNT applications or for non-navigation uses, their existence and requirements are recognized in the Federal PNT 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 PNT 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 PNT 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, Track Defect Location (TDL), Automated Asset Mapping (AAM), and bridge monitoring systems. GPS and dead-reckoning/map-matching are being developed as systems that take advantage of PNT systems and at the same time improve safety and efficiency of land navigation.

4.4.2.2 Categories of Land Transportation

4.4.2.2.1 Highways

PNT 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. Tables 4-7 and 4-8 identify current Highway and Trucking user requirements. Applications are being developed that rely on PNT as an input to an overall navigation solution for safety applications. Today, GPS and NDGPS, as part of CORS, provides highway transportation agencies with the critical survey grade solutions needed for building and maintaining our nation’s highway.

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 4-7 Highway User Requirements

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS					
	ACCURACY (meters, 2 drms)	AVAILABILITY	CONTINUITY	INTEGRITY (Alert Limit)	TIME TO ALERT	COVERAGE
Navigation and route guidance	1 – 20	>95%	*	2 – 20 m	5 sec	Nationwide / Surface Coverage
Automated vehicle monitoring	0.1 – 30	>95%	*	0.2 – 30 m	5 s – 5 min	Nationwide / Surface Coverage
Automated vehicle identification	1	99.7%	*	3 m	5 sec	Nationwide / Surface Coverage
Public safety	0.1 – 30	95-99.7%	*	0.2 – 30 m	2 – 15 sec	Nationwide / Surface Coverage
Resource management	0.005 – 30	99.7%	*	0.2 – 1 m	2 – 15 sec	Nationwide / Surface Coverage
Collision avoidance	0.1	99.9%	*	0.2 m	5 sec	Nationwide / Surface Coverage
Geophysical survey	1	**	*	***	N/A	Nationwide / Surface Coverage
Geodetic control	0.01	**	*	***	N/A	Nationwide / Surface Coverage
Accident Survey	0.1 – 4	99.7%	*	0.2 – 4 m	30 sec	Nationwide / Surface Coverage
Emergency Response	0.1 – 4	99.7%	*	0.2 – 4 m	30 sec	Nationwide / Surface Coverage
Intelligent Vehicle Initiative	0.1	99.9%	*	0.2	5 sec	Nationwide / Surface Coverage

* Continuity applies to phases of operations. For highway applications, this has not been defined.

** In these instances, availability of a real-time solution is not needed, but is beneficial.

*** This is typically done using post-processing techniques. While integrity of the data is important, it is not used to directly support safety and can be provided after data is collected

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 PNT 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 subsystems.

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.

Table 4-8 Trucking User Services Requiring Use of PNT

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS					
	ACCURACY (meters, 2 drms)	AVAILABILITY	CONTINUITY	INTEGRITY (Alert Limit)	TIME TO ALERT	COVERAGE
Truck Parking	2 – 20 m	95%	TBD	50 m	5 s	Nationwide / Surface Coverage
Geo-fencing / Facility Access	10 – 20 m	99%	TBD	10 m	5 s	Nationwide / Surface Coverage
Hazardous Materials (HAZMAT) Tracking	10 – 20 m	99%	TBD	10 m	5 s	Nationwide / Surface Coverage
Trailer Tracking	20 m	95%	TBD	50 m	5 s	Nationwide / Surface Coverage
Cabotage Violations	10 – 20 m	99%	TBD	10 m	5 s	Nationwide / Surface Coverage
Fleet Management	20 m	95%	TBD	50 m	5 s	Nationwide / Surface Coverage
Commercial Drivers License (CDL) Skills Test	5 – 20 m	99%	TBD	10 m	5 s	Nationwide / Surface Coverage

4.4.2.2.2 Transit

Transit systems also benefit from the same PNT-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.

Currently, the integrity requirements are unknown for transit PNT applications, but user requirements are generally similar to Highway User Requirements. Table 4-7 may be used as a reference for transit. As the transit research starts to define current applications and develop newer applications for the safety and mobility that integrate GPS, DGPS, and other PNT solutions, specific requirements for accuracy, integrity and availability have to be established for the transit PNT systems. Ongoing and future research will also need to coordinate with FHWA and FRA to define and enhance these requirements.

4.4.2.2.3 Rail

The railroad industry has not identified any specific short term need for NDGPS. There are several potential applications, however, that might be of benefit to the rail industry over the long term, including positive train control (PTC), an advanced signal and train control system that will deployed on certain portions of the national rail system over the next several years. The systems currently being deployed are not dependent upon the availability of NDGPS. If GPS and augmentation systems such as NDGPS and the new HA-NDGPS signal, which is currently being tested and validated, are part of the future PNT infrastructure, designers of PTC enhancements would certainly consider using these capabilities. NDGPS, however, is not required for the successful implementation of Positive Train Control.

4.4.2.2.3.1 Positive Train Control (PTC):

NDGPS might aid the development of some PTC system designs by providing an affordable and reliable location determination system with ubiquitous coverage throughout the contiguous United States and along the Alaska Railroad. In order to meet PTC accuracy requirements, the baseline distance to the NDGPS reference stations would have to be no more than 150 miles. Due to planned maintenance and occasional outages of NDGPS reference stations, dual coverage would be needed to meet the availability requirement of 99.9%.

Railroads and their suppliers have evaluated their requirements for train location 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 (INS), accelerometers, and other devices and techniques would 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.

4.4.2.2.3.2 Other Potential Uses

Railroad operations and infrastructure development and maintenance have a wide range of locational and timing needs including surveying and mapping, track defect location, weather forecasting and high capacity communications. While the rail industry has not identified any specific requirement for NDGPS to meet these needs in the short-term, to the extent that the future includes NDGPS in the national PNT infrastructure, it can be reasonably expected that NDGPS-dependent systems will be considered for meeting such needs.

4.4.2.3 Other Land User Requirements

Agriculture and natural resources applications account for many civil applications of positioning and navigation. 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. Requirements for signal sensitivity in compromised topography and foliage, functionality in harsh environment conditions, and processing efficiency to promote longer duration of usage are all more acute requirements considerations for individual users constrained to hand held devices. Requirements for non-transportation land users are to be found in Table 4-9.

Table 4-9 Other Land User Requirements

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS					
	ACCURACY (meters, 2 drms)	AVAILABILITY	CONTINUITY	INTEGRITY	TIME TO ALERT	COVERAGE
Agriculture Applications	TBD	TBD	TBD	TBD	TBD	TBD
Natural resources	TBD	TBD	TBD	TBD	TBD	TBD

4.5 Sub-surface PNT User Requirements

4.5.1 Marine User Requirements

Subsurface marine PNT users consist of naval submariners, off shore oil exploration, deep sea salvage, trans-oceanic cabling, deep sea fishing, and even recreational SCUBA divers. The positioning and timing requirements vary drastically depending on the application. Submarines use PNT for navigating the ocean floor and deployment of weapon and intelligence gathering systems. Oil exploration PNT needs support the operation of remotely operated vehicles, installation of maritime structures and seabed mapping, bathymetric surveys, submarine equipment installation, well drilling location selection, pipeline installation, and spools metrology. The subsurface environment makes practical employment of traditional PNT sensors and systems, such as GPS, more of a challenge. Subsurface marine users typically rely on systems more adept to this milieu, such as sound navigation and ranging (SONAR), compasses, and water pressure sensors, but research may lead to development of systems such as underwater GPS pseudolites. Requirements for sub-surface marine users can be found in Table 4-10.

Table 4-10 Sub-surface Marine User Requirements

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS					
	ACCURACY (meters, 2 drms)	AVAILABILITY	CONTINUITY	INTEGRITY	TIME TO ALERT	COVERAGE
Sub Surface Marine Applications	TBD	TBD	TBD	TBD	TBD	TBD

4.5.2 Land User Requirements

Subsurface land users include mining operations, oil exploration, underground construction, utility engineering, security robotics, and positioning of seismic activity. Subsurface applications typically require a great deal of accuracy. Requirements for sub-surface land users can be found in Table 4-11.

Table 4-11 Sub-surface Land User Requirements

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS					
	ACCURACY (meters, 2 drms)	AVAILABILITY	CONTINUITY	INTEGRITY	TIME TO ALERT	COVERAGE
Subsurface Land Applications	TBD	TBD	TBD	TBD	TBD	TBD

4.6 Other PNT Applications and Requirements

The use of PNT 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 4.6.6, can be grouped under the following seven broad headings:

- Geodesy and Surveying;
- mapping, charting;
- Geographic Information Systems (GIS);

- agriculture and natural resources applications (already addressed in 4.4.2.3);
- 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 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 1370 stations, including the NDGPS stations belonging to USCG, DOT, and U.S. Army Corps of Engineers (USACE), and the WAAS stations belonging to FAA.

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. Many high-accuracy (few centimeters) geodetic and surveying activities involve differencing techniques using the carrier phase observable. Single receiver positioning software can now produce sub-decimeter point positioning accuracy.

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-decimeters to few-meters 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.

A similar application is made by hydrographic survey vessels for position and attitude determination for multi-beam survey systems. Also, 3-D GPS hydrographic surveys are now being conducted to relate seafloor height to the WGS 84 ellipsoid. Water depth locations will eventually be related to both the low water tidal datum and height of seafloor above the WGS 84 ellipsoid, which will allow systems to alarm for shoal waters/obstructions without application of tides.

4.6.3 Geographic Information System (GIS) Applications

GIS applications support recording, planning, analysis, and information output for diverse applications that include natural resource applications, demographics, site planning, archeology, transpiration routing, and many others. 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 the 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.

4.6.4 Geophysical Applications

The ability of GPS carrier phase observations to provide centimeter-level differential positioning on a regional and worldwide basis has led 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.

4.6.5 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, 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 recent termination 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.

4.6.6 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.

4.6.7 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 4-13 and lie in the few-millimeters to few-meters 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 4-12 Surveying, Timing, and Other Applications User Requirements

(a) Surveying

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS						
	ACCURACY (meters, 2 drms)		AVAILABILITY	CONTINUITY	INTEGRITY (Observing Session Duration)	Recording Interval	COVERAGE *
	Horizontal	Vertical					
Static Survey *	0.015	0.04	99%	$1\text{-}1\times10^{-4}$/hr to $1\text{-}1\times10^{-8}$/hr	4 hr	30 s	Global
Rapid Survey *	0.03	0.08	99%	$1\text{-}1\times10^{-4}$/hr to $1\text{-}1\times10^{-8}$/hr	15 min	30 s	Global
Kinematic Survey **	0.04	0.06	99%	$1\text{-}1\times10^{-4}$/hr to $1\text{-}1\times10^{-8}$/hr	Two 3-min sessions separated by 45 min	1 s	Global
Hydrographic Survey ***	3	0.15	99%	$1\text{-}8\times10^{-6}$/15 s	1 s	1 s	Global

* Using OPUS-S
** Using real-time GNSS networks
*** IHO Standards for Hydrographic Surveys are published in IHO publication S-44, which can be obtained gratis from the publication section at www.iho.int

(b) Timing and Other Applications

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS					
	ACCURACY (Time with respect to UTC)	AVAILABILITY	CONTINUITY	INTEGRITY	TIME TO ALERT	COVERAGE
Financial transaction timestamp	1 s					Worldwide
Electric power transmission	1 µs					North America
Cellular telephony	1 µs	Outages not to exceed 8 hr				North America
Inter-carrier telephone and data networks	1 µs					North America
Scientific community	nanoseconds					Worldwide

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 cm or better) 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, station and satellite clock corrections, Earth orientation parameters, and 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 the 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. GPS reference station requirements for non-navigation users are 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 to upgrade equipment. Also, if user equipment and software are 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 reference 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 PNT 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 PNT systems to meet future user requirements. Thus, the plan provides the framework for operation, development, and evolution of systems.

5.1 Global Positioning System

GPS is a dual-use, space-based PNT 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 GPS SPS PS (Ref. 34) available on the USCG Navigation Center website: http://www.navcen.uscg.gov.

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 SPS PS (Ref. 34).

Coordination of planned interference testing activities nominally begins 60 days before testing events. Users are notified by 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 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 PNT 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 baseline 24-satellite constellation. The September 2008 SPS PS provides for an expandable 24-slot constellation that DoD is currently implementing, since adequate satellites are projected to be available. The constellation will be contracted back to the baseline 24 slots if the additionnal satellites are no longer available to support the specific expanded slots.

5.1.1 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 receivers that are compliant with *Navstar GPS Space Segment/Navigation User Interfaces*, Interface Specification (IS-GPS-200) (Ref. 51), 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 is introducing three additional coded civil signals to the existing civil signal, L1 C/A, to support future civil applications:

- L1C, frequency 1575.42 MHz, to provide better performance than the current C/A signal being used by civilian receivers. This signal is being adopted by foreign providers and users as an international standard;
- L2C, frequency 1227.6 MHz to support dual frequency civil PNT; and

- L5, frequency 1176.45 MHz, to support dual frequency PNT that meets the needs of critical safety-of-life applications, such as civil aviation.

In addition, a secure and spectrally separated military M-Code will be broadcast on the L1 and L2 frequencies. The first launch of an L2C capable satellite (GPS Block IIR-M) was in 2005, and the first satellite with operational L5 capability (GPS Block IIF) was launched in May 2010. Twenty-four L2C capable GPS satellites are projected to be on orbit by approximately 2017, and 24 GPS L5 capable satellites are projected to be on orbit by approximately 2019. Providing these 2nd and 3rd frequency civilian signals will allow dual frequency civilian users to directly compensate for ionospheric effects and thus achieve greater accuracy than previous reliance on a single frequency capability. These additional signals will also foster the development of tri-frequency GPS applications. The first launch of an L1C capable satellite (GPS Block III) is projected for 2014.

As published in FRN Vol. 73 No. 185 (Ref. 37), 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.

5.1.2 Plans for Mitigating Disruptions to GPS

Like all radio-based services, GPS is subject to interference from both natural and human-made sources. For this reason, USG strongly encourages all GPS users to maintain backup capabilities for PNT. The following paragraphs discuss sector specific mitigation and backup capabilities. In accordance with NSPD-39 (Ref. 12), the Secretary of Transportation, in coordination with the Secretary of Homeland Security, is responsible for the development, acquisition, operation, and maintenance of backup PNT capabilities that can support critical transportation, homeland security, and other critical civil and commercial applications.

5.1.2.1 Mitigating Disruptions in NASA Applications

Navigation for launch vehicles is provided by an INS using multiple redundant Inertial Measurement Units (IMU) and GPS receivers. IMU measurements are considered primary, so a disruption to GPS service does not critically affect navigation.

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

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 space vehicle re-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 Kennedy Space Center, FL; Edwards Air Force Base, CA; and White Sands Space Harbor, 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.

To meet safety-of-life requirements, human spaceflight retains ground and space-based tracking via the NASA networks and ground-in-the-loop processing. 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 in conjunction with 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.

5.1.2.2 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, FAA is committed to delivering satellite-based PNT 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 PNT receivers. 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. Ionospheric anomalies may cause periodic outages of LPV approach capability using WAAS until an L5-capable GPS constellation is available.

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 an alternate means of navigation in the event of a GPS outage, several other solutions have been identified to help mitigate the effects of a satellite navigation (SATNAV) service disruption:

- 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 PNT position updating depending on the route or procedure being flown. In some cases, this capability may prove adequate to depart an area with localized interference, or alternatively the flight can proceed under visual flight rules in appropriate weather conditions, however, inertial performance without PNT updates degrades with time and will eventually fail to meet airspace requirements.

- Integrated GPS/inertial avionics, as well as improvements in antennas and algorithms, could provide increased interference resistance, effectively reducing the area affected by GPS jamming or unintentional interference. Industry research is proceeding to enhance these technologies, with an expectation that they might be marketed to a broader cross section of the aviation community at some point in the future.

- FAA is currently developing requirements and recommendations for future alternative PNT solutions that address mitigations for GPS disruptions.

5.1.2.3 Mitigating Disruptions in Maritime Operations

USCG has identified two critical maritime applications:

- inland waterway and harbor entrance and approach; and

* 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.

- timing and synchronization (maritime AIS standard).

For the most part, mariners practice conventional navigation, and employ a variety of shipboard and external systems such as GPS, DGPS, shipboard radar, visual aids to navigation, fathometers, paper and electronic charts, 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.

5.1.2.4 Mitigating Disruptions in Land Operations

Surface transportation users currently use PNT services from GPS and its augmentations to supplement other available non-space-based PNT systems. Under this operational paradigm, users seamlessly use other 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 PNT 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.

5.1.2.5 Mitigating Disruptions in Railroad Operations

The FRA 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 INS, 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.

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.

5.1.2.6 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 backup options that could meet the accuracy requirements of these applications, depending on the capabilities and preparation of these operators.

5.2 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. Augmentations alone provide no service if the GPS civil signal itself is unavailable.

5.2.1 Wide Area Augmentation System (WAAS)

WAAS, an SBAS operated by FAA, provides improved navigation accuracy, availability, integrity, and continuity 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 supports advanced capabilities such as RNP arrival and departure procedures with radius-to-fix (RF) legs (curved and segmented paths), more efficient en route navigation and parallel runway operations, 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.

5.2.2 Local Area Augmentation System (LAAS)

LAAS is a GBAS developed by FAA 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 augments GPS by providing local differential corrections to users via a VHF data broadcast. In the future, LAAS may allow suitably equipped aircraft to conduct precision approaches at other airfields in the vicinity of "LAAS-equipped" airfields. After completion of planned development activities, it will also allow suitably equipped aircraft to conduct curved approaches and segmented approaches. LAAS is also being developed with the intent to provide positioning service with high integrity to potentially support more efficient capabilities, such as parallel runway operations, and airport surface operations.

A major milestone was reached by FAA in September 2009 with the system design approval of the first non-federal LAAS certified by FAA for CAT I precision approaches. Facility and service approvals for the implementation of the system are currently underway at Memphis, TN and Newark, NJ International Airports in joint efforts with two participating airlines. Additional contributions for LAAS, as a NextGen enabling technology, are being explored in areas such as closely spaced parallel runway operations and wake turbulence avoidance. DoD is also leveraging the LAAS system design and certification experiences to facilitate development of the Joint Precision Approach and Landing System (JPALS).

FAA is currently conducting research and is in the process of developing requirements and standards for a LAAS CAT II/III precision approach capability. FAA expects to make an investment decision on the federal procurement of CAT II/III systems by 2012.

5.2.3 Joint Precision Approach and Landing System (JPALS)

The JPALS program is a DoD joint program with Tri-Service partners for acquisition of JPALS.

JPALS is a GPS-based precision approach and landing system that will replace several aging and obsolete aircraft landing systems with a Family of Systems (FoS) that is more affordable and will function in more operational environments, and support all DoD land and sea based applications. The U.S. National Defense Strategy calls for highly mobile forces that can rapidly respond to crises worldwide. Success in meeting this challenge requires the ability to land aviation assets virtually anywhere, at any time. JPALS will provide this capability by being rapidly deployable, survivable, and interoperable among the U.S. Services and with U.S. allies, as well as civil aircraft and landing facilities. JPALS will eventually support unmanned and highly automated aircraft, and will be able to operate during some restricted Emission Control (EMCON) conditions.

