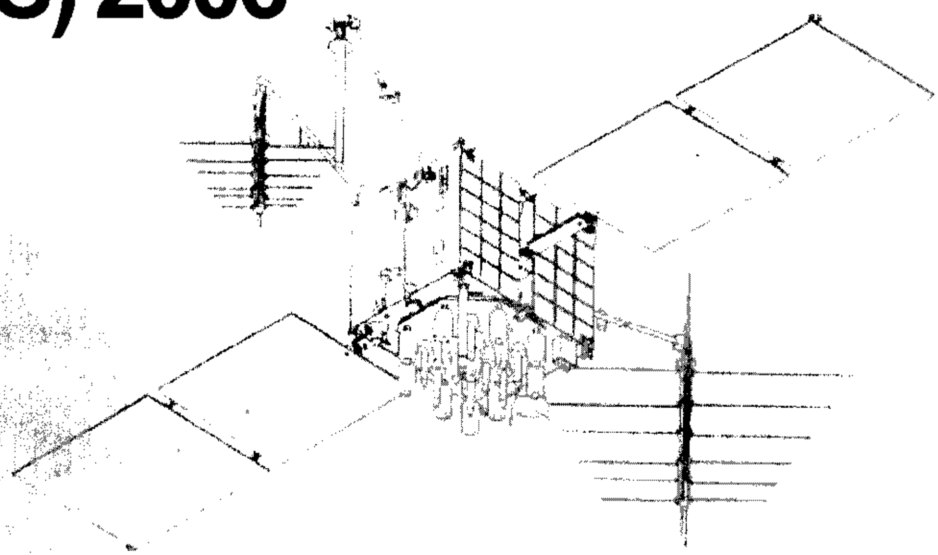
Department of Defense

Global Positioning System (GPS) 2006



A Report to Congress
31 October 2006

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ASSISTANT SECRETARY OF DEFENSE
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NETWORKS AND INFORMATION
INTEGRATION

FOREWARD

The National Defense Authorization Act for Fiscal Year 1998 (Public Law 105-85) established a requirement (10 U.S.C. 2281) for the Department of Defense (DoD), in consultation with the Departments of State, Commerce, and Transportation, to submit biennial reports to the Senate Committee on Armed Services and the House Committee on Armed Services on the status of specific elements of the Global Positioning System.

The Secretary of Defense has delegated responsibility for this report to the Office of the Assistant Secretary of Defense for Networks and Information Integration.

The National Coordination Office for Space-Based Positioning, Navigation and Timing, established in 2005, provides the conduit for coordination of this report with appropriate USG departments and agencies.

This document is the fifth in a continuing series of reports. Previous DoD GPS Reports were submitted to Congress in October 1998, 2000, 2002, and 2004.

John G. Grimes

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Contents

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ACRONYMS

AEP	Architecture Evolution Plan
AFB	Air Force Base
AFSPC	Air Force Space Command
AMCS	Alternate Master Control Station
ARNS	Aeronautical Radionavigation Service
ASD	Assistant Secretary of Defense
AT&L	Acquisition, Technology and Logistics
BDA	Burst Detector Analyzer (NDS)
BDP	Burst Detector Processor (NDS)
BMCS	Backup Master Control Station
CDD	Capability Development Document
CENTCOM	Central Command
CHAMP	Challenging Minisatellite Payload
CJCS	Chairman of the Joints Chiefs of Staff
cm	centimeter(s)
CNS/ATM	Communications, Navigation, Surveillance/Air Traffic Management
COCOM	Combatant Command
CORS	Continuously Operating Reference Stations
COSMIC	Constellation Observing System for Meteorology Ionosphere and Climate
CXD	Combined X-ray and Dosimeter (NDS sensor)
DAGR	Defense Advanced GPS Receiver
DASS	Distress Alerting Satellite System
DGPS	Differential GPS
DHS	Department of Homeland Security
DoD	Department of Defense
DOC	Department of Commerce
DOT	Department of Transportation
DSB	Defense Science Board
DSP	Defense Support (satellite) Program
EMI	Electro-Magnetic Interference
EMP	Electro-Magnetic Pulse
EP	Electronic Protection (Navwar)
EU	European Union
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FRP	Federal Radionavigation Plan
GANS	Global Air Navigation System
GBAS	Ground-Based Augmentation System (e.g., NDGPS)
GDGPS	Global Differential GPS (System)
GETS	GPS Enhanced Theater Support
GLONASS	Global Navigation Satellite System (Russian)
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment

IALA	International Association (of Marine Aids to Navigation) and Lighthouse Authorities
ICAO	International Civil Aviation Organization
ICG	International Cooperation Guidance (for GPS and Navwar)
ILS	Instrument Landing System
IMO	International Maritime Organization
INS	Inertial Navigation System
IRNS	India Regional Navigation System
ITU	International Telecommunications Union
JNWC	Joint Navigation Warfare Center
JPALS	Joint Precision Approach and Landing System
JPO	Joint Program Office
JPL	Jet Propulsion Lab (NASA)
JROC	Joint Requirements Oversight Council
LAAS	Local Area Augmentation System
LPTV	Low Power Television
M-code	Military Code
MGUE	Military GPS UE
MCS	Master Control Station
MILSPEC	Military Specifications
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MGUE	Military GPS User Equipment
MUE	Modernized User Equipment
NAS	National Airspace System or National Air Space
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
Navwar	Navigation Warfare
NCO	National Coordinating Office for Space-Based PNT
NDGPS	Nationwide Differential GPS
NDS	NUDET Detection System
NGA	National Geospatial-Intelligence Agency
NII	Networks and Information Integration
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPEC	National (Space-Based) PNT Executive Committee
NSA	National Security Agency
NSP	Navigation Systems Panel
NSPD	National Security Presidential Directive
NSTC	National Science and Technology Council
NTIA	National Telecommunications and Information Administration
NUDET	Nuclear Detonation
OCS/OCX	Operational Control System (Current/Future)
OIF	Operation Iraqi Freedom
ORD	Operational Requirements Documents
PDD	Presidential Decision Directive
PNT	Positioning, Navigation and Timing
PPS	Precise Positioning Service

RTCM	Radio Technical Commission for Maritime (services)
QZSS	Quasi-Zenith Satellite System (Japan)
RNSS	Radio-Navigation Satellite Service
SAASM	Selective Availability / Anti-Spoofing Module
SAC	Satellite de Applicaciones Cientificas (Scientific Applications Satellite)
SAR	Search And Rescue
SBAS	Space-Based Augmentation System (e.g., WAAS)
SC	Special Committee
SORD	System(s) Operational Requirements Document
SPS	Standard Positioning Service
STRATCOM	Strategic Command
TACAN	Tactical Air Navigation (system)
TASS	TDRSS Augmentation Service for Satellites
TDRSS	Tracking and Data Relay Satellite System
TTPs	Tactics, Techniques and Procedures
UAV	Unmanned Aerial Vehicle
UE	User Equipment (also known as "GPS receivers")
UHF	Ultra-High Frequency
US/U.S.	United States
USD	Under Secretary of Defense
USCENTCOM	United States Central Command
USCG	United States Coast Guard
USG	United States Government
USNDS	United States NUDET Detection System
USNO	United States Naval Observatory
USSTRATCOM	United States Strategic Command
UTC	Coordinated Universal Time
UWB	Ultra-Wide Band
WAAS	Wide Area Augmentation System
WRC	World Radiocommunication Conference

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EXECUTIVE SUMMARY

This Department of Defense (DoD) report to Congress on the status of the Global Positioning System (GPS) expands the scope of previous reports and provides more detail about GPS program successes and challenges. It adds GPS-related sections on: 1) the Nuclear Detonation Detection System; 2) Navigation Warfare; 3) the U.S. Naval Observatory and precise timing; 4) the Joint Precision Approach and Landing System; 5) challenges faced by users in Iraq and Afghanistan; and 6) findings from the recent Defense Science Board (DSB) task force on the future of GPS.

A National Security Presidential Directive (NSPD) for Space-Based Positioning, Navigation and Timing (PNT) was signed by the President in December 2004. The new policy provides guidance on the procurement, management, and protection of the GPS segments. The NSPD creates a National PNT Executive Committee (NPEC) to advise and coordinate among federal agencies on policies, issues, and initiatives pertaining to GPS and related space-based PNT systems. It also provides a framework to ensure compatibility or interoperability with other (foreign) space-based PNT systems. Various U.S. Government (USG) departments and agencies are using this national policy to develop and deliver more specific directives and instructions for military and civil GPS developers and users.

The 2004 NSPD led the DoD to develop its major space-based PNT goals: 1) sustain current capability; 2) modernize all GPS segments; and 3) eliminate or mitigate emerging threats. These DoD goals support the overall U.S. interagency goal to deliver a mix of common-use radionavigation systems that will include GPS to: 1) meet diverse PNT user requirements; 2) maintain current services and performance while providing for future growth; and 3) eliminate unnecessary duplication of PNT services.

The DoD remains committed to ensuring a healthy and robust satellite constellation. In the face of fiscal, technical, and programmatic challenges, GPS continues to function at or above specified performance levels. Currently, there are 30 operational satellites on orbit. However, 16 of these are past their design life and 19 lack redundancy for critical on-board subsystems. Should delivery and launch of the next generation space and control segments continue to be delayed, sustainment of the GPS constellation will be difficult, and the USG could fail to meet published performance standards. Despite these challenges, great efforts are being taken by a number of military and civil organizations to prolong satellite life and provide other enhancements to increase GPS performance, accuracy, and availability for military and civil users worldwide.

The Air Force has sponsored studies and analyses which have resulted in an increase to the Mean Life Estimate of existing (IIR) satellites. Based on this increase and in response to a Congressional inquiry regarding GPS IIF and III, the Air Force outlined a potential plan to decrease the number of IIF purchases from the planned 19 satellites to 12, but also warned that any acceleration of GPS III should take place via a strategy that lowers risk and raises probability of success. To ensure the protection of this critical space-based PNT asset, the Air Force potential plan also included incremental delivery of GPS III capabilities. This would allow the DoD to maintain constellation health while promoting future space-based PNT mission success.