For military authorized 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. Sea-based JPALS will utilize a two-way UHF data link between a JPALS equipped ship and landing aircraft. Land-based JPALS will utilize a one-way UHF data link broadcast for precision approach and landing operations in fixed and tactical environments. The land-based JPALS will also provide a civil mode that will broadcast an ICAO Standards and Recommended Practices (SARPS) GBAS-compliant VHF data broadcast.

Sea-based JPALS is currently in the engineering and manufacturing development (EMD) phase with planned initial operational capability (IOC) of 2014. The land-based JPALS is projected to start EMD in 2011 with an IOC date of 2016.

5.2.4 Nationwide Differential GPS (NDGPS)

The NDGPS service augments GPS by providing increased accuracy and integrity 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 USCG, DOT, and USACE, as well as several states, and scientific organizations, all cooperating to provide the combined national DGPS utility, with plans to complete NDGPS system coverage throughout the lower 48 states.

The two major deployment milestones which have been established are nationwide single station coverage and nationwide dual station coverage (CONUS only). Under single station coverage, predicted to occur no earlier than 2012 (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 2014.

5.2.4.1 NDGPS System Recapitalization

USCG completed a recapitalization project in 2009 for the maritime sites. This project extended system life at least 15 years and provided a substantial increase in performance (accuracy and integrity), flexibility, and maintainability. The improvements were 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 has been 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 requested funding in the 2011 President's budget for recapitalization of the inland NDGPS sites, and within DOT, NDGPS recapitalization funding remains a priority.

5.2.4.2 High Accuracy NDGPS (HA-NDGPS)

The HA-NDGPS research program goal is to develop an inexpensive technique to achieve sub-decimeter navigation using existing infrastructure to the maximum extent possible. If added to the NDGPS, this upgrade is expected to provide 2 to 15 cm accuracy and a time to alarm of 1 s throughout the United States. This high-accuracy signal will enable a wide range of new applications that are not currently possible with today's NDGPS signal. DOT is in the process of fully identifying and documenting requirements which could lead to an investment decision.

Development began in 2001 with the implementation of a single site near Hagerstown, MD. Over the next two years, two additional sites were developed. All three are considered pre-prototype sites and are being used to further develop the broadcast algorithms and to determine appropriate data needed to support sub-decimeter navigation. This stage includes development of atmospheric delay models and determining data rates. Early successes in achieving the sub-decimeter accuracy for navigation are documented in the Phase I (http://www.tfhrc.gov/its/ndgps/02110/index.htm) and Phase II (http://www.tfhrc.gov/its/pubs/05034/) research reports.

The current approach focuses on required data compression to broadcast, each epoch, all code and carrier observables for L1 and L2 for up to 12 satellites in 1000 bits. Early testing indicates this is as much as 10 times faster than needed and provides enough capacity to include additional data such as the ionospheric and tropospheric models, additional GPS downlinks, and additional GNSS downlinks.

The program is currently focused on documenting modifications to NDGPS facilities to support test site deployment at up to three additional locations. These additional locations will support testing for surface users in diverse terrain and applications. The goal of this additional testing is to document signal availability in diverse environments, to analyze the ability to meet accuracy requirements for specific applications, and to begin to quantify benefits to various user groups.

5.2.4.2.1 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 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 PNT 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 and NOAATrop have been shown to provide atmospheric signal delay correctors with significantly improved accuracy and reliability. These models are being evaluated for their feasibility in creating differential correction messages for broadcast to help resolve carrier phase ambiguities over long baselines.

5.2.4.2.2 Increased Data Throughput for Broadcast of GPS Observables

Initial data broadcast from the pre-prototype sites included all code and carrier observables for L1 and L2 from all visible satellites. With the data compression used on these sites, it was feasible to compress these data to less than 200 bps and still broadcast all observables every epoch. The channel capacity with the prototype modulator was 1000 bps. Testing indicted that sending all observables every epoch was more than needed, but easily ensured data were received by the end user in a timely manner. Data compression for the NOAATrop and USTEC has been examined and preliminary analysis indicates acceptable compression techniques are available to compress these data into the same data stream as the GPS observables while maintaining the 1000 bps data rate.

5.2.4.2.3 Future Explorations for HA-NDGPS

While testing demonstrates that sub-decimeter accuracy can be obtained with observables, additional enhancements can be explored that will aid in faster acquisition and reduced integer resolution times. Methods to be explored include:

- improved "post SA" reference station correction generation algorithms that increase accuracy for code only solutions,
- improved integrity monitoring processes that reduce user vulnerabilities,
- differential corrections that enable use of WAAS pseudo-ranges in HA-NDGPS position solutions,
- enhanced beacon almanacs that enable users to intelligently select the best beacon by signal specification,
- network distribution of correction data between adjacent beacon sites, and
- distribution of precise orbit data over the HA-NDGPS data link.

5.3 Long Range Navigation (Loran)

5.3 Loran-C

Pub. L. 111-83 (Ref. 35) allowed for termination of the Loran-C signal on January 4, 2010, after certification from the Commandant, USCG, that it was not needed for maritime navigation, and from the Secretary of Homeland Security that it was not needed as a backup for GPS. These certifications were completed in December 2009.

USCG published in the Federal Register, Volume 75, Number 4, January 7, 2010, Page 998 (Ref. 52), the intention to terminate transmission of the Loran-C signal February 8, 2010. In addition, a Loran Programmatic Environmental Impact Statement Record of Decision stating that the environmentally preferred alternative is to decommission the Loran-C Program and terminate the North American Loran-C signal was published in the Federal Register, Volume 75, Number 4, January 7, 2010 Pg. 997 (Ref. 53).

After publication of these documents, USCG began strongly urging mariners who were using Loran-C for navigation to shift to a GPS navigation system and become familiar with its operation as soon as possible.

In accordance with the DHS Appropriations Act, USCG terminated the transmission of all U.S. Loran-C signals on February 8, 2010. At that time, the U.S. Loran-C signal became unusable and permanently discontinued. The USCG transmission of the Russian-American Loran-C/Chayka signal was terminated on August 1, 2010. The USCG transmission of the Canadian Loran-C signals was terminated on August 3, 2010. Termination of these International transmissions was delayed until August 2010 to allow time to negotiate termination of the corresponding International Agreements.

5.4 Instrument Landing System (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.

ILS localizers share the 108-111.975 MHz portion of the 108-117.975 MHz ARNS band with VOR. 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 air-to-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. 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 ILS have been decommissioned.

ILS glide slope subsystems operate in the 328-335.4 MHz UHF band. The inherent physical characteristics of this band, like those of the 108-111.975 MHz VHF 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.

ILS marker beacons operate in the 74.8-75.2 MHz VHF 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.

5.5 VOR, DME, and TACAN

5.5.1 Very High Frequency (VHF) Omnidirectional Range (VOR)

VOR provides a bearing from an aircraft to the VOR transmitter. The current VOR services will be maintained at their current level 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, not earlier than 2011, which 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. VOR 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. Select VOR stations also broadcast weather information or air traffic communications.

As noted in Section 5.4, several potential aeronautical applications of the 108-117.975 MHz VHF band are being investigated for possible implementation after VOR has been partially decommissioned.

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.

5.5.2 Distance Measuring Equipment (DME)

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.

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. FAA plans 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. Continued use of a substantial portion of the 960-1215 MHz ARNS band will be required to support DME.

The DoD 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 PNT systems to other aircraft and to the ground Air Navigation Service Provider (ANSP) network.

5.5.3 Tactical Air Navigation (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 TACAN and two mobile VORTAC 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.

5.6 Nondirectional Beacons (NDB)

NDB 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 NDB. 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 NDB as users equip with GPS. NDB 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 NDB that define low-frequency airways in Alaska or serve international gateways and certain offshore areas like the Gulf of Mexico will be retained.

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. Marine radiobeacons have been phased out.

5.7 Microwave Landing System (MLS)

MLS is an all-weather, precision landing system originally intended to replace or supplement the ILS. MLS has a number of operational advantages, including a wide selection of channels to avoid interference with other nearby airports, excellent performance in all weather, and a small footprint at the airports.

Although some MLS systems became operational in the 1990s, the widespread deployment initially envisioned by its designers never became a reality. GPS-based systems, notably WAAS, allowed the expectation of the same level of positioning detail with no equipment needed at the airport. GPS/WAAS dramatically lowers the cost of implementing precision landing approaches, and since its introduction most existing MLS systems in North America have been turned off.

FAA and the rest of the civil aviation community are investigating potential aeronautical applications of the 5000 – 5150 MHz C-band for implementation because it is estimated by many that portions of this 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;

- An airport local area network, called AeroMACS, a 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. AeroMACS plans to use the 5000-5030 MHz and the 5091-5150 MHz C-bands;

- Future Unmanned Aircraft System (UAS) functions to be implemented in the 5030-5091 MHz C-band; and

- The 5091-5150 MHz C-band is used for transmitting flight test telemetry data from aircraft to ground.

5.8 Aeronautical Transition Plan

Table 5-1 summarizes the current navigation infrastructure and services in the NAS.

Table 5-1 Navigation Infrastructure Elements and Services

Operational Services		Supporting Systems/Infrastructure			
		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 & 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**	GPS, SBAS	Inertial (as part of a multi-sensor system)	N/A
	Arrival and Departure	DME/DME** VOR/DME**	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)	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., 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

5.8.1 Transition to Satellite-based PNT

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);

- SBAS, such as WAAS; and
- GBAS, such 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.

5.8.2 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) and RNP 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 PNT equipment. Required mitigations to terrain and obstructions, as well as airport improvements, are unchanged from ILS-based precision approach operations. LAAS supports precision approach operations to multiple runway ends at an airport. LAAS may eventually contribute to a higher acceptance rate than ILS, but mixed usage must be accommodated during transition.

5.9 Timing Plan

5.9.1 NIST Timing Plan

NIST will continue to operate and maintain its time dissemination services in the foreseeable future. Status and changes will be documented at http://tf.nist.gov/. Users of the Internet Time Service are advised to check periodically for the establishment of new time servers, or for servers that change IP address due to Internet growth and reconfiguration. An additional server for the Automated Computer Time Service (ACTS) is under development to provide increased operational robustness. Users of the ACTS service are advised to check periodically for an announcement of alternative telephone numbers.

5.9.2 USNO Timing Plan

USNO disseminates time via various mediums; these include GPS, Two-Way Satellite Time Transfer (TWSTT), Network Time Protocol (NTP), and telephone voice announcers.

5.9.2.1 GPS Time Transfer

GPS time transfer is the optimum means of globally obtaining precise time at the nanosecond level (see paragraph 3.2.5 for more information).

5.9.2.2 Two-Way Satellite Time Transfer

Time transfer via TWSTT provides comparison and synchronization to remote precise time stations and international timing centers with DoD time standards provided by the USNO Master Clock, UTC. Time transfers take place via commercial (Ku-band, 11-14 GHz), geostationary, and DoD Defense Satellite Communications Systems (DSCS) (X-band, 7-10 GHz) satellites between fixed and portable time transfer stations. Time transfer accuracy is 1 ns and coverage is provided among remote sites worldwide.

5.9.2.3 Network Time Protocol

Computer network time synchronization is a system of distributed network time servers that provide an accurate and reliable time synchronization service for computers on the Internet (Tick or Tock) and the Secret Internet Protocol Router Network (SIPRNet). The protocol provided by this system is Internet RFC-1305 (NTP) Version 3. This protocol provides mechanisms to synchronize time and to coordinate time distribution by computer on the worldwide Internet. Network time transfer is achieved by robust estimation between remote systems of clock offset, network delays, and network dispersion. Network time synchronization over the non-deterministic Internet is maintained at the millisecond level and coverage is worldwide.

5.9.2.4 Telephone Time Voice Announcer

The USNO Telephone Time Voice Announcer produces an audible tick every second from the USNO Master Clock and announces the time every 10 seconds. The time is announced in both local time and UTC. The USNO operates two time announcers; one in Washington, D.C., and one at the USNO Alternate Master Clock (AMC) in Colorado Springs, CO. Time dissemination accuracy is 1 second and can be accessed worldwide.

Chapter 6

National PNT Architecture

PNT is integral to U.S. national security, infrastructure, and prosperity; however, in most cases its role is not obvious. From a national economic perspective, PNT plays a critical role in the operation of transportation, communications, power distribution networks, emergency response operations, and other critical infrastructures. In terms of national security, PNT is vital to command, control, and communications capabilities and to all forms of precision operations such as locating targets, delivering weapons on target, and providing logistical support.

The National PNT Architecture highlights the importance of the supporting infrastructure necessary to implement and maintain future PNT services, addresses capability gaps projected to exist in the 2025 timeframe, and articulates recommended initiatives to close those gaps (or mitigate their effects). It does this by guiding future PNT capabilities that will sustain U.S. military, civil, and scientific activities through the mid-21st century or longer; motivating studies, analyses, and assessments for the development, demonstration, and implementation of PNT technology; and providing a coordinated framework to inform USG investment decisions regarding PNT. The National PNT Architecture will evolve from the current “As Is” PNT Architecture to the desired “Should Be” PNT Architecture.

The “As Is” PNT Architecture is the current de facto architecture consisting of an ad hoc mix of dependent and autonomous PNT sources as well as augmentations that provide PNT to civil and military users operating in space, air, land, and maritime environments. PNT services are supported by a large number of PNT-enabling capabilities and infrastructure, and are provided in environments with spectrum, weather, fiscal, and geo-political challenges. The “As-Is” PNT Architecture is characterized by widespread use of the GPS, government-provided GPS augmentations optimized for different user groups, for-profit commercial GPS augmentations, and non-space based systems that provide PNT services. These developments have greatly improved PNT capability over the past several decades, but the USG believes significant capability gaps are developing and will continue to grow since they are not fully addressed by the “As Is” PNT Architecture. [Reference report]

The “Should Be” National PNT Architecture enhances U.S. leadership in global PNT by promoting a “Greater Common Denominator” strategy, where the core needs of many users are efficiently met through commonly-available solutions, rather than by numerous, individually-customized systems. The strategy will be implemented through four vectors: PNT sources based on multiple phenomenologies; the ability to integrate data from different PNT sources into a single, common PNT solution; the synergy of communications and PNT capabilities, and the development of cooperative organizational structures.

6.1 Vision

The National PNT Architecture vision anticipates that the United States will maintain leadership in global PNT by efficiently developing and fielding effective PNT capabilities that are available worldwide. The U.S. can achieve this vision by implementing the following practices:

- Enabling commercial sector innovation and advancement of government-provided PNT capabilities by developing and adhering to stable policies that will build domestic and international credibility with respect to commitments to funding, performance, advanced notice of change, etc.

- Providing PNT capabilities in a coordinated manner, sharing information, and presenting a unified view of National objectives by promoting inter-agency cooperation across the full scope of PNT activities.

- Maximizing the practical use of military, civil, commercial and foreign systems and technologies, and leading the effort to integrate available signals to achieve assured higher-performing PNT solutions.

- Developing and applying comprehensive standards and best practices, while encouraging others to adopt or align with U.S. capabilities.

- Encourage the adoption of U.S. developed standards and best practices through comprehensive development and application.

6.2 Strategy

The “Greater Common Denominator” strategy is expected to make greater common core capabilities available to an unlimited number of users around the globe while addressing the uniquely stressing needs of a few users through custom solutions. The strategy therefore calls for the development of autonomous capabilities that balance the need for a national security advantage with the advantages inherent in providing greater common capabilities, in accordance with national policies.

6.3 Architectural Vectors

The vision and strategy are supported by four vectors, which together constitute the guiding principles of the National PNT Architecture:

1. Multiple Phenomenologies – Use multiple phenomenologies to the maximum extent practical to ensure robust availability.
2. Interchangeable Solutions – Strive for interchangeable solutions to enhance efficiency and exploit source diversity.
3. Synergy of PNT and Communications – Pursue, where appropriate, fusion of PNT with new and evolving communications capabilities.
4. Cooperative Organizational Structures – Promote interagency coordination and cooperation to ensure the necessary levels of information sharing.

6.3.1 Multiple Phenomenologies

Multiple phenomenologies refer to diverse physical phenomena such as radio frequencies, inertial sensors, and scene mapping, as well as diverse sources and data paths using those physical phenomena (e.g., multiple radio frequencies) to provide interchangeable solutions to the user; it also addresses 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. The National PNT Architecture promotes the use of multiple phenomenologies to ensure robust availability and to address the capability gaps.

6.3.2 Interchangeable Solutions

Interchangeable solutions refer to the ability to combine signals from multiple data sources into a single PNT solution, as well as the ability to provide a solution from an alternative source when a primary source is not available. It presumes a leadership role by the U.S. in international forums as part of the effort to establish clear, reasonable standards to enable efficient, effective exploitation of diverse PNT data sources. The National PNT Architecture promotes interchangeable solutions to provide the flexibility needed for timely, accurate, and reliable PNT solutions that meet user needs regardless of the data sources available.

6.3.3 Synergy of PNT and Communications

Data communications networks can support PNT capabilities by providing PNT aiding and augmentation data, geospatial information, etc. The National PNT Architecture leverages users' increasing connectivity to more capable communications networks in order to use those networks 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 (e.g., wireless networks), in ways which will benefit both technologies , and in particular, which will enable increased PNT robustness by providing PNT data sources outside of the traditional radionavigation spectrum.

6.3.4 Cooperative Organizational Structures

The effective implementation of the National PNT Architecture and subsequent architecture development efforts require interagency coordination and cooperation. This vector better enables coordination between the responsible organizations to ensure effective operations, efficient acquisition (for both data source equipment and user equipment), and relevant science and technology application development. This vector also incorporates an enterprise-level PNT modeling and simulation capability to benefit, for example, mission planning and user equipage decisions.

6.4 Transitioning to the Future

The process for transitioning from the "As-Is" Architecture to the "Should-Be" Architecture involves systematic implementation of the recommendations associated with the architecture vision, strategy, and vectors identified in the architecture development phase and refined during transition planning. The product of transition planning, the National PNT Architecture Implementation Plan, can be viewed as an evolving structure that encompasses many separate but interrelated plans, system capabilities, standards, and policies. A step in this evolution will be to help the PNT community understand the relationship of Federal PNT systems plans and policies beyond those covered by radionavigation systems through a continued effort to document the National PNT enterprise in a series of architectural framework products. Developing these products and implementing the plan requires a strong and continued commitment of the PNT community stakeholders who have developed the plan. The processes that coordinate stakeholder activities will likely need to evolve as the implementation of the PNT architecture progresses and the PNT architecture itself continues to evolve.

Appendix A

System Parameters and Descriptions

A.1 System Parameters

Systems described in Section A.2 are defined below in terms of system parameters that determine the use and limitations of the individual PNT system's signal-in-space. These parameters are:

- Signal Characteristics
- Accuracy
- Availability
- Coverage
- Integrity
- Reliability
- Ambiguity
- Fix Dimensions
- Fix Interval
- Spectrum
- System Capacity

A.1.1 Signal Characteristics

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

A.1.2 Accuracy

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

Statistical Measure of Accuracy

PNT 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% confidence level will be used. Vertical or bearing accuracies will be specified in one-dimensional terms, 95% confidence level (2 sigma).

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%; as the error ellipse becomes circular, the confidence level approaches 98%. The GPS 2 drms accuracy will be at 95% 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%. In the past, DoD had specified horizontal accuracy in terms of Circular Error Probable (CEP – the radius of a circle containing 50% 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 PNT system accuracy generally refer to one or more of the following definitions:

- Predictable accuracy: The accuracy of a PNT 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 PNT system.
- Relative accuracy: The accuracy with which a user can measure position relative to that of another user of the same PNT system at the same time.

A.1.3 Availability

The availability of a PNT 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 PNT signals transmitted from external sources are available for use. It is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities.

A.1.4 Coverage

The coverage provided by a PNT 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.

A.1.5 Reliability

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

A.1.6 Fix Interval

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

A.1.7 Fix Dimensions

This characteristic defines whether the PNT 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 PNT signals is also included.

A.1.8 System Capacity

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

A.1.9 Ambiguity

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

A.1.10 Integrity

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

A.1.11 Spectrum

Spectrum describes the range of operating frequencies for a given PNT system. FAA, DoD, and USCG require spectrum as providers and operators of PNT systems.

A.2 System Descriptions

This section describes the characteristics of those individual PNT systems currently in use or under development. These systems are described in terms of the parameters previously defined in Section A.1. All of the systems used for civil navigation are discussed. The systems that are used exclusively to meet the special applications of DoD are discussed in the CJCSI 6130.01D (Ref. 1).

A.2.1 Global Positioning System (GPS)

GPS is a space-based dual use PNT 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.

GPS has three major segments: space, control, and user, as depicted in Figure A-1. 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), at an altitude of approximately 20,200 km (10,900 nmi), and at an inclination angle of 55 deg, 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.

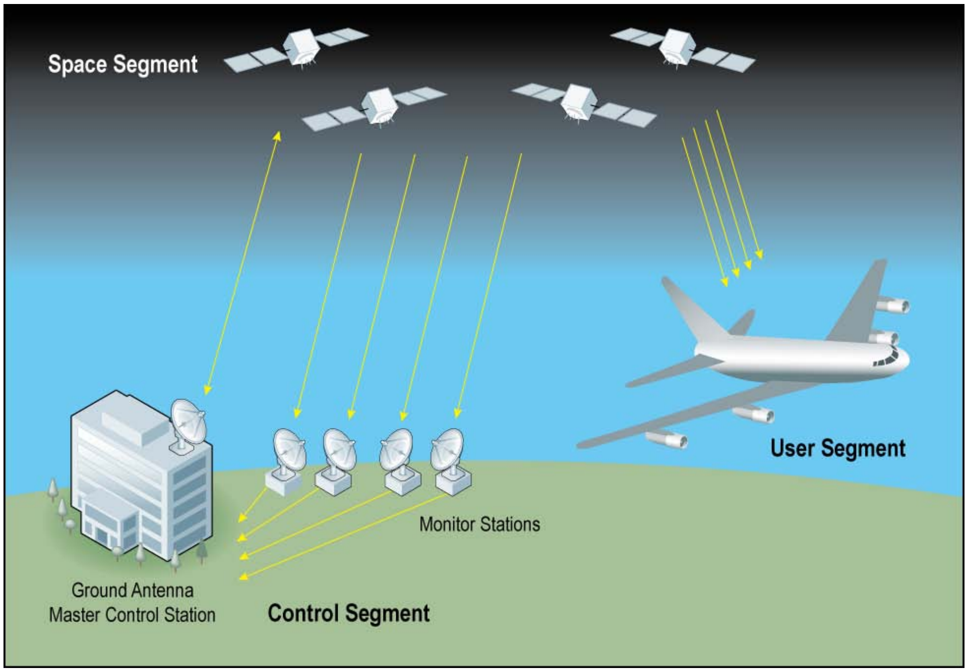

Figure A-1 GPS Architecture

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.

Table A-1 GPS/SPS Characteristics

SPS ACCURACY (meters) 95%* PREDICTABLE	SERVICE AVAILABILITY	COVERAGE	SERVICE RELIABILITY**	FIX RATE	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
Horz ≤ 9 Vert ≤ 15 Time ≤ 40 ns	99%	Terrestrial Service Volume	1-1x10^{-5}/hr/SIS	1 – 20 per sec	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.

The characteristics of GPS are summarized in Table A-1. Further details on the performance of GPS SPS may be found in the GPS SPS PS (Ref. 34).

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 have begun broadcasting additional signals as described 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 1563.42 to 1587.42 MHz L-band. 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 min. Within this 12.5 min repeat cycle, satellite clock and ephemeris data for the transmitting satellite are sent 25 separate times so they repeat every 30 s. 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 hr). The receiver will update these data whenever the satellite and ephemeris information are updated - nominally once every 2 hr.

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.

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%) horizontally and 15 m (95%) vertically and time transfer accuracy within 40 ns (95%) of UTC. For more detail, refer to the GPS SPS PS (Ref. 34).

C. Availability

The SPS provides a global average availability of 99%. Service availability is based upon the expected horizontal error being less than 17 m (95%) and the expected vertical error being less than 37 m (95%). 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 SIS 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 > $1\text{-}1\text{x}10^{-5}$/hr.

F. Fix Interval

The fix interval is essentially continuous, but the need for receiver processing to retrieve the spread-spectrum signal from the noise results in an effective user fix interval 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 hr. 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 three L-band frequencies: L1 in the 1559-1610 MHz ARNS/RNSS band, L2 in the 1215-1260 MHz band, and L5, centered at 1176.45 MHz in the 1164-1215 MHz ARNS/RNSS band.

A.2.2 Augmentations to GPS

GPS may exhibit variances from a predicted grid established for navigation, charting, or derivation of guidance information. This variance may be caused by propagation anomalies, accidental perturbations of signal timing, or other factors.

GPS must be augmented to meet the most demanding 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. A receiver at a fixed reference site receives signals from all visible satellites and measures the pseudorange to each. Since the satellite signal contains information on the satellite orbits and the reference receiver knows its position, the true range to each satellite can be calculated. By comparing the calculated range and the measured pseudorange, a correction term can be determined for each satellite. The pseudorange corrections are broadcast and applied to the satellite measurements at each user's location. This method is employed by the USCG MDGPS Service, the NDGPS service, and the FAA LAAS.

The FAA WAAS employs a network of GPS reference/measurement stations at surveyed locations to collect dual-frequency measurements of GPS pseudorange and pseudorange rate for all spacecraft in view, along with local meteorological conditions. These measurements are processed to yield highly accurate ephemeris, ionospheric and tropospheric calibration maps, and corrections for the broadcast spacecraft ephemeris and clock offsets. In the WAAS, these corrections and system integrity messages are relayed to users via dedicated transponders on commercial 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.

A.2.2.1 Wide Area Augmentation System (WAAS)

The WAAS consists of equipment and software that augments the DoD-provided GPS SPS (see Figure A-2). 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.

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.

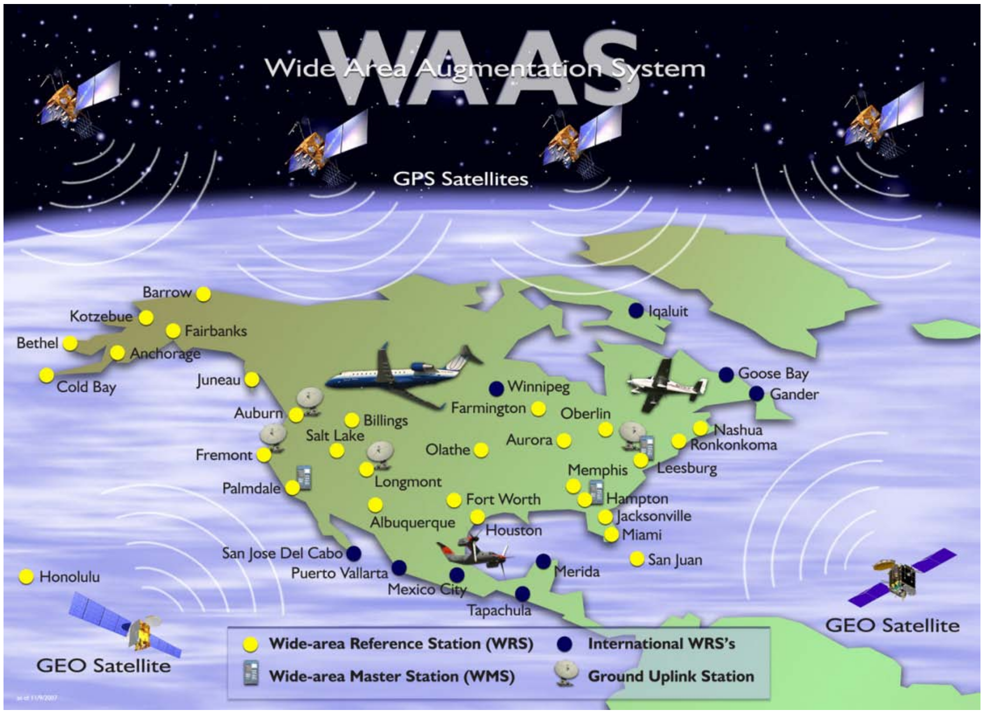

Figure A-2 WAAS Architecture

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%) 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%).

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 deg West or outside of the GEO satellite broadcast area).

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%.

F. Fix Interval

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

* 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.

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 Fault Detection and Exclusion (FDE), the performance values are:

PHMI	10^{-7} per hr
Time to Alert	8 s
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 s
Alert Limit*	Horizontal 40m/Vertical 50 m
Alert Limit**	Horizontal 40m/Vertical 35 m

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.

A.2.2.2 Local Area Augmentation System (LAAS)

The U.S. version of GBAS has traditionally been referred to as LAAS. The worldwide community has adopted GBAS as the official term for this type of navigation system. To coincide with international terminology, the FAA is also adopting the term GBAS to be consistent with the international community. LAAS is a safety critical precision navigation and landing system consisting of equipment to augment the DoD-provided GPS SPS with differential GPS pseudorange corrections (see Figure A-3). It provides 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 provides: (1) local area differential corrections for GPS satellites and for WAAS GEO satellites used as ranging sources***; (2) the associated integrity parameters; and (3) precision approach final approach segment description path points.

* for approaches with ceiling and visibility minimums as low as 250 ft and ¾ mi
** for approaches with ceiling and visibility minimums as low as 200 ft and ½ mi
*** Corrections to WAAS GEO ranging sources are optional for LAAS equipment.

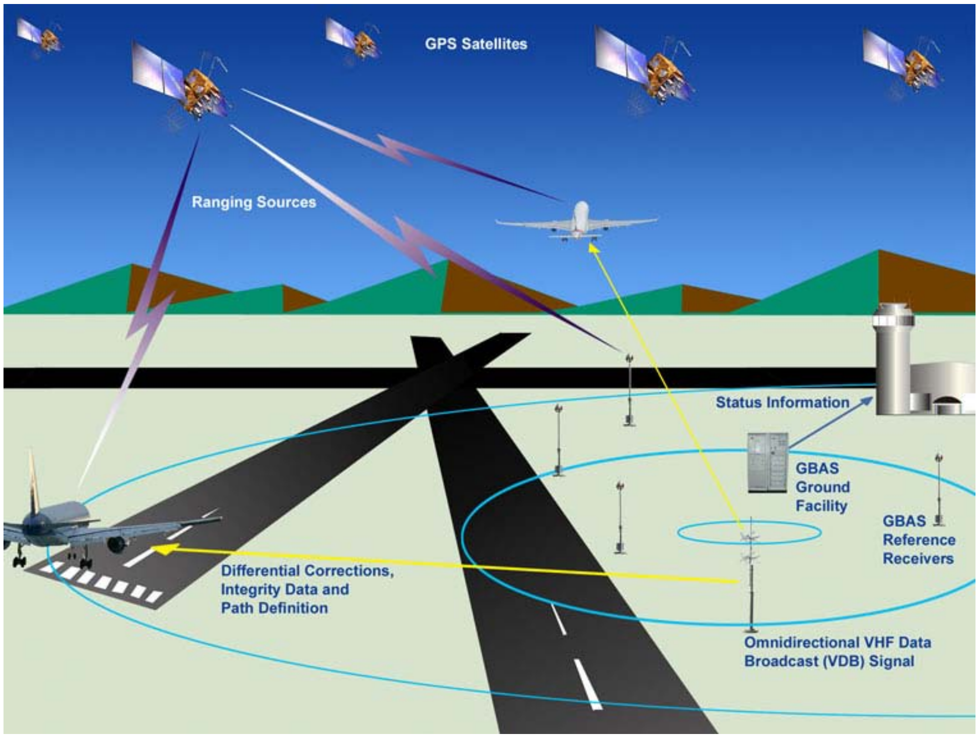

Figure A-3 LAAS Architecture

The LAAS uses 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 collects raw GPS range data from all available range sources that support the navigation service.

The LAAS ground facility (LGF) generates differential correction messages as well as pseudorange correction error parameters for each of the ranging measurements. The LAAS VHF data broadcast transmitter then broadcasts the LAAS DGPS data to users. The VHF 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%. The LAAS CAT I vertical accuracy requirement is 4.0 m, 95%.

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

E. Reliability

Reliability figures have not been developed.

F. Fix Interval

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

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 s. 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 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.

A.2.2.3 Joint Precision Approach and Landing System (JPALS)

JPALS, both sea-based and land-based UHF, is for DoD use and not intended for civil use. Land-based JPALS is intended to include an ICAO SARPS GBAS-compliant civil mode to support civil air operations at military installations. As such, the technical characteristics of the civil functionality in land-based JPALS is as described in Section A.2.2.2 above.

A.2.2.4 Nationwide Differential GPS (NDGPS)

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. Pub. L. 105-66 (Ref. 8) § 346, 111 Stat. 1449, authorizes the Secretary of Transportation to improve and expand the USCG MDGPS into a Nationwide DGPS, or NDGPS, by adding an inland segment. The NDGPS service augments GPS by providing increased accuracy and integrity 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 USCG, DOT, and USACE.

Each NDGPS facility meets all operating parameters established to qualify an 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, NDGPS provides a robust operational backbone to the DOC 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.

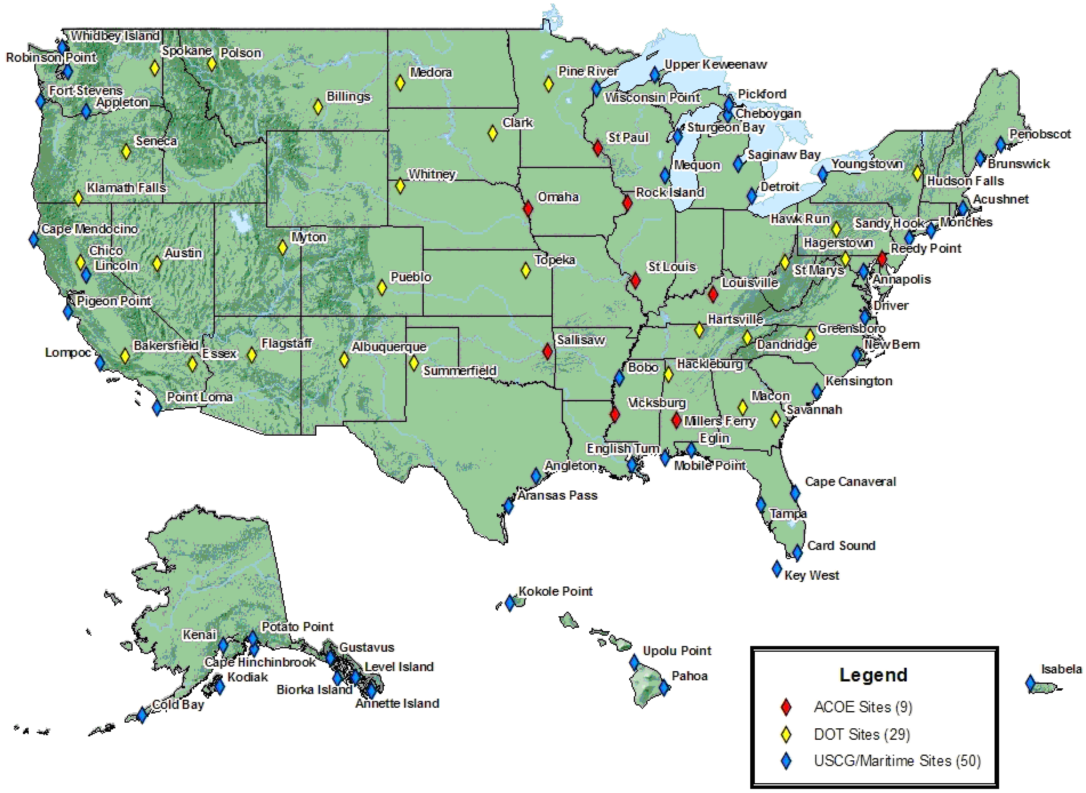

Figure A-4 NDGPS Sites

The NDGPS service, when completed, 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 NDGPS 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).

Today, 50 USCG and 9 USACE broadcast sites make up the MDGPS, and provide coastal coverage of CONUS, the Great Lakes, Puerto Rico, portions of Alaska and Hawaii, and portions of the Mississippi River Basin. DOT sponsors 29 sites in the inland portion of the NDGPS program providing signal coverage over inland surface areas of the U.S. to meet the growing requirements of surface users. These sites are depicted in Figure A-4. The NDGPS network provides single coverage over 92% and dual coverage over 65% of CONUS.