Since the last report, GPS has continued to expand its applications for national and economic infrastructures, military operations, and many scientific and commercial efforts. The USG departments and agencies, via the NPEC, continue to establish GPS as an integral component of the 21st century global marketplace and work to maintain U.S. preeminence in satellite PNT technologies and services. The senior leadership within the USG must support these efforts. If successful, the U.S. will ensure GPS remains the world's "gold standard" for space-based PNT.

While GPS currently enjoys unprecedented acceptance throughout the world, new threats to GPS are emerging and foreign satellite navigation systems are on the horizon. Threats must be understood and dealt with, and foreign PNT systems must be made compatible or interoperable with GPS. One of our greatest successes since the last report was the conclusion of a cooperative agreement signed on the GPS and Galileo satellite systems between the U.S. and the European Union. In addition to providing affordable modernized space and control segments in a timely manner, one of our greatest challenges is supplying the warfighter with advanced military user equipment and protecting them from jamming, spoofing, and unintentional interference. The DoD is pursuing an incremental and systematic upgrade to a number of space, control, and user features through the GPS Modernization Program. Maintaining GPS at the forefront of the world's space-based PNT technology can only be achieved through a continued national commitment accompanied by adequate and stable funding throughout the lifecycle of the program.

Global Positioning System (GPS) 2006

A Report to Congress

BACKGROUND

The National Defense Authorization Act for Fiscal Year 1998 (Public Law 105-85) established a requirement (10 U.S.C. 2281) for the Department of Defense (DoD), in consultation with the Departments of State, Commerce, and Transportation, to submit biennial reports to the Senate Committee on Armed Services and the House Committee on Armed Services on the status of specific elements of the Global Positioning System. Since that time, the National Aeronautical and Space Administration (NASA) and the Department of Homeland Security (DHS) have been added as well.

This document constitutes the fifth in a continuing series of reports. Previous DoD GPS Reports were submitted to Congress in October 1998, 2000, 2002, and 2004. Since the last report, an updated national policy for Space-Based Positioning, Navigation, and Timing (PNT) was signed by the President in December 2004.

OPERATIONAL STATUS

The GPS constellation continues to age, but continues to function at or above U.S. Government (USG) published levels of performance.

The DoD remains committed to ensuring a constellation of no fewer than 24 GPS satellites. In order to maintain a 95% probability that 24 satellites will be available to support PNT users, the GPS constellation is typically maintained by the Air Force at more than 24 satellites. Currently, there are 30 operational satellites on orbit. The constellation consists of one GPS II, 15 IIA, 12 IIR, and two IIR-Modified (or IIR-M) satellites. There are six IIR-M satellites awaiting launch. The GPS Modernization Program (which includes IIR-M satellites, as well as future GPS IIF and GPS III satellites) is addressed in more detail later in this report.

Air Force Space Command's (AFSPC) 2nd Space Operations Squadron operates the GPS space and control segments from Schriever Air Force Base (AFB), Colorado, under the Combatant Command (COCOM) of United States Strategic Command (USSTRATCOM), headquartered at Offutt AFB, Nebraska.

While the GPS constellation is healthy, many satellites are approaching or beyond the end of their expected design life. Of the 30 GPS satellites currently on orbit, 16 are past their design life, and 19 are without redundancy in either the navigation mission equipment or the satellite bus, or both. However, a sufficient number of satellites are available for launch to ensure that the U.S.

meets its national and international commitment to maintain constellation health for the near-term. Should IIF delivery and launch be delayed, sustainment of the GPS constellation will be difficult, and the USG could fail to meet performance levels prescribed in published federal plans and standards.

The GPS Operational Control System (OCS) consists of the Master Control Station (MCS) at Schriever AFB, CO; a Backup Master Control Station (BMCS) located at a contractor facility in Gaithersburg, MD; the Alternate Master Control Station (AMCS) at the Vandenberg Tracking Station, CA (projected to be fully operational by the end of 2007); four dedicated (and one shared) remote Ground Antennas, and six dedicated Monitor Stations worldwide. Since the 2004 report, GPS signal monitoring data from eight additional National Geospatial-Intelligence Agency (NGA) monitor stations have been incorporated into the GPS OCS. These NGA monitor stations enable the OCS to provide improved accuracy to all users. This combined Air Force/NGA monitor station network is designed to provide 100% global monitoring capability to improve GPS signal quality, which in the event of satellite problems, will minimize the time anomalous navigation signals are visible to users.

The current OCS requires upgrade, as it cannot fully support some capabilities of the newer satellites on orbit. The ongoing Architecture Evolution Plan (AEP) upgrade is replacing aging hardware and software and, when complete, will provide full support to the GPS IIR and IIR-M, and basic command and control for GPS IIF satellites. The next generation control segment upgrade called OCX (which is in the design concept