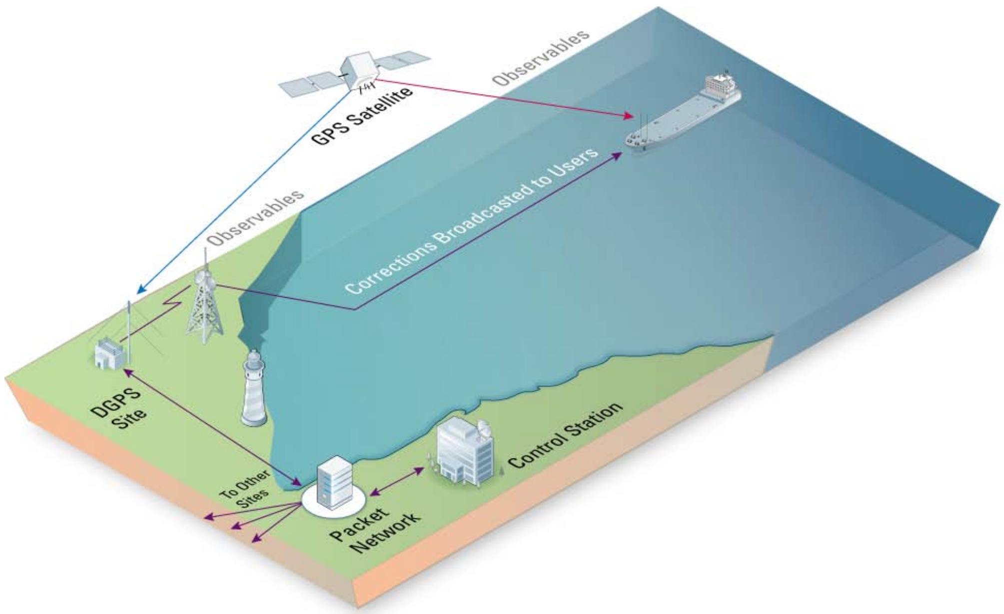

Figure A-5 NDGPS Architecture

NDGPS currently meets all of the USCG DGPS performance requirements and the combined national DGPS utility is monitored and operated by USCG from one of three independent control stations. As a new NDGPS site is added to the 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, it too is monitored and maintained by 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

Figure A-5 shows the NDGPS architecture. 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.

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 MDGPS Service are summarized in Table A-2.

Table A-2 NDGPS Service Characteristics (Signal-in-Space)

ACCURACY (2 drms)	AVAILABILITY (%)	COVERAGE	INTEGRITY	RELIABILITY	FIX INTERVAL	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
<10 m	99.9 selected areas 99.7 all other areas	Continental U.S. including coastal areas, selected areas of HI, AK, and PR	On-site integrity monitor and 24 hr DGPS control center	< 500 outages per 1,000,000 hr	1 – 20 per sec	3D	Unlimited	None

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 m horizontal accuracies in real-time, throughout the coverage area. High-end user equipment routinely achieves accuracies better than 1 m, 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 averaged them together. While this 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 nmi 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% in selected waterways and dual coverage areas, with more stringent VTS requirements and at least 99.7% in other parts of the coverage area. Availability is calculated on a per site per month basis, generally discounting GPS anomalies.

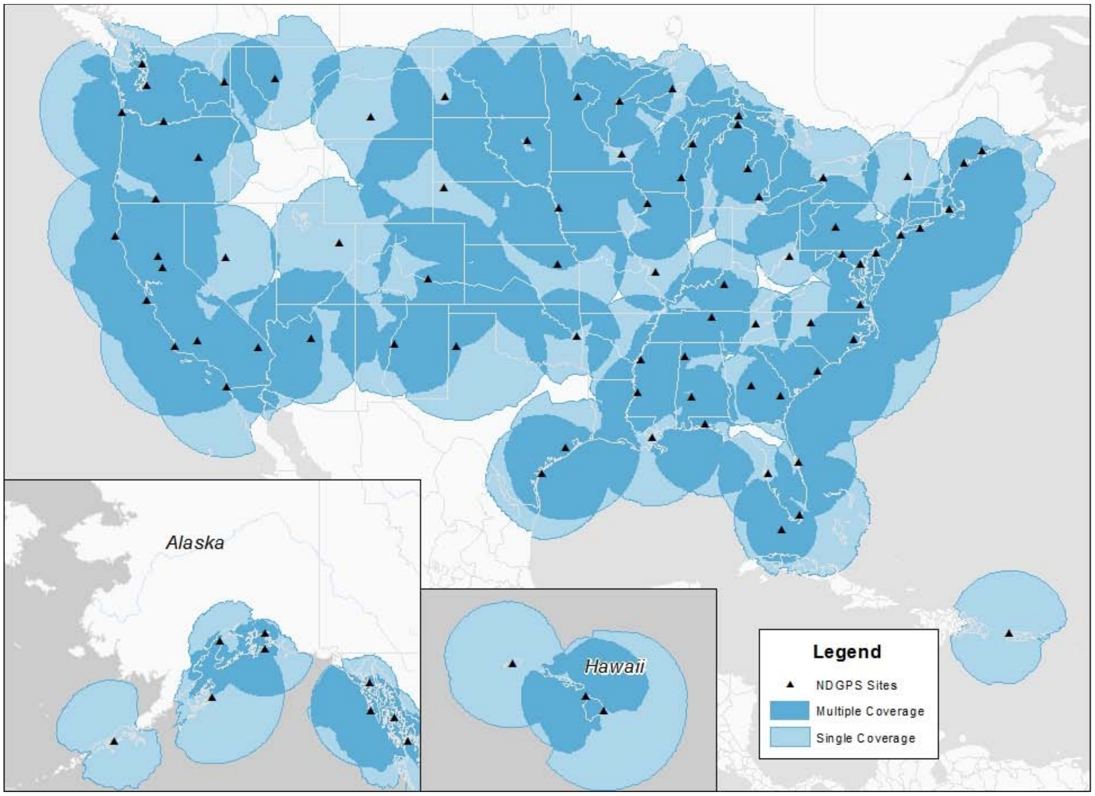

Figure A-6 NDGPS Signal Coverage

D. Coverage

The combined U.S. DGPS Service is operated by USCG and is deployed in three distinct segments. Figure A-6 illustrates the signal coverage for the combined system.

(1) In accordance with COMDTINST M16577.1, *Broadcast Standard for the USCG DGPS Navigation Service* (Ref. 54), the MDGPS Service is designed to provide complete coastal DGPS coverage (to a minimum range of 20 nmi from shore) of CONUS, selected portions of Hawaii, Alaska, and Puerto Rico, and inland coverage of the major inland rivers.

(2) Much of this inland waterway portion is provided by the USACE.

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 Interval

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

G. System Capacity

Unlimited.

H. Fix Dimensions

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

I. Ambiguity

None.

J. 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 s.

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 hr 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.

K. Spectrum

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

A.2.3 Instrument Landing System (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 A-3.

Table A-3 ILS Characteristics (Signal-in-Space)

ACCURACY AT MINIMUM APPLICABLE DECISION HEIGHT (meters - 2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE*	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
CATEGORY	AZIMUTH	ELEVATION							
I	± 9.1	± 4.1	Approaches 99%	Normal limits from center of localizer ± 10° out to 18 nmi and ± 35° out to 10 nmi	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
II	TBD**	TBD**							
III	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 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 ±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 deg (2 sigma). Glide slope course alignment is maintained within ±7.0 ft at 100 ft

[*] 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.

(2 sigma) elevation and glide path bends during the final segment of the approach do not exceed ±0.07 deg (2 sigma).

C. Availability

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

D. Coverage

Coverage for individual systems is as follows:

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

E. Reliability

ILS reliability is 98.6%. 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 Interval

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 A-4.

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 A-4 Aircraft Marker Beacons

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

I. Ambiguity

Any potential ambiguities are resolved by imposing system limitations as described in Section A.2.3.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 in Table A-5.

Table A-5 ILS Shutdown Delay

CATEGORY	LOCALIZER	GLIDE SLOPE
I	<10 s	<6 s
II	<5 s	<2 s
III	<2 s	<2 s

K. Spectrum

ILS marker beacons operate in the 74.8-75.2 MHz VHF band. ILS localizers share the 108-111.975 MHz portion of the 108-117.975 MHz ARNS band with VOR. ILS glideslope sub-systems operate in the 328-335.4 MHz UHF band.

A.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 PNT 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 range 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.

A.2.4.1 Very High Frequency (VHF) Omnidirectional Range (VOR)

A. Signal Characteristics

The signal characteristics of VOR are summarized in Table A-6. VOR 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 A-6 VOR and DME System Characteristics (Signal-in-Space)

ACCURACY* (2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE							
VOR: 90 m (± 1.4°)**	23 m (± 0.35°)***	--	Approaches 99% to 99.99%	Line of Sight	Approaches 100%	Continuous	Heading in degrees or angle off course	Unlimited	None
DME: 185 m (±0.1 nmi)	185 m (± 0.1 nmi)	--					Slant range (nmi)	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 deg. The summation of course selection, receiver, and flight technical errors (FTE), when calculated using root-sum-squared (RSS) techniques, is ±4.5 deg.

- 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 deg. The VOR ground station relative error is ±0.35 deg.

- 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 deg.

C. Availability

VOR availability is typically 99% to 99.99%.

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 A-7. 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.

Table A-7 VOR/DME/TACAN Standard Service Volumes (SSV)

SSV CLASSDESIGNATOR	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 nmi.
L (Low Altitude)	From 1,000 ft AGL up to and including 18,000 ft AGL at radial distances out to 40 nmi.
H (High Altitude)	From 1,000 ft AGL up to and including 14,500 ft AGL at radial distances out to 40 nmi. From 14,500 AGL up to and including 60,000 ft at radial distances out to 100 nmi. From 18,000 ft AGL up to and including 45,000 ft AGL at radial distances out to 130 nmi.

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)* (Ref. 55). Complete functional and performance characteristics are described in FAA Order 9840.1, *U.S. National Aviation Standard for the VOR/DME/TACAN Systems* (Ref. 56).

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 deg. Azimuth information from TACAN is normally usable from the radio horizon to elevation angles of at least 40 deg. 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%.

F. Fix Interval

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

G. Fix Dimensions

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

H. System Capacity

The capacity of a VOR station is unlimited.

I. Ambiguity

There is no ambiguity possible for a VOR station.

J. Integrity

VOR provides system integrity by removing a signal from use within 10 s of an out-of-tolerance condition detected by an independent monitor.

K. Spectrum

VOR operates in the 108-117.975 MHz VHF band. It shares the 108-111.975 MHz portion of that band with ILS.

A.2.4.2 Distance Measuring Equipment (DME)

A. Signal Characteristics

The signal characteristics of DME have been summarized above in Table A-6. 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). In addition, Y-channel DME are identified by a wider interrogation pulse-pair time spacing of 0.036 ms versus X-channel DME at 0.012 ms 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 nmi. The overall system error (airborne and ground RSS) is not greater than ±0.5 nmi or 3% 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%, 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 A-7. Because of facility placement, almost all of the airways have coverage and most of 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%.

F. Fix Interval

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 nautical miles.

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 s 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, and L5, the third civil frequency for GPS, located at frequency 1176.45 MHz. This protected ARNS band meets the needs of critical safety-of-life applications.

A.2.4.3 Tactical Air Navigation (TACAN)

A. Signal Characteristics

TACAN is a short-range UHF (962-1215 MHz ARNS band) PNT 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 A-8.

Table A-8 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° (±63 m at 3.75 km)	Azimuth ±1° (± 63 m at 3.75 km)	Azimuth +1° (±63 m at 3.75 km)	98%	Line of sight	99%	Continuous	Distance and bearing from station	110 for distance	No ambiguity in range
DME: 185 m (±0.1 nmi)	DME: 185 m (±0.1 nmi)	DME: 185 m (±0.1 nmi)						Unlimited in azimuth	Slight potential for ambiguity at multiples of 40°

B. Accuracy (2 sigma)

- Predictable - The ground station errors are less than ±1.0 deg for azimuth for the 135 Hz element and ±4.5 deg 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% of the time.

D. Coverage

TACAN coverage is described in the preceding section on VOR and in Table A-8.

E. Reliability

A TACAN station can be expected to be reliable 98% of the time. Unreliable stations, as determined by remote monitors, are automatically removed from service.

F. Fix Interval

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 deg.

J. Integrity

TACAN provides system integrity by removing a signal from use within 10 s 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.

A.2.5 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. Aeronautical 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. Marine radiobeacons have been phased out. The characteristics of NDBs are summarized in Table A-9.

Table A-9 Radiobeacon System Characteristics (Signal-in-Space)

ACCURACY (2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE							
Aeronautical ±3 - 10°	N/A	N/A	99%	Maximum Service volume – 75 nmi	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 50 nmi or 100 fathom curve					

A. Signal Characteristics

Aeronautical NDB operate in the 190 to 415 kHz and 510 to 535 kHz ARNS bands. (Note: NDB 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 Lines of Position (LOP), 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 deg. Achievement of ±3 deg accuracy requires that the ADF 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 deg on approaches and ±10 deg in the en route area.

C. Availability

Availability of Aeronautical NDB is in excess of 99%.

D. Coverage

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

E. Reliability

Reliability is in excess of 99%.

F. Fix Interval

The beacon provides continuous bearing information.

G. Fix Dimensions

In general, one LOP is available from a single radiobeacon. If within 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 s of an out-of-tolerance condition.

K. Spectrum

Aeronautical NDB operate in the 190-435 and 510-535 kHz frequency bands, portions of which it shares with maritime NDB.

A.2.6 Microwave Landing System (MLS)

The U.S. plans to use augmented GPS systems to satisfy the requirements originally earmarked for the MLS. Accordingly, FAA has terminated all activity associated with MLS. DoD employs MLS systems where their characteristics are useful. NASA uses a microwave landing system for Space Shuttle operations with different characteristics than the FAA/international standard MLS. Characteristics of the FAA/international standard MLS are summarized in Table A-10..

Table A-10 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							
I	±9.1	±3.0	Expected to approach 100%	±40° from center line of runway out to 20 nmi in both directions*	Expected to approach 100%	6.5 – 39 fixes/s depending on function	Heading and deviation in degrees Range in nmi	Limited only by aircraft separation requirements	None
II	±4.6	±1.4							
III	±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%.

D. Coverage

Azimuthal coverage typically extends ±40 deg on either side of the runway centerline, and elevation coverage from 0 deg to a minimum of 15 deg over the azimuthal coverage area, and out to 20 nmi. Some systems have ±60 deg azimuthal coverage. MLS signal format has the capability of providing coverage to the entire 360 deg area but with less accuracy in the area outside the primary coverage area of ±60 deg 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%.

F. Fix Interval

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 5000 – 5250 MHz C-band. However its operational band is now limited to the 5030 – 5150 MHz C-band. The 5030 – 5091 MHz C-band is channelized by ICAO for MLS, and the 5091 – 5150 MHz C-band is termed the MLS extension band. Other services have not yet attempted to utilize the 5030 – 5091 MHz C-band due to the safety of life aspects of the MLS function.

A.2.7 Timing Systems

NIST and USNO provide additional means to determine time (UTC) separate from systems that support positioning and navigation. NIST services are documented at http://tf.nist.gov/and in NIST Special

Publication 432, *NIST Time and Frequency Services*, January 2002 (Ref. 57), which may be downloaded from the website.

DoD Directive (DoDD) 4650.05, *Positioning, Navigation, and Timing (PNT)*, February 19, 2008 (Ref. 58) and CJCSI 6130.01D (Ref. 1) designates the USNO responsibility to coordinate timing activities for DoD and related national defense supporting activities. As Precise Time and Time Interval (PTTI) manager, USNO is responsible for coordination of PTTI requirements and maintenance of a PTTI reference standard (astronomical and atomic) for use by all DoD Components, DoD contractors, and related laboratories. This includes programming the necessary resources to maintain the reference standard and to disseminate precise time to DoD users. USNO historically supports U.S. PNT systems by providing the coordinating timing reference between USG navigation services ensuring interoperability between systems. USNO disseminates time via various mediums; these include GPS, TWSTT, NTP, and voice announcers. USNO plans to continue these time dissemination services but with the termination of the Loran system, USNO plans to discontinue the UTC Loran time monitoring service, contained in USNO Series 5 Publication effective 30 Sep 2010. Users of the USNO Internet Time Service are advised to check periodically for the establishment of new time servers, or for servers that change IP address due to Internet growth and reconfiguration http://tycho.usno.navy.mil/. USNO services are documented at http://www.usno.navy.mil/USNO/time.

A.2.7.1 Time Measurement and Analysis Service

The NIST Time Measurement and Analysis Service (TMAS) is designed to assist laboratories maintain a high-accuracy, local time standard. The service continuously compares the customer's local time standard to the NIST time scale, and reports the comparison results to the customer in near real-time.

A. Signal Characteristics

TMAS works by making simultaneous common-view measurements at NIST and at the customer's laboratory with up to eight GPS satellites. Each customer receives a time measurement system that performs the measurements and sends the results to NIST via the Internet for instant processing.

B. Accuracy

Time is measured with a combined standard uncertainty of less than 15 ns, and frequency is measured with an uncertainty of less than 1×10^{-13} after 1 day of averaging.

C. Availability

TMAS is available to the extent that GPS satellites are in view of the customer, and that a bidirectional Internet data path is available between the customer and NIST.

D. Coverage

TMAS is available worldwide. TMAS can process data in an all-in-view mode when satellites are not in common view.

E. Reliability

Not specified, and dependent on Internet reliability.

F. Fix Interval

Measurements are made using a time interval counter with a single shot resolution of less than 30 ps.

G. Fix Dimensions

Not Applicable.

H. System Capacity

The capacity is unlimited.

I. Ambiguity

There is no ambiguity.

J. Integrity

NIST personnel monitor deployed TMAS time measurement systems from Boulder, Colorado, verify and analyze the data, and quickly troubleshoot any problems that may occur.

K. Spectrum

TMAS receives the GPS L1 frequency and utilizes spectrum for Internet connectivity, as required.

A.2.7.2 Internet Time Service

The Internet Time Service (ITS) allows digital devices to obtain the time through their Internet connection. ITS supports standard Internet protocols, primarily Network Time Protocol (NTP, RFC-1305), and also Daytime Protocol (RFC-867) and Time Protocol (RFC-868).

A. Signal Characteristics

ITS does not utilize signals in space, except as might be required to obtain an Internet connection.

B. Accuracy

The uncertainty of Daytime, Time, and SNTP (Simple NTP) time clients is usually <100 ms, but the results can vary due to the Internet path (e.g., asymmetry in packet travel time to/from NIST), and the type of computer, operating system, and client software. In extreme cases, the uncertainty might be 1 s or more. The uncertainty of a continuously running NTP client that polls multiple servers is often <10 ms.

C. Availability

NIST supports 23 ITS servers at 19 locations around the United States. Availability approaches 100% for client software with the ability to poll multiple sites.

D. Coverage

The ITS servers provide worldwide service. However, outside of the United States better results may be obtained by using a local NTP server.

E. Reliability

The reliability of ITS depends mostly on the capabilities of the client software. A completely and well-implemented NTP client will poll many servers, perform self-consistency checks, and respect status data provided by the servers. However, this is not typical for consumer-grade devices. For a sufficiently large number of servers polled, reliability is limited by that of the Internet connection.

F. Fix Interval

All users should ensure that their software never queries a server more frequently than once every 4 s. Systems that exceed this rate will be refused service. In extreme cases, systems that exceed this limit may be considered as attempting a denial-of-service attack. The normal interval between NTP requests (the “polling interval”) depends on the client software being used and the needs of the user. The most sophisticated software automatically adjusts its polling interval to between 16 s and 1024 s, depending on statistics. For many non-precision applications, a polling interval of hours or days apart would be sufficient.

G. Fix Dimensions

Not Applicable.

H. System Capacity

NIST currently processes in excess of 3 billion ITS transactions daily. Because use of ITS continues to grow rapidly, NIST is interested in expanding the number of servers and broadening their geographic distribution. Organizations interested in possibly hosting an ITS server are invited to contact NIST for more information, including a discussion of technical requirements.

I. Ambiguity

There is no ambiguity, with one exception. Time Protocol (RFC-868), which is now used by only about 1% of ITS customers, will roll back to the year 1900 in 2036.

J. Integrity

All ITS servers are monitored by NIST for integrity. A completely and well-implemented NTP client will poll many servers, perform self-consistency checks, and respect status data provided by the servers.

K. Spectrum

ITS does not utilize spectrum, except as might be required by the user to obtain an Internet connection.

A.2.7.3 Automated Computer Time Service

The NIST ACTS allows digital devices to obtain the time through dial-up telephone connections, using computer modems. ACTS works only with analog modems that use ordinary telephone lines. Digital modems, such as Digital Subscriber Line (DSL), cable, and wireless modems, may not work properly. For computers with Internet access, ITS should be used instead. ACTS has been provided since 1988, predating wide public use of the Internet. However, ACTS remains preferred in certain user applications with security or documentation requirements.

A. Signal Characteristics

When a digital device connects to ACTS by telephone, it receives an ASCII time code. ACTS works at speeds up to 9600 baud with 8 data bits, 1 stop bit, and no parity. To receive the full time code, you must connect at a speed of at least 1200 baud. The full time code is transmitted every second and contains more information than the 300 baud time code, which is transmitted every 2 s.

B. Accuracy

ACTS determines the round-trip path delay from cooperating user client software. Presuming symmetry in the path delay to and from NIST, the time can be determined with respect to UTC(NIST) with an uncertainty of <15 ms.

C. Availability

The availability of ACTS approaches 100% for client software with the ability to dial multiple sites.

D. Coverage

The ACTS servers provide worldwide service. However, accuracy will be degraded by long-haul telephony with asymmetric delays, which may be caused by satellite links.

E. Reliability

The reliability of ACTS depends on the capabilities of the client software. A well-implemented ACTS client will perform self-consistency checks, and if necessary dial into multiple servers. Reliability is limited by that of the telephone connection.

F. Fix Interval

The full time code is transmitted every second and contains more information than the 300 baud time code, which is transmitted every 2 s.

G. Fix Dimensions

Not Applicable.

H. System Capacity

The ACTS system in Colorado has 12 phone lines and receives an average of more than 4,000 telephone calls per day. It can be reached by dialing (303) 494-4774. The ACTS system in Hawaii has 4 phone lines and receives an average of a few-hundred calls per day. It can be reached by dialing (808) 335-4721. Long distance charges may apply.

I. Ambiguity

There is no ambiguity.

J. Integrity

ACTS servers are monitored by NIST for integrity.

K. Spectrum

ACTS does not utilize spectrum, except as might be required by the user to obtain a telephone connection.

A.2.7.4 Radio Station WWVB

NIST radio station WWVB continuously broadcasts time and frequency signals at 60 kHz from near Fort Collins, Colorado. The carrier frequency provides a stable frequency reference traceable to the national standard. There are no voice announcements on the station, but a time code is modulated onto the carrier that enables digital devices to learn the time (UTC).

A. Signal Characteristics

A time code is synchronized with the 60 kHz carrier and is broadcast continuously at a rate of 1 bps using pulse width modulation. The carrier power is reduced and restored to produce the time code bits. The carrier power is reduced by 17 dB at the start of each second, so that the leading edge of every negative going pulse is on time. Full power is restored 0.2 s later for a binary “0”, 0.5 s later for a binary “1”, or 0.8 s later to convey a position marker. The binary coded decimal (BCD) format is used so that binary digits are combined to represent decimal numbers. The time code contains the year, day of year, hour, minute, second, and flags that indicate the status of Daylight Saving Time, leap years, and leap seconds. For more details, see http://tf.nist.gov/stations/wwvbtimecode.htm. WWVB identifies itself by advancing its carrier phase 45° at 10 min after the hour and returning to normal phase at 15 min after the hour. Plotting WWVB phase results in a phase step of approximately 2.08 µs.

B. Accuracy

The frequency uncertainty of the WWVB signal as transmitted is less than 1 part in 10^{12}. If the path delay is removed, WWVB can provide UTC with an uncertainty of about 100 µs. The variations in path delay are minor compared to those of radio stations WWV and WWVH. The longest possible path delay in the continental United States is <15 ms.

C. Availability

Although WWVB broadcasts continuously, the propagation characteristics of LF radio waves cause the signal strength to vary diurnally and seasonally at locations remote from the transmitter. In most of the U.S., the signal is best received at night. The signal is generally easiest to receive when it is dark at both the transmitter site in Fort Collins, Colorado, and the receiving location. Such “dark path hours” vary in length from about 4 hr (Anchorage summer) to about 14 hr (Seattle winter). During daylight hours, the signal can be received using good antennas and more sensitive receivers.

D. Coverage

WWVB may be received in most of North America, though the fog of radio noise and other impairments make reception more difficult in the Northeast and Southeast U.S.

E. Reliability

There are three transmitters at the WWVB site. Two are in constant operation and one serves as a standby that is activated if one of the primary transmitters fails. Occasional outages and periods of reduced power operation have occurred, and are documented at http://tf.nist.gov/stations/wwvboutages.htm. Near real-time status from monitoring stations may be seen at http://tf.nist.gov/tf-cgi/wwvbmonitor_e.cgi.

F. Fix Interval

Each frame of data takes one minute to transmit. Consecutive frames can be compared for error detection and correction.

G. Fix Dimensions

Not Applicable.

H. System Capacity

The capacity is unlimited.

I. Ambiguity

There is no ambiguity.

J. Integrity

The WWVB signal is monitored by NIST for integrity. In most cases, user receivers can estimate the integrity of the signal through comparison with a local “flywheel” clock. However, the integrity of the system can be compromised by purposeful interference.

K. Spectrum

WWVB uses a 60 kHz carrier frequency in the LF (low frequency) portion of the radio spectrum. This frequency is assigned for purposes of time and frequency dissemination by the World Radio Conference, and is also used by radio station MSF in the UK (Rugby) and radio station JJY in Japan (Hagane-yama Station).

A.2.7.5 Radio Stations WWV and WWVH

NIST radio stations WWV and WWVH continuously broadcast time and frequency information from near Fort Collins, Colorado, and Kekaha

(Kauai Island), Hawaii, respectively. They provide time announcements, standard time intervals, standard frequencies, UT1 time corrections, a BCD time code, geophysical alerts, marine storm warnings, and GPS status reports.

A. Signal Characteristics

WWV and WWVH operate in the high frequency (HF) portion of the radio spectrum. WWV radiates 10,000 W on 5, 10, and 15 MHz; and 2500 W on 2.5 and 20 MHz. WWVH radiates 10,000 W on 5, 10, and 15 MHz, and 5000 W on 2.5 MHz. Each frequency is broadcast from a separate transmitter. Although each frequency carries the same information, multiple frequencies are used because the quality of HF reception depends on many factors such as location, time of year, time of day, the frequency being used, and atmospheric and ionospheric propagation conditions. The variety of frequencies makes it likely that at least one frequency will be usable at all times. The signals broadcast by WWV use double sideband amplitude modulation. The modulation level is 50% for the steady tones, 50% for the BCD time code, 100% for the second pulses and the minute and hour markers, and 75% for the voice announcements. The signal format is described at http://www.nist.gov/physlab/div847/grp40/wwv_format.cfm.

B. Accuracy

WWV and WWVH are referred to the primary NIST Frequency Standard and related NIST atomic time scales in Boulder, Colorado. The frequencies *as transmitted* are maintained within a few parts in 10^{13} for frequency and <100 ns for timing with respect to UTC(NIST). However, the received performance of WWV and WWVH is generally worse than the received performance of WWVB. This is because an HF radio path is much less stable than an LF radio path. Within the United States, the time should be delayed by less than 20 ms.

C. Availability

Although WWV and WWVH broadcast continuously, the propagation characteristics of HF radio waves cause the signal strength to vary diurnally and seasonally at locations remote from the transmitter. HF reception depends on many factors, including atmospheric and ionospheric conditions.

D. Coverage

The coverage area of the two stations is essentially worldwide on 5, 10, and 15 MHz, although reception might be difficult in some areas, since standard time and frequency stations in other parts of the world use these same frequencies.

E. Reliability

Occasional outages have occurred, and are documented at http://tf.nist.gov/timefreq/stations/wwvoutages.htm.

F. Fix Interval

The broadcast schedule is found at http://www.nist.gov/physlab/div847/grp40/iform.cfm. In general, each frame of data takes one minute to transmit. Consecutive frames can be compared for error detection and correction.

G. Fix Dimensions

Not Applicable.

H. System Capacity

The capacity is unlimited.

I. Ambiguity

There is no ambiguity.

J. Integrity

The signals are monitored by NIST for integrity. In most cases, user receivers can estimate the integrity of the signal through comparison with a local "flywheel" clock. However, the integrity of the system can be compromised by purposeful interference.

K. Spectrum

WWV and WWVH use frequencies in the HF (high frequency, shortwave) portion of the radio spectrum. These frequencies are assigned for purposes of time and frequency dissemination by the World Radio Conference, and are also used by such radio stations as ATA in India (New Delhi), BPM in China (Lintong), IAM in Italy (Rome), and LOL in Argentina (Buenos Aires).

A.2.7.6 NIST Telephone and Web-based Services

For the convenience of the public, NIST provides easy-to-use time services over the telephone and Internet. The audio portions of the WWV and WWVH broadcasts can also be heard by telephone. Dial (303) 499-7111 for WWV (Colorado), and (808) 335-4363 for WWVH (Hawaii). These are not toll-free numbers; callers outside the local calling area are charged for the call at regular long-distance rates. In addition, NIST provides a web-based time service at http://time.gov/. This website provides a digital clock on the screen and a map of the world showing where it is day and where it is night.

A. Signal Characteristics

The telephone service is audio. The web-based service uses HTTP and Java.

B. Accuracy

The time announcements on the telephone service are normally delayed by less than 30 ms when using land lines from within the continental United States, and the stability (delay variation) is generally < 1 ms. When mobile phones or voice over IP networks are used, the delays can be as large as 150 ms. In the very rare instances when the telephone connection is made by satellite, the time is delayed by more than 250 ms. The Internet web page is accurate to about 200 ms within the U.S.

C. Availability

Both services operate continually.

D. Coverage

Both services are accessible worldwide.

E. Reliability

Occasional outages may occur.

F. Fix Interval

The telephone service provides a voice announcement once each minute. The web service usually responds within a few seconds, depending on the user's Internet connection.

G. Fix Dimensions

Not Applicable.

H. System Capacity

The capacity is unlimited for the web page. A few telephone lines are available for the audio service.

I. Ambiguity

There is no ambiguity.

J. Integrity

The signals are monitored by NIST for integrity.

K. Spectrum

These services do not utilize spectrum, except as might be required by the user to obtain a telephone or Internet connection.

A.2.7.7 GPS Time Distribution Service

GPS time transfer is the optimum means of globally obtaining precise time at the nanosecond level (see paragraph 3.2.5 for more info). USNO works jointly with the GPS program to supply a UTC(USNO) timing service that is used globally as the standard for timing systems.

A. Signal Characteristics

See section A.2.1.A

B. Accuracy

See section A.2.1.B

C. Availability

See section A.2.1.C

D. Coverage

See section A.2.1.D

E. Reliability

See section A.2.1.E

F. Fix Interval

See section A.2.1.F

G. Fix Dimensions

Not Applicable.

H. System Capacity

The capacity is unlimited.

I. Ambiguity

There is no ambiguity.

J. Integrity

See section A.2.1.J

K. Spectrum

See section A.2.1.K

A.2.7.8 Network Time Protocol (NTP)

Network Time Protocol (NTP) is an Internet standard (RFC-1305a) which enables clients computers to maintain system time synchronization to the US Naval Observatory Master Clocks in Washington, DC and Colorado Springs, Colorado, and to UTC(USNO) via GPS. USNO provides a distributed ensemble of distributed network time servers providing accurate and reliable time synchronization for computers, routers, and other hardware on the Internet, on Non-classified Internet Protocol Router Network (NIPRNet) and on the SIPRNet. The current (2010) NTP is version 4, which is also backward compatible with previous versions. NTP provides mechanisms to synchronize time and to coordinate time distribution by computer on both local and wide area networks. Network time transfer is achieved by robust estimation between remote systems of clock offset, network delays, and network dispersion.

A. Signal Characteristics

NTP messages are User Datagram Protocol/Internet Protocol (UDP/IP) datagrams (packets) generated by a daemon process and exchanged between NTP clients and their peers or higher-stratum servers. An NTP datagram with associated UDP, IP, and Ethernet headers uses one 90-byte Ethernet frame. NTP datagrams may be transmitted via unicast, broadcast, or multicast messaging. NTP clients obtain time stamps from to one or more servers, deriving confidence intervals for time sources enabling detection of bad sources. Responses are filtered and combined to derive continuous adjustments to the local system clock.

B. Accuracy

Typical accuracy achieved is in the range 1 - 30 ms continuous, and is highly dependent on the symmetry and speed of the Internet path between client and server. Best results are achieved using a combination of servers which are closest to the client in a network sense.

C. Availability

Public access to USNO NTP service is provided. Reference http://tycho.usno.navy.mil/ntp.html for an updated list of NTP servers operated by USNO. USNO also operates NTP services SIPRNet. In the future USNO may offer a form of authenticated NTP service supporting USG and DoD operations.

D. Coverage

USNO provides a distributed group of NTP servers located across the CONUS, Alaska and Hawaii. USNO NTP servers provide worldwide service. However, outside of the United States better results may be obtained by using a local NTP server.

E. Reliability

The reliability of NTP depends in part upon the proper configuration of the client software. An optimally configured NTP client will poll three or more servers, perform self-consistency checks, and respect status data provided by the servers. For a sufficiently large number of servers polled, reliability is limited by that of the Internet connections involved.

F. Fix Interval

NTP clients typically poll servers initially at 16 s intervals, and adjust this interval as their synchronization improves. The maximum interval between messaging is 17 min (1024 s).

G. Fix Dimensions

Not Applicable.

H. System Capacity

USNO currently processes approximately 550 million transactions daily (at over 6,000 packets per second). The USNO Washington NTP service can provide in excess of 40,000 packets per second.

I. Ambiguity

Network source and destination addresses are processed by the NTP protocol to eliminate ambiguity. NTP properly handles out-of-order delivery and loss of packets.

J. Integrity

USNO designs and operates NTP servers which obtain UTC(USNO) directly from the USNO Master Clocks or GPS. Servers are protected against intrusion and have operated authoritatively for 16 years.

K. Spectrum

NTP does not utilize spectrum.

A.2.7.9 Two-way Satellite Time Transfer (TWSTT)

Two-way satellite time transfer (TWSTT) allows for direct comparison of time and frequency signals over long baselines. The USNO provides TWSTT services for remote users to receive precise time and frequency referenced to UTC(USNO). TWSTT operations range from a one-time calibration service to determine the difference between the DoD Master Clock and a user’s time reference or to a full service Earth station to provide continued monitoring of a user’s reference.

A. Signal Characteristics

TWSTT uses a Code-division multiple access (CDMA) spread spectrum signal with a bandwidth ranging from 1 MHz to several MHz.

B. Accuracy

One nanosecond time transfer can be achieved using TWSTT with an associated frequency uncertainty of less than 1 x 10^{-14} after 1 day of averaging.

C. Availability

TWSTT is conducted on a schedule and operates continuously 24 hours a day and 7 days a week. Heavy rain may degrade performance and bi-yearly sun outages may cause signal outages that can last a few minutes.

D. Coverage

TWSTT is available under the coverage area of the geostationary satellite in use. Presently USNO Ku-band coverage is limited to the United States including Alaska and Hawaii. DSCS X-band coverage is Global.

E. Reliability

Dependant on the Earth station system design, redundancy can be built in each system. A satellite outage while rare is a concern and would result in a long term data outage.

F. Fix Interval

Measurements are made using a special spread spectrum time transfer modem with a single shot resolution of less than 10 ps. USNO typically schedules a time transfer experiment once an hour for 10 min.

G. Fix Dimensions

Not Applicable.

H. System Capacity

The capacity is limited by satellite signal power and bandwidth.

I. Ambiguity

Absolute time transfer requires periodic time calibration, typically using a mobile TWSTT system. Accuracies of one nanosecond are possible using this calibration service.

J. Integrity

USNO personnel monitor deployed TWSTT systems from Washington DC, verify and analyze the data, and quickly troubleshoot any problems that may occur.

K. Spectrum

TWSTT typically uses geostationary satellites run by commercial entities (Ku-band) or by the Defense Satellite Communications System (X-band).

A.2.7.10 USNO Telephone and Web-based Services

The USNO Telephone Time Voice Announcer produces an audible tick every second from the USNO Master Clock and announces the time every 10 s. The time is announced in both local time and UTC. The USNO operates two time announcers; one in Washington, D.C., and one at the USNO AMC in Colorado Springs, Colorado. Time dissemination accuracy is 1 s and can be accessed worldwide.

(202) 762-1401,
(202) 762-1069, and
(719) 567-6742

A. Signal Characteristics

The telephone service is audio. The web-based service uses HTTP and Java.

B. Accuracy

The time announcements on the telephone service are normally delayed by less than 30 ms when using land lines from within the continental United States, and the stability (delay variation) is generally < 1 ms. When mobile phones or voice over IP networks are used, the delays can be as large as 150 ms. In the very rare instances when the telephone connection is made by satellite, the time is delayed by more than 250 ms. The Internet web page is accurate to about 200 ms within the U.S.

C. Availability

Both services operate continually.

D. Coverage

Both services are accessible worldwide.

E. Reliability

Occasional outages may occur.

F. Fix Interval

The telephone service provides a voice announcement once each minute. The web service usually responds within a few seconds, depending on the users Internet connection.

G. Fix Dimensions

Not Applicable.

H. System Capacity

The capacity is unlimited for the web page. A few telephone lines are available for the audio service.

I. Ambiguity

There is no ambiguity.

J. Integrity

The signals are monitored by USNO for integrity.

K. Spectrum

These services do not utilize spectrum, except as might be required by the user to obtain a telephone or Internet connection.

Appendix B

PNT Information Services

B.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, and DGPS PNT information as well as general maritime navigation information. The NIS Website also provides the user with information on policy changes or developments about PNT 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.

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.

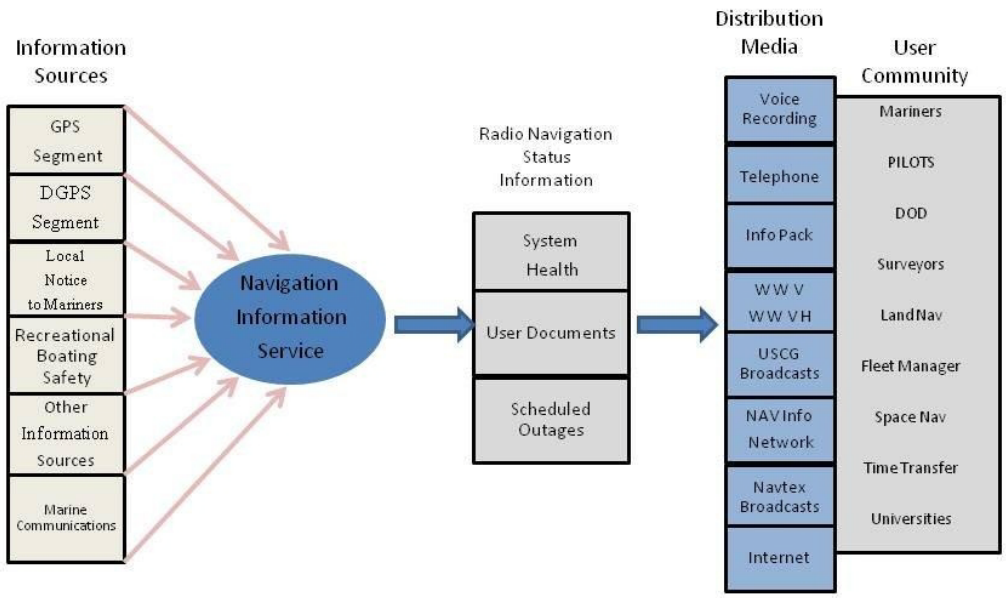

Figure B-1 NIS Information Flow

Figure B-1 and Table B-1 show the services through which the NIS provides Operational Advisory Broadcasts. Information on GPS and USCG-operated PNT systems can be obtained from the USCG NAVCEN at:

7327 Telegraph Road
Alexandria, VA 22315-3998
24-hour hotline: (703) 313-5900
email: webmaster@smtp.navcen.uscg.mil
website: http://www.navcen.uscg.gov/

Table B-1 NIS Services

SERVICE	AVAILABILITY	INFORMATION TYPE	CONTACT NUMBER
NIS Watchstander	24 hr	User Inquiries	(703)313-5900 FAX (703) 313-5920
Internet	24 hr	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 hr	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 hr, broadcast upon receipt	Status Forecasts Marine Navigation Warnings	(301) 227-3147 MCDWWNWS@nga.mil
NGA Weekly Notice to Mariners	On line Notices updated weekly	Status Forecasts Outages	(301) 227-3126 MCDNtM@nga.mil
Marine Safety Information Website	24 hr	Status Forecasts Notice to Mariners, Nautical Publications	http://www.nga.mil/maritime Webmaster_NSS@nga.mil (301) 227-3120
NAVTEX Data Broadcast	All stations broadcast 6 times daily at alternating times	Status Forecasts Outages	518kHz (703) 313-5900
RAIM Prediction	24 hr	User inquiry, status forecasts for RNAV Terminal, and En route RAIM	http://www.raimprediction.net

B.2 GPS NOTAM/Aeronautical Information System

DoD provides notice of GPS satellite vehicle outages through the NOTAM system. These NOTAM are reformatted NANU 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 NOTAM 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 NOTAM are computed based on criteria in the RTCA/DO-208, *Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)*, July 1991 (Ref. 59), and FAA Technical Standard Order (TSO)-C129(a), *Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS)*, February 20, 1996 (Ref. 60). The baseline RAIM algorithm, as specified in the Minimum Operational Performance Standards (MOPS) and TSO, is used for computing the NOTAM 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.

GPS RAIM outage NOTAM are accessible through web-based distribution systems, and are available at military bases that have an RNAV approach procedure. An example of a GPS RAIM NOTAM is provided below:

A) KADW
B) 1001081018
C) 1001081045
E) QXXXX GPS NON-PRECISION APPROACH NOT
AVAILABLE

This NOTAM means that a GPS nonprecision approach at Andrews Air Force Base is unavailable on Jan. 8, 2010 from 10:18 to 10:45 UTC.

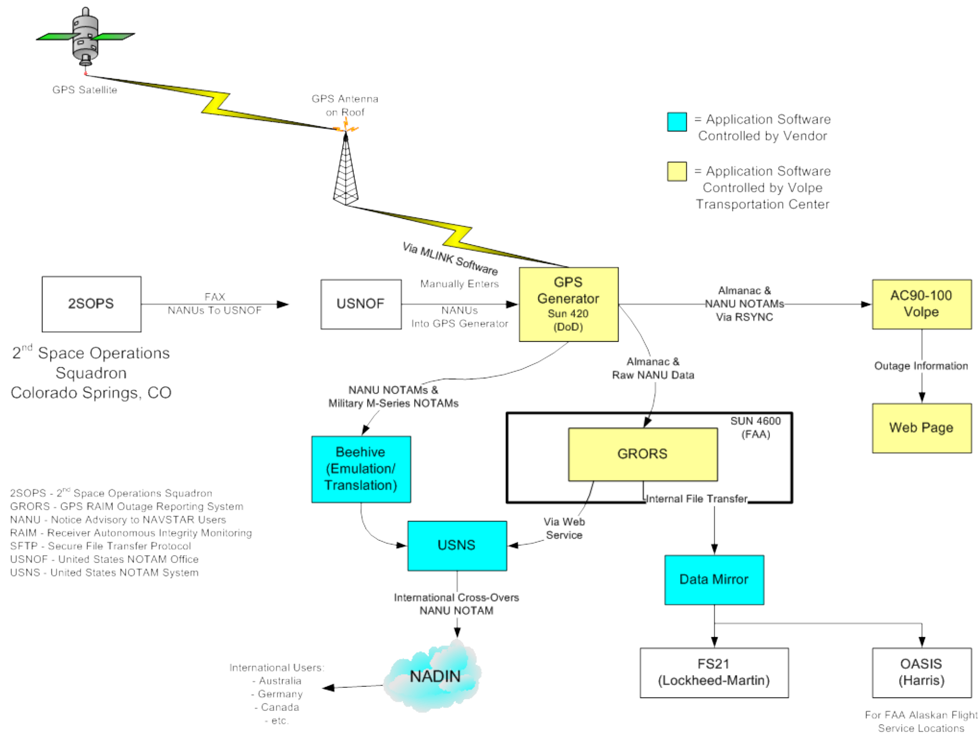

Figure B-2 GPS NOTAM/Aeronautical Information Distribution System

FAA provides similar GPS outage information as aeronautical information distributed through Flight Service Stations (FSS), Direct User Access Terminal System (DUATS) vendors, and other commercial vendors as shown in Figure B-2. The 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 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 hr.

B.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 of the control of 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 necessarily stationary. Pilots need to know where and when WAAS is or will be unavailable.

WAAS distributes two types of NOTAM: (1) NOTAM D for airport approach status and (2) FDC NOTAM for wide area coverage outages. The term UNRELIABLE is used in conjunction with GPS and WAAS NOTAM as an advisory to pilots indicating that the expected level of WAAS service (LNAV/VNAV, LPV) may not be available. WAAS UNRELIABLE NOTAMs are published for flight planning purposes. Upon commencing an approach at locations with a WAAS UNRELIABLE NOTAM, if the WAAS avionics indicate LNAV/VNAV or LPV service is available, the guidance may be used to complete the approach using the displayed level of service. Should an outage occur during the approach, reversion to another line of minima; a different approach procedure; or a missed approach may be required.

Outages are based on WAAS service unavailability for LNAV, LNAV/VNAV, and LPV approach minima on RNAV approach charts, and also are designed to provide outage information for en route operations. NOTAMs are formatted in the U.S. domestic NOTAM format. Airfields that have been determined not to have a high enough availability (98% or an average of one outage per day or more) are marked with an "inverse W" (W) to indicate that WAAS service may be unreliable for short periods of time at those airfields.

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.

B.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.

The NGA Office of Global Navigation is the Area Coordinator for issuance of marine navigation warnings for two of the sixteen NAVAREAs, IV and XII (areas in the IHO and IMO established World-Wide Navigational Warning Service) providing coverage of North America, see Figure B-3. 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.

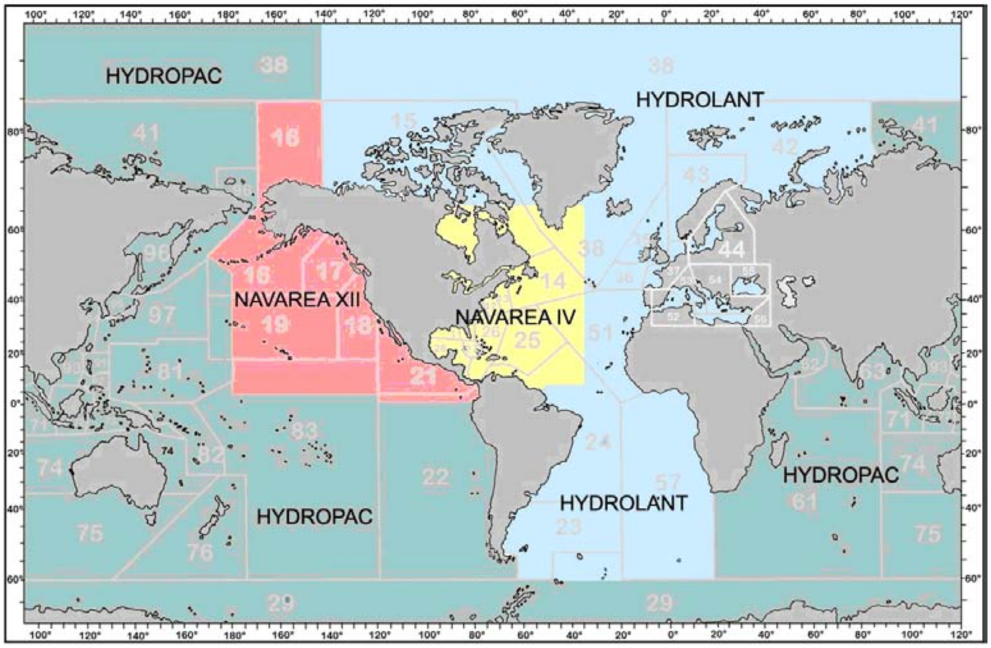

Figure B-3 NGA Maritime Warnings NAVAREA (IV & XII)

NAVAREA messages are promulgated to one of four INMARSAT-C satellites depending on the ocean region covered, see Figure B-4. 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.

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.”

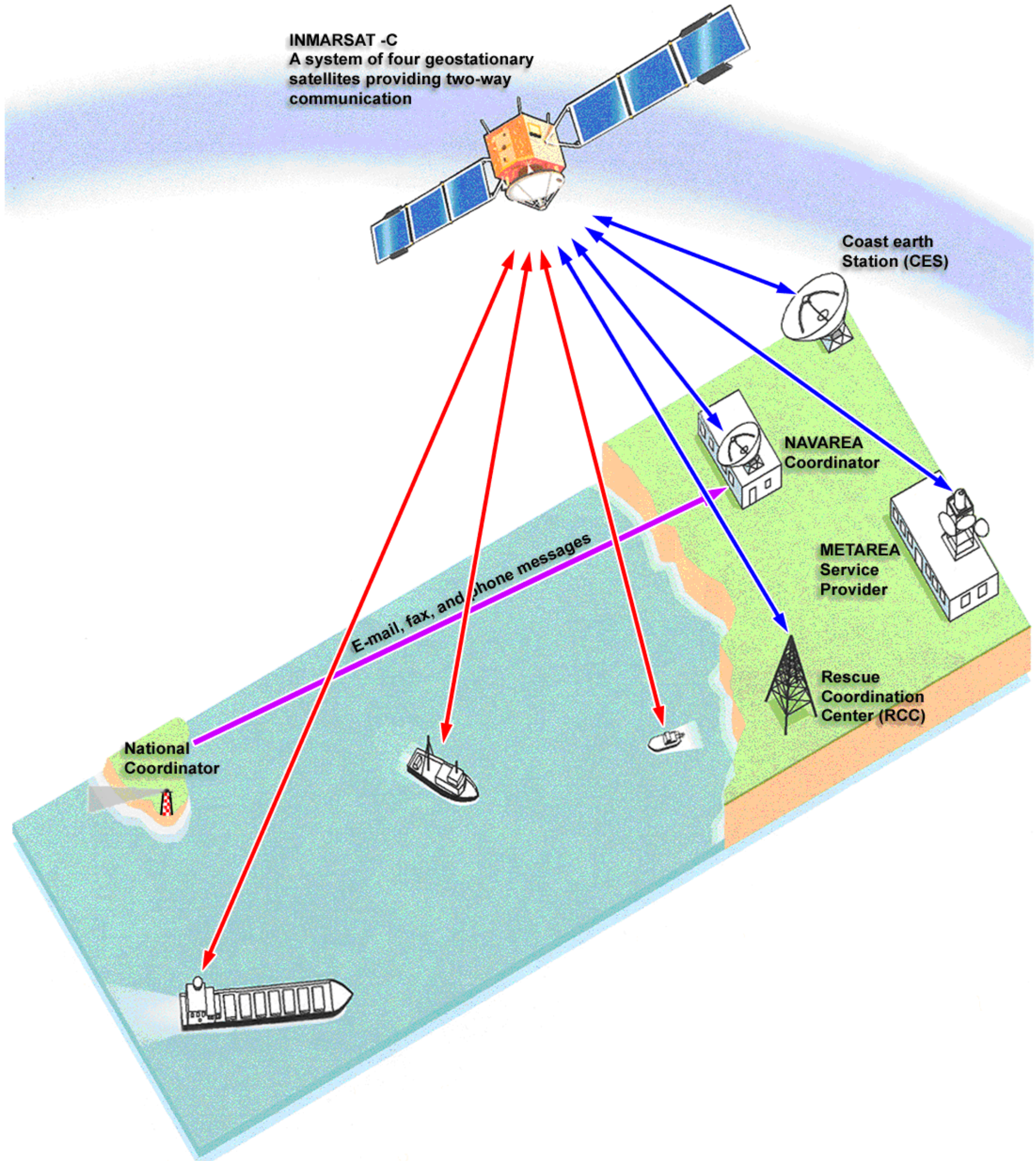

Figure B-4 IHO/IMO World-Wide Navigational Warning Service, NAVAREA Broadcast Service

B.5 NASA GPS Data and Space-User Services

B.5.1 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 the California Institute of Technology, 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, USNO, NGA, NSF, and the NOAA NGS. The IGS mission is to provide the highest quality data and products as the standard for GNSS 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. These data, and other information, may be obtained from the IGS website at: http://igscb.jpl.nasa.gov.

B.5.2 Space-Based Range (SBR) and GPS Metric Tracking (GPS MT)

Space-based navigation, GPS, and space-based range safety technologies are key components of the next generation launch and test range architecture being developed. Its objective is to replace the legacy ground-based tracking infrastructures. 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. Both expendable and reusable launch vehicles are expected to be part of the mix of aviation and space traffic.

Development is underway for using GPS-based tracking of launch vehicles using the NASA Tracking Data Relay Satellite Service (TDRSS), also known as GPS Metric Tracking (GPS MT) as a primary means for tracking of all DoD, NASA, and commercial vehicles launched at the Eastern and Western launch ranges.

B.5.3 Global Differential GPS (GDGPS)

GDGPS is a high-accuracy GPS augmentation system, developed by JPL, to support the real-time positioning, timing, and orbit determination requirements of NASA 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.

B.5.4 TDRSS Augmentation Service for Satellites (TASS)

A demonstration TASS signal providing GDGPS corrections to space users has been broadcast since 2006. NASA plans to continue developing the TASS. When fully developed, TASS will continually broadcast a navigation signal that includes: GNSS integrity information; TDRS information (status, health, TDRS ephemerides, TDRS maneuver information); Space Weather data; Earth Orientation Parameters;

User Specific Command fields; PRN ranging code for Time synchronization and sub-nanosecond time transfer, and ranging measurements for navigation applications.

B.6 Continuously Operating Reference Station (CORS) System

The NOAA NGS, an element of DOC, has established 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 September 2009, data were being provided from more than 1,370 stations.

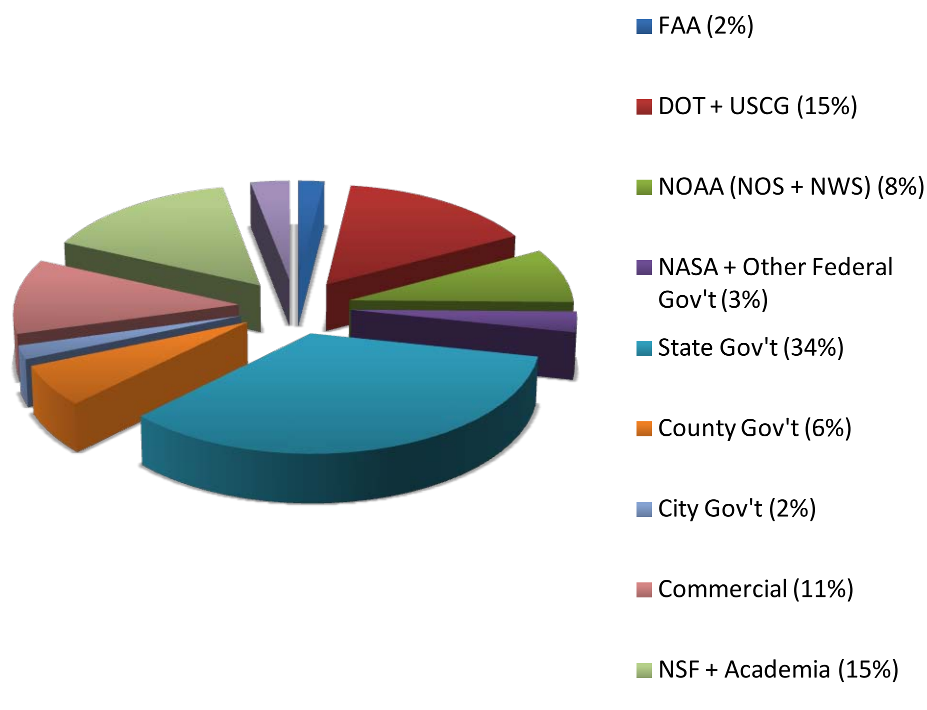

Figure B-5 Partners in the CORS System

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 15% 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 the NOAA Earth Systems Research Laboratory, in support of meteorological applications. The breakdown of CORS partners is illustrated in Figure B-5.

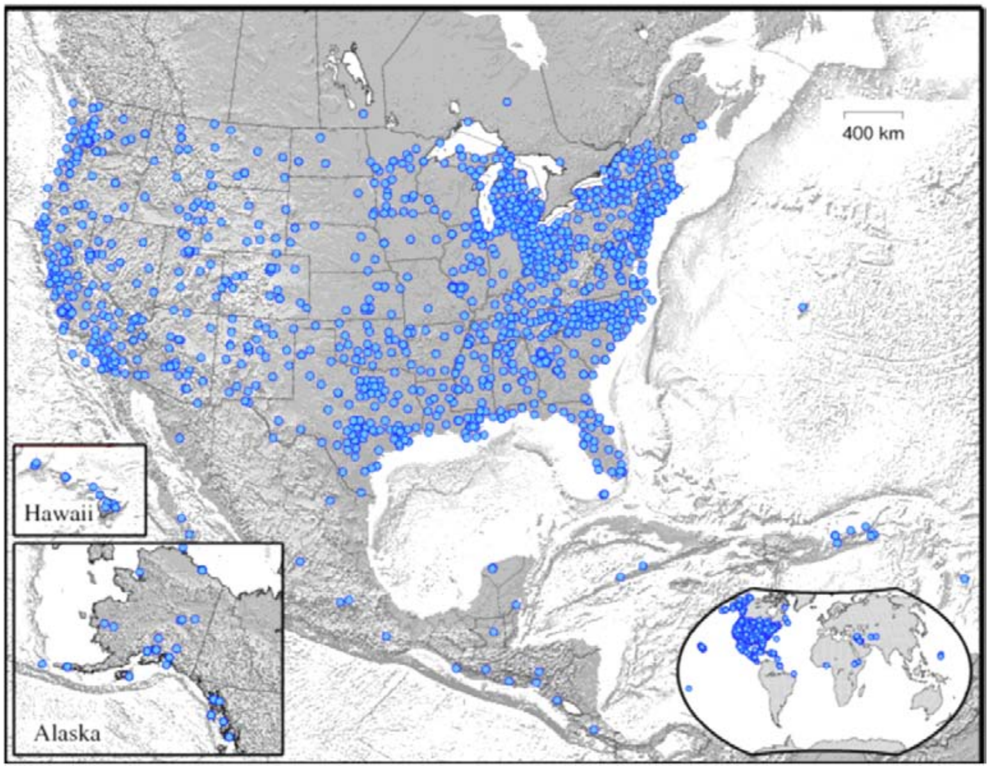

Figure B-6 Map of the CORS System

The CORS system collects GPS data at each of two Parallel Data Facilities (one located in Silver Spring, MD and the other in Boulder, CO) from the contributing stations using either the Internet or a telephone packet service (such as Frame Relay). At each Parallel Data Facility, the GPS data are converted to the Receiver Independent Exchange (RINEX) format, quality controlled, and placed in publicly accessible files on the Internet. In addition to the GPS data, NGS provides software to support the extraction, manipulation and interpolation of the data. Precise positions of the CORS antennas are rigorously computed and monitored. Using CORS data, NGS provides simplified access to high-accuracy positional coordinates via a

Web service called OPUS. A user may submit GPS data collected with a survey-grade GPS receiver to OPUS and obtain, via email, positional coordinates with an accuracy of a few centimeters for the location where the GPS data were collected.

The NOAA Space Weather Prediction Center uses CORS data to produce maps showing the spatial distribution of free electrons in the ionosphere above CONUS once every 15 minutes. The NOAA Earth Systems Research Lab uses CORS data to produce maps of the distribution of precipitable water vapor in the troposphere above CONUS once every hour. Figure B-6 presents a map of the stations contained in the CORS network as of September 2009. This network is currently growing at a rate of about 200 new stations per year.

Appendix C

Geodetic Reference Systems and Datums

C.1 Terrestrial Reference Systems

Geodetic positions referenced to the Earth are defined in the general context of a *terrestrial reference system* and with respect to a specific *terrestrial reference frame*. The reference system defines the physical constants, models, conventions, and coordinate system needed to unambiguously and consistently define the coordinates of a point. For example, the coordinate system is usually defined in an abstract sense as a 3-dimensional Cartesian (x,y,z) system with its origin at the Earth's center of mass and the three coordinate axes aligned with the equator and the rotational axis of the Earth, and rotating with the Earth's crust. Constants include quantities such as the gravitational constant (GM), the semi-major axis of the Earth, and the speed of light, while models include tidal corrections, a gravitational model, and tectonic plate motion models.

The scientific standard for the terrestrial reference system is the *International Terrestrial Reference System (ITRS)*. The ITRS embodies a set of conventions that represent the state-of-the-art for referencing geodetic positions to the Earth. These conventions are established by the International Earth Rotation and Reference Systems Service (IERS). The physical realization (or materialization) of this system is a global network of ground stations (on the Earth's crust) whose 3-dimensional coordinates and linear velocities are derived from space-based observations. These observations are collected using the techniques of Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), GPS, and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). The station coordinate and velocity solutions conform to the ITRS/IERS conventions. This station set defines the *International Terrestrial Reference Frame (ITRF)*. The ITRF is refined periodically with updated solutions for the station coordinates and velocities that define it, and applying any changes that have been adopted in the ITRS. The current version of the reference frame is ITRF 2005.

The terrestrial reference system used by DoD is WGS 84. WGS 84 constitutes an Earth-centered Earth-fixed coordinate system and a prescribed set of constants, models and conventions that are largely adopted from the ITRS. The *WGS 84 reference frame* is defined by a global network of GPS stations whose coordinates are closely aligned with the ITRF. As with the ITRF, the WGS 84 reference frame is periodically updated and designated by the GPS Week Number at which the new reference frame became effective. WGS 84(G1150) is the current reference frame and was aligned to ITRF2000 to approximately 1 cm in each coordinate. The operational reference frame for GPS is WGS 84 so that the broadcast satellite navigation message orbits are referenced to WGS 84 and positions derived directly from the navigation message orbits are also referenced to WGS 84. See National Imagery and Mapping Agency (NIMA), Technical Report (TR) 8350.2, *Department of Defense World Geodetic System 1984, Its Definition and Relationships with Local Geodetic Systems*, 3rd Ed., 4 July 1997 (Ref. 61)

In order to express coordinates in geodetic terms as longitude, latitude and height, a *reference ellipsoid* is defined. For geocentric terrestrial reference systems, this ellipsoid is chosen such that its center coincides with the center of mass of the Earth, its axes are oriented and fixed to the ITRS coordinate axes, and its semi-major and semi-minor axes and rotation rate approximate those of the Earth. The ITRF and WGS 84 both use the Geodetic Reference System 1980 (GRS 80) ellipsoid as their reference ellipsoid. This relationship between the ellipsoid and the terrestrial reference system constitutes the *datum definition* as described in the next section.

In the U.S., the *North American Datum 1983 (NAD 83)* is the standard geocentric geodetic reference system that defines *horizontal control* for the country. The GRS 80 ellipsoid was adopted as the reference surface. Ellipsoidal heights are associated with the horizontal control points. [Reference http://www.ngs.noaa.gov/faq.shtml#Datums]

The MDGPS and NDGPS augmentations to GPS provide users with DGPS corrections that are referenced to NAD 83. (See Appendix Section A.2.2.4.) The national CORS system, described in Appendix B.6, includes coordinate databases in both the NAD 83 and ITRF 2000.

C.2 Geodetic Datums

Since the physical shape of the Earth is closely approximated by the surface of an ellipsoid, an ellipsoid is conventionally chosen as the reference surface for geodetic coordinates. The set of parameters that defines the relationship between a specific reference ellipsoid and a terrestrial reference system is called a *geodetic datum*. A *global* geodetic datum is defined by an ellipsoid that best fits the figure of the Earth as a whole, whose origin coincides with the center of mass of the Earth, and whose major and minor axes are parallel with (in the same direction as) the coordinate axes of the terrestrial reference system. Both WGS 84 and NAD 83 use such a global reference ellipsoid (specifically, the Geodetic Reference System 1980 (GRS80) ellipsoid) for their datum definitions. A global geodetic datum is also essential for positioning and navigation using satellite observations. The three-dimensional geodetic coordinates (latitude, longitude and ellipsoidal height) computed using GPS and its broadcast satellite orbits are referenced to the WGS 84 ellipsoid. Thus, the WGS 84 ellipsoid acts as a three-dimensional reference surface (horizontal and vertical) for satellite-derived geodetic positions. The parameters that define the specific reference ellipsoid are also required for making map projections, the process of mathematically representing the surface of the 3-dimensional figure of the Earth on a plane, in effect, on a two-dimensional map.

Prior to the availability of satellite data, each nation or region established a *local* geodetic datum that was generally not geocentric and for which the reference ellipsoid was a best fit only for the local area. Many maps are still based on these local datums. In these cases, the reference ellipsoid is used only as a local *horizontal* (2-dimensional) *datum*, whose origin and orientation are defined by six topocentric parameters. *North American Datum 1927 (NAD 27)* is one example. NAD 83 removed many significant local distortions in NAD 27, changed the reference ellipsoid, with its origin at the geocenter rather than a survey point in Kansas. NAD 83 was affirmed as the official horizontal datum for the U.S. by a notice in the Federal Register (Vol. 54, No. 113 Pg. 25318) on June 14, 1989 (Ref. 62). Note that, although they use the same reference ellipsoid, the origins of NAD 83 and WGS 84 are offset about 2 meters due to the difference in the realization of the reference systems.

A separate *vertical* datum is traditionally defined using (local) mean sea level (MSL) as the reference surface and a level gravitational surface (the geoid) as a surrogate for MSL (see below). Transformation parameters have been computed in many cases to convert local horizontal datum coordinates to global datum coordinates. This involves at a minimum a shift (or translation) in the origin of the coordinate system from the one defined by the local datum ellipsoid to the one defined by the global datum ellipsoid. In practice, the local ellipsoids may not be exactly aligned with the geocentric terrestrial reference system on which the global datum is based, so rotations and scaling of the local system may be needed in addition to the origin shift to convert coordinates. Tables of these transformation parameters are available, for example, from the National Geospatial-Intelligence Agency [Reference Geographic Translator

(GEOTRANS) Version 2.4.2 (Oct. 2008), http://earth-info.nga.mil/GandG/geotrans/index.html].

C.3 Vertical Datums and the Geoid

A *vertical datum* is the reference surface for *orthometric* heights. Unlike ellipsoidal heights, which are purely of geometric nature, orthometric heights are related to the Earth's gravity field, and are of physical nature. Orthometric heights are measured along the plumb line in the direction of local gravity. Vertical datums are traditionally defined as Mean Sea Level (MSL) or averaged tidal observations based on low or high water (for example, Mean Lower Low Water). Since the ocean surface, in an idealized sense, is subject only to the force of gravity, one can define an equilibrium state such that the surface represents a level surface on the Earth's gravity field. This average state is used then to effectively define zero elevation. All elevations on land are referenced to this zero value.

North American Vertical Datum 1988 (NAVD 88) applied this concept by adopting the single tide gauge elevation at Point Rimouski, Quebec, Canada as the continental elevation reference point and essentially references all other elevations in the U.S. to this. NAVD 88 was affirmed as the official vertical datum for the U.S. by a notice in the Federal Register (Vol. 58, No. 120, Pg. 34325) on June 24, 1993 (Ref. 63). By contrast, the *National Geodetic Vertical Datum 1929 (NGVD 29)* was fixed to a set of reference tide gauges, without correction for local variations in the sea state, as a method of defining the vertical reference. Depending on their age, U.S. topographic products and data can be referenced to either NAVD 88 or NGVD 29. [Reference http://www.ngs.noaa.gov/faq.shtml#Datums]

The "best fit" approximation or realization of mean sea level at continental and global scales is a level surface of the Earth's gravity field defined as the *geoid*. Due to effects such as atmospheric pressure, temperature, prevailing winds and currents, and salinity variations, MSL will depart from this level surface by a meter or more. Once defined, the geoid becomes the zero-elevation surface to which heights can be referenced. Note that the differences in heights referenced to the geoid versus heights referenced to the ellipsoid can be as much as 100 m.

Many national and 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 ways the various vertical datums are realized, other departures at the meter level or more will be found when comparing elevations to a global geoid reference.

For the U.S., a *hybrid* geoid model, *GEOID09*, has been developed to directly relate ellipsoidal heights from the NAD 83 datum to the NAVD 88 vertical datum. The control data consist of bench marks where both the GPS-derived NAD 83 ellipsoidal height and leveled NAVD 88 orthometric height are known. Conversion of GPS-derived ellipsoidal height to orthometric height can generally be accomplished in the conterminous U.S. to about 2.5 cm (1-sigma); however, this is not a true measure of the accuracy of GEOID09 due to the inclusion of GPS elevations in its original derivation. [Reference http://www.ngs.noaa.gov/GEOID/GEOID09/]

On a global basis, the WGS 84 *Earth Gravitational Model 2008 (EGM08)* is the latest and most accurate and complete gravitational model from which a global geoid is derived. This supersedes EGM96, the previous model. The WGS 84 (EGM08) geoid is accurate to better than 15 cm (RMS error) over areas where high-accuracy gravity data were available for inclusion in the model. Over the conterminous U.S., EGM08 is accurate to approximately 5 cm (1-sigma), based on comparisons with independent GPS and leveling data. [Reference: N. K. Pavlis et al., An Earth Gravitational Model to Degree 2160: EGM2008, presented at EGU General Assembly 2008, Vienna, Austria, Apr. 13-18, 2003 (Ref. 64); http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008/index.html]

C.4 Land Maps

As discussed earlier, the NAD 83 and the NAVD 88 datums were adopted by Congress for use in the U.S., and new maps such as U.S. Geological Survey topographic maps are compiled on these datums. Except for the largest map scales, the horizontal components of WGS 84 and NAD 83 are equivalent. Older U.S. maps are compiled on older datums, such as the North American Datum of 1927 (NAD 27) and the National Geodetic Vertical Datum of 1929 (NGVD 29). When using coordinates and heights taken from maps created on these and other older datums, care should be taken to convert coordinates and heights between the NAD 27 and the NAD 83 datums, and the NGVD 29 and NAVD 88 datums. Datum transformations are available which relate the NAD 27 and NAD 83 datums, and which relate the NGVD 29 and NAVD 88 datums.

C.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, IHO designated the use of the WGS 84 as the universal datum. Since then, the horizontal features have been based on WGS 84 or on other geodetic reference systems that are compatible, such as NAD 83. All electronic charts are required to be based upon WGS 84.

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.

C.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).

C.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.

C-8

Appendix D

Acronyms

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

ABAS	Aircraft-Based Augmentation System
ACTS	Automated Computer Time Service
ADF	Automatic Direction Finder
ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance-Broadcast
ADS-C	Automatic Dependent Surveillance-Contract
AFSPC	Air Force Space Command
A/G	Air-to-Ground
AGL	Above Ground Level
AIM	Aeronautical Information Manual
AIS	Automatic Identification System
AM	Amplitude Modulation
AMC	Alternate Master Clock
ANLE	Airport Network and Location Equipment
ANSP	Air Navigation Service Provider
APV	Approach Procedure with Vertical Guidance
ARNS	Aeronautical Radionavigation Service

ASD(NII)	Assistant Secretary of Defense for Networks and Information Integration
ASR	Airport Surveillance Radar
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
BCD	Binary Code Decimal
BIPM	International Bureau of Weights and Measures
BTS	Bureau of Transportation Statistics
CAPE	Cost Assessment & Program Evaluation
C/A	Coarse/Acquisition
CAT	Category
CCW	Coded Continuous Wave
CDL	Commercial Drivers License
CDMA	Code Division Multiple Access
CEP	Circular Error Probable
CES	Coast Earth Station
CFR	Code of Federal Regulations
CGPM	Conférence Générale des Poids et Mesures
CGS	Civil GPS Service
CGSIC	Civil GPS Service Interface Committee
CJCS	Chairman, Joint Chiefs of Staff
CNS	Communication, Navigation and Surveillance
COMPETES	Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science
CONUS	Conterminous United States
CORS	Continuously Operating Reference Stations
CPDLC	Controller Pilot Data Link Communications
CRAF	Civil Reserve Air Fleet
DGPS	Differential Global Positioning System

DHS	Department of Homeland Security
DIA	Defense Intelligence Agency
DME	Distance Measuring Equipment
DNI	Director of National Intelligence
DOC	Department of Commerce
DoD	Department of Defense
DOI	Department of Interior
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DOS	Department of State
DOT	Department of Transportation
DSCS	Defense Satellite Communications Systems
DSL	Digital Subscriber Line
DUATS	Direct User Access Terminal System
EA	Electronic Attack
EFVS	Enhanced Flight Vision System
EGM	Earth Gravity Model
eLoran	Enhanced Loran
EMCON	Emission Control
EMD	Engineering, Manufacturing, and Development
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FAR	Federal Aviation Regulation
FCC	Federal Communications Commission
FDC	Flight Data Center
FDE	Fault Detection and Exclusion
FDF	Flight Dynamics Facility
FHWA	Federal Highway Administration
FL	Flight Level

FMCSA	Federal Motor Carrier Safety Administration
FMS	Fight Management Systems
FOC	Full Operational Capability
FoS	Family of Systems
FRA	Federal Railroad Administration
FRN	Federal Register Notice
FRP	Federal Radionavigation Plan
FRS	Federal Radionavigation Systems
FSS	Flight Service Station
FTA	Federal Transit Administration
FTE	Flight Technical Error
GATM	Global Air Traffic Management
GBAS	Ground-Based Augmentation Systems
GDGPS	Global Differential GPS
GEO	Geosynchronous Earth Orbit
GES	Ground Earth Station
GIS	Geographic Information Systems
GLONASS	Global Navigation Satellite System (Russian Federation)
GMDSS	Global Maritime Distress and Safety System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPS-MT	Global Positioning System – Metric Tracking
GRORS	GPS RAIM Outage Reporting System
GRS	Geodedic Reference System
HA-NDGPS	High Accuracy Nationwide Differential Global Positioning System
HAZMAT	Hazardous Materials
HEA	Harbor Entrance and Approach

HSPD-7	Homeland Security Presidential Directive – 7
HUD	Head-up Display
IAG	International Association of Geodesy
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IC	Intelligence Community
ICAO	International Civil Aviation Organization
IDM	Interference Detection and Mitigation
IERS	International Earth Rotation and Reference Systems Service
IFR	Instrument Flight Rules
IGEB	Interagency GPS Executive Board
IGS	International GNSS Service
IHO	International Hydrographic Organization
ILS	Instrument Landing System
IMDS	Interference Monitoring Detection System
IMO	International Maritime Organization
INMARSAT	International Maritime Satellite Organization
INS	Inertial Navigation System
INU	Inertial Navigation Unit
IOC	Initial Operational Capability
IP	Internet Protocol
IRAC	Interdepartment Radio Advisory Committee
IRNSS	India Regional Navigation Satellite System
IRP	Interagency Requirements Process
IRU	Inertial Reference Unit
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
ITS	Intelligent Transportation Systems

ITS	Internet Time Service
ITS-JPO	Intelligent Transportation Systems Joint Program Office
ITU	International Telecommunication Union
JCIDS	Joint Capabilities Integration and Development System
JCS	Joint Chiefs of Staff
JPALS	Joint Precision Approach and Landing System
JPDO	Joint Planning and Development Office
JPL	Jet Propulsion Laboratory
JPO	Joint Program Office
JROC	Joint Requirements Oversight Council
JTIDS	Joint Tactical Information Distribution System
LAAS	Local Area Augmentation System
LEO	Low Earth Orbit
LF	Low Frequency
LGF	LAAS Ground Facility
LMSL	Local Mean Sea Level
LNAV	Lateral Navigation
LOP	Line of Position
Loran	Long Range Navigation
LPV	Localizer Performance with Vertical Guidance
MARAD	Maritime Administration
MCS	Master Control Station
MCW	Modulated Continuous Wave
MDGPS	Maritime Differential GPS Service
MEO	Medium Earth Orbit
MIDS	Multi-function Information Distribution System
MLLW	Mean Lower Low Water

MLS	Microwave Landing System
MNPS	Minimum Navigation Performance Specification
MOA	Memorandum of Agreement
MOPS	Minimum Operational Performance Standards
MPNTP	Master Positioning, Navigation, and Timing Plan
MSC	Military Sealift Command
MSK	Minimum Shift Keying
MSL	Mean Sea Level
NAC_p	Navigation Accuracy Category for Position
NAC_v	Navigation Accuracy Category for Velocity
NAD	North American Datum
NADIN	National Airspace Data Interchange Network
NANU	Notice Advisories to Navstar Users
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NAVAID	Navigation Aid
NAVCEN	USCG Navigation Center
NAVD	North American Vertical Datum
NAVWAR	Navigation Warfare
NC FCB	Netcentric Functional Capabilities Board
NCIS	Net-Centric Information Sharing
NCO	National Coordination Office
NDB	Nondirectional Beacon
NDGPS	Nationwide Differential Global Positioning Service
NextGen	Next Generation Air Transportation System
NGA	National Geospatial-Intelligence Agency
NGS	National Geodetic Survey

NGVD	National Geodetic Vertical Datum
NHTSA	National Highway Traffic Safety Administration
NIC	Navigation Integrity Category
NII	Networks and Information Integration
NIMA	National Imagery and Mapping Agency
NIPRNet	Non-classified Internet Protocol Router Network
NIS	Navigation Information Service
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
NPA	Nonprecision Approach
NRL	Naval Research Laboratory
NSA	National Security Agency
NSF	National Science Foundation
NSRS	National Spatial Reference System
NTIA	National Telecommunications and Information Administration
NTP	Network Time Protocol
OAB	Operational Advisory Broadcast
OASIS	Operational and Supportability Implementation System
OCS	Operational Control System
OPUS	Online Positioning User Service
ORD	Operational Requirements Document
OST	Office of the Secretary of Transportation
OST/B	Assistant Secretary for Budget Programs
OST/C	General Counsel's Office
OST/M	Assistant Secretary for Administration
OST/P	Assistant Secretary for Transportation Policy

PAR	Precision Approach RADAR
PBN	Performance Based Navigation
PDD	Presidential Decision Directive
PHMI	Probability of Hazardously Misleading Information
PHMSA	Pipeline and Hazardous Materials Safety Administration
PNT	Positioning, Navigation, and Timing
POS/NAV	Positioning and Navigation
PPS	Precise Positioning Service
PRN	Pseudo-Random Noise
PS	Performance Standard
PTC	Positive Train Control
Pub. L.	Public Law
QZSS	Quasi Zenith Satellite System
R&D	Research & Development
RADAR	Radio Detecting and Ranging
RAIM	Receiver Autonomous Integrity Monitoring
RCC	Rescue Coordination Center
RF	Radio Frequency
RF	Radius-to-Fix
RFI	Radio Frequency Interference
RINEX	Receiver Independent Exchange
RITA	Research and Innovative Technology Administration
RNAV	Area Navigation
RNP	Required Navigation Performance
RNPSORSG	Required Navigation Performance and Special Operational Requirements Study Group
RNS	Radionavigation Service
RNSS	Radionavigation Satellite Service

RSS	Root Sum Square
RTCM	Radio Technical Commission for Maritime Services
RVR	Runway Visual Range
SA	Selective Availability
SAR	Search and Rescue
SARPS	Standards and Recommended Practices
SATNAV	Satellite-based Navigation
SBAS	Space-Based Augmentation System
SBR	Space-Based Range
SCaN	Space Communications and Navigation
SCUBA	Self Contained Underwater Breathing Apparatus
SDA	System Design Assurance
SFTP	Secure File Transfer Protocol
SID	Standard Instrument Departure
SIL	Source Integrity Level
SIPRNet	Secret Internet Protocol Router Network
SIS	Signal-In-Space
SLR	Satellite Laser Ranging
SLSDC	Saint Lawrence Seaway Development Corporation
SNTP	Simple Network Time Protocal
SOMD	Space Operations Mission Directorate
SONAR	Sound Navigation and Ranging
SPC	Senior Policy Committee
SPS	Standard Positioning Service
SSV	Standard Service Volume
STAR	Standard Terminal Arrival Route
Stat.	Statute
S&T	Science and Technology

TACAN	Tactical Air Navigation
TASS	TDRSS Augmentation Service Satellites
TD	Time Difference
TDRSS	Tracking and Data Relay Satellite System
TDWR	Terminal Doppler Weather Radio
TERPS	Terminal Instrument Procedures
TIS	Traffic Information Services
TMAS	Time Measurement and Analysis Service
TRSB	Time Reference Scanning Beam
TSO	Technical Standard Order
TT&E	Tests, Training, and Exercises
TWSTT	Two-Way Satellite Time Transfer
UAS	Unmanned Aircraft System
UHF	Ultra High Frequency
UN	United Nations
UNAVCO	University NAVSTAR Consortium
URA	User Range Accuracy
URE	User Range Error
USACE	U.S. Army Corps of Engineers
USAF	United States Air Force
USC	United States Code
USCG	United States Coast Guard
USDA	U.S. Department of Agriculture
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
USD(I)	Under Secretary of Defense for Intelligence
USD(P)	Under Secretary of Defense for Policy
UDP	User Datagram Protocol
USG	United States Government

USMC	United States Marine Corps
USN	United States Navy
USNO	United States Naval Observatory
USNOF	United States NOTAM Office
USNS	United States NOTAM System
USSTRATCOM	United States Strategic Command
UTC	Coordinated Universal Time
US-TEC	United States Total Electron Content
VDB	VHF Data Broadcast
VFR	Visual Flight Rules
VHF	Very High Frequency
VLBI	Very Long Baseline Interferometry
VNAV	Vertical Navigation
VOR	Very High Frequency Omnidirectional Range
VORTAC	Collocated VOR and TACAN
VTS	Vessel Traffic Services
WAAS	Wide Area Augmentation System
WGS	World Geodetic System
WMS	Wide Area Master Station
WRC	World Radiocommunication Conference
WRS	Wide Area Reference Stations
2SOPS	2^{nd} Space Operations Squadron
4-D	Four Dimensional

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

bps	bits per second
dBW	Decibel watt (decibels relative to one watt)
deg	degrees
drms	distance root mean squared
ft	feet
hr	hour
Hz	Hertz (cycles per second)
GHz	Gigahertz
kHz	kilohertz
MHz	Megahertz
m	meter
cm	centimeter
km	kilometer
mm	millimeter
min	minute
mi	mile
nmi	nautical mile
s	second
ms	millisecond
µs	microsecond
ns	nanosecond
ps	picosecond
W	Watt

Appendix E

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. PNT system accuracy is usually presented as a statistical measure of system error and is specified as:

- Predictable - The accuracy of a PNT 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 ground or space-based navigation aids or within the limits of capability of self-contained aids, or a combination of these.

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.

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 nmi 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 s.

Coverage - The coverage provided by a PNT 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 that affect signal availability.

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

Divestment – The transfer of a PNT facility to a non-Federal service provider when it no longer meets criteria for sustainment as a Federal service. If a PNT 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.

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.

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

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.

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.

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 (Ref. 65).

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 PNT.

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 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.

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

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.

UT1 - A time scale based on the rotation of Earth on its axis with respect to the Sun, rather than atomic clocks. UT1 takes polar motion into account. Leap seconds are used in the UTC time scale to maintain it within 0.9 s of UT1.

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. Chairman, Joint Chiefs of Staff Instruction 6130.01D, *DoD Master Positioning, Navigation, and Timing Plan* (MPNTP), 13 April 2007 [CJCSI 6130.01D]

2. Title 49 United States Code, Section 101 [49 USC § 101]

3. Title 10 United States Code, Section 2281 [10 USC § 2281]

4. Public Law 95-564, November 1, 1978, 92 Stat. 2392 (47 USC 751 et seq.), *International Maritime Satellite (INMARSAT) Telecommunications Act of 1978* [Pub. L. 95-564]

5. Public Law 107-296, November 25, 2002, 116 Stat. 2135 (6 USC 101 et seq.), *Homeland Security Act of 2002* [Pub. L. 107-296]

6. Department of Transportation, Office of the Secretary of Transportation, Memorandum to Departmental Officers and Heads of Operating Administrations, *Positioning, Navigation, and Timing (PNT) and Spectrum Management, Realignment under the Research and Innovative Technology Administration (RITA),* August 01, 2007 [OST MEMO]

7. Title 49 United States Code, Section 44505 [49 USC § 44505]

8. Public Law 105-66, October 27, 1997, 111 Stat. 1425, *Department of Transportation and Related Agencies Appropriations Act of 1998*, [Pub. L. 105-66]

9. Title 14 United States Code, Section 81 [14 USC § 81]

10. Public Law 85-568, July 29, 1958, 72 Stat. 426 (42 USC 2451 et seq.), *National Aeronautics and Space Act of 1958* [Pub. L. 85-568]

11. Title 33 United States Code, Section 883a. through c. [33 USC § 883a-c.]

12. National Security Presidential Directive-39, *U.S. Space-Based Position, Navigation, and Timing Policy*, December 8, 2004 [NSPD-39]

13. *National Space Policy of the United States of America*, June 28, 2010 [*National Space Policy*]

14. Public Law 85-726, August 23, 1958, 72 Stat. 737, *Federal Aviation Act of 1958* [Pub. L. 85-726]

15. Public Law 84-627, June 29, 1956, 70 Stat. 374, Chapter 462, Title I, *The National Interstate and Defense Highways Act of 1956 (Federal-Aid Highway Act of 1956)* [Pub. L. 84-627]

16. The Report of the President's Commission on Critical Infrastructure Protection, *Critical Foundations, Protecting America's Infrastructures*, October 13, 1997

17. Presidential Decision Directive/NSC-63, *Critical Infrastructure Protection*, May 22, 1998, Annex B: Additional Taskings [PPD/NSC-63]

18. Department of Transportation, Research and Innovative Technology Administration (RITA), John A.Volpe National Transportation Systems Center, *Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System, Final Report*, August 29, 2001 [Volpe Report]

19. Homeland Security Presidential Directive-7, *Critical Infrastructure Identification, Prioritization, and Protection*, December 17, 2003 [HSPD-7]

20. Department of Homeland Security, *Positioning, Navigation, and Timing, Interference Detection and Mitigation (IDM) Plan*, August 20, 2007 [PNT IDM Plan]

21. Department of Homeland Security, *Interference Detection and Mitigation (IDM) Plan Implementation Strategy*, January 2008

22. Federal Aviation Regulations (FAR), Title 14, Code of Federal Regulations (CFR), Part 171, *Non-Federal Navigation Facilities* [14 CFR 171]

23. Title 31 United States Code, Section 9701 [31 USC § 9701]

24. Chairman, Joint Chiefs of Staff Manual 3212.03 (series), *Performing Tests, Training, and Exercises Impacting the Global*

Positioning System (GPS) in the United States and Canada, 15 DEC 2008 [CJCSM 3212.03]

25. Department of Commerce, National Telecommunications and Information Administration (NTIA), *Manual of Regulations and Procedures for Federal Radio Frequency Management*, January 2008 Edition (September 2009 Revision)

26. Department of Transportation, Office of the Secretary of Transportation, Order 1120.32, *Navigation and Positioning Coordination and Planning*, April 27, 1979 [DOT 1120.32]

27. Department of Transportation, Office of the Secretary of Transportation Order 1120.32C, *Navigation and Positioning Coordination and Planning*, October 06, 1994 [DOT 1120.32C]

28. Title 49 United States Code, Section 301 [49 USC § 301]

29. National Security Presidential Directive-27, *U.S. Commercial Remote Sensing Policy*, April 25, 2003 [NSPD-27]

30. Public Law 108-176, December 12, 2003, 117 Stat. 2490, *Vision 100--Century of Aviation Reauthorization Act* [Pub. L. 108-176]

31. Public Law 110-69, August 9, 2007, 121 Stat. 572, *America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (COMPETES) Act* [Pub. L. 110–69]

32. The White House, Office of the Press Secretary, *"Statement by the President Regarding the United States' Decision to Stop Degrading Global Positioning System Accuracy*, May 1, 2000 [Presidential SA Statement]

33. International Maritime Organization, Assembly Resolution A.953(23), *World-Wide Radionavigation System*, 5 December 2003 [IMO A 23/Res.953]

34. Department of Defense, Assistant Secretary of Defense for Networks and Information Integration (ASD(NII)), *Global Positioning System (GPS) Standard Positioning Service (SPS) Performance Standard (PS)*, September 2008 [GPS SPS PS]

35. Public Law 111-83, October 28, 2009, 123 Stat. 2142, *Department of Homeland Security Appropriations Act* [Pub. L. 111-83]

36. United States Army Aviation Center, Operational Requirements Document, *Global Air Traffic Management (GATM)*, 12 Jun 2000 [GATM ORD]

37. Federal Register, Volume 73, Number 185, Page 54792, *Preservation of Continuity for Semi-Codeless GPS Applications*, September 23, 2008 [FRN Vol. 73, No. 185, Pg. 54792]

38. Department of Transportation, Federal Aviation Administration (FAA), Order 8620.3B, *United States Standard for Terminal Instrument Procedures (TERPS)*, Third Addition, July 07, 1976 [TERPS]

39. International Civil Aviation Organization, Doc 9613 AN/937, *Performance Based Navigation (PBN) Manual*, Third Edition, 2008 [ICAO 9613 AN/937]

40. International Civil Aviation Organization, Annex 11 to the Convention on International Civil Aviation, *Air Traffic Services*, Thirteenth Edition, July 2001 [ICAO Annex 11]

41. International Civil Aviation Organization, Doc 4444 ATM/501, *Procedures for Air Navigation, Air Traffic Management*, Fifteenth Edition, 22 November 2007 [PANS-ATM]

42. International Civil Aviation Organization, Doc 8168 OPS/611, *Procedures for Air Navigation Services, Aircraft Operations*, Volume I, Flight Procedures, and Volume II, Construction of Visual and Instrument Flight Procedures, Fifth Edition, October 2006, [PANS-OPS]

43. International Civil Aviation Organization, Doc 7030, *Regional Supplementary Procedures*, Fifth Edition, January 2008 [ICAO 7030]

44. International Civil Aviation Organization, Doc 9426 AN/924, *Air Traffic Services Planning Manual*, 1984 [ICAO 9426 AN/924]

45. International Civil Aviation Organization, Doc 9689 AN/953, *Manual on Airspace Planning Methodology for the Determination of Separation Minima*, First Edition, December 1998 [ICAO 9689 AN/953]

46. International Civil Aviation Organization, Annex 10 to the Convention on International Civil Aviation, *Aeronautical Telecommunications*, Volume I – *Radio Navigation Aids* [ICAO Annex 10 Vol. I]

47. Department of Transportation, Federal Aviation Administration (FAA), Advisory Circular (AC) 90-100A, *U.S. Terminal and En Route Area Navigation (RNAV) Operations*, March 1, 1997 [AC 90-100A]

48. Federal Aviation Regulations (FAR), Title 14, Code of Federal Regulations (CFR), Part 91, *General Operating and Flight Rules* [14 CFR 91]

49. Air Force Space Command/Air Combat Command, *Operational Requirements Document (ORD) AFSPC/ACC 003-92-I/II/III for Global Positioning System (U)*, 1998 [GPS ORD]

50. Federal Railroad Administration, Report to the Committees on Appropriations, *Differential GPS: An Aid to Positive Train Control,* June 1995 [FRA PTC Report]

51. Navstar Global Positioning System Joint Program Office, Interface Specification, *Navstar GPS Space Segment/Navigation User Interfaces*, Revision D, 7 December 2004 [IS-GPS-200]

52. Federal Register, Volume 75, Number 4, Page 998, *Terminate Long Range Aids to Navigation (Loran-C) Signal*, January 7, 2010 [FRN Vol. 75, No. 4, Pg. 998]

53. Federal Register, Volume 75, Number 4, Page 997, *Record of Decision (ROD) on the U.S. Coast Guard Long Range Aids to Navigation (Loran-C) Program*, January 7, 2010 [FRN Vol. 75, No. 4, Pg. 997]

54. Department of Transportation, United States Coast Guard (USCG), *Broadcast Standard for the USCG DGPS Navigation Service*, April 1993 [COMDTINST M16577.1]

55. Department of Transportation, Federal Aviation Administration (FAA), *Aeronautical Information Manual (AIM)*, February 11, 2010 [AIM]

56. Department of Transportation, Federal Aviation Administration (FAA), Order 9840.1, *U.S. National Aviation Standard for the VOR/DME/TACAN Systems*, December 10, 1984 [FAA Order 9840.1]

57. Department of Commerce, National Institute of Standards and Technology (NIST), NIST Special Publication 432, *NIST Time and Frequency Services*, January 2002 [NIST Pub. 432]

58. Department of Defense Directive 4650.05, Assistant Secretary of Defense for Networks and Information Integration, *Positioning, Navigation, and Timing (PNT)*, February 19, 2008 [DODD 4650.05]

59. Radio Technical Commission for Aeronautics, RTCA/DO-208, *Minimum Operational Performance Standards for Airborne*

Supplemental Navigation Equipment Using Global Positioning System (GPS), July 1991 [RTCA/DO-208]

60. Department of Transportation, Federal Aviation Administration (FAA), Technical Standard Order (TSO)-C129a, *Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS)*, February 20, 1996 [TSO-C129a]

61. National Imagery and Mapping Agency, Technical Report 8350.2, *Department of Defense World Geodetic System 1984, Its Definition and Relationships with Local Geodetic Systems*, Third Edition, Amendment 1, 3 January 2000 [NIMA TR8350.2]

62. Federal Register, Volume 54, Number 113, Page 25318, *Affirmation of Datum for Surveying and Mapping Activities*, June 14, 1989 [FRN Vol. 54, No. 113, Pg. 25318]

63. Federal Register, Volume 58, Number 120, Page 34325, *Affirmation of Vertical Datum for Surveying and Mapping Activities*, June 24, 1993 [FRN Vol. 58, No. 120, Pg. 34325]

64. Department of Defense, National Geospacial-Intelligence Agency (NGA), N. K. Pavlis et al., *An Earth Gravitational Model to Degree 2160: EGM2008*, Presented EGU General Assembly 2008, Vienna, Austria, April 13-18, 2003 [NGA EGM2008 2160]

65. International Maritime Organization, Publication IMO-951E , *The NAVTEX Manual*, 1994 [IMO-951E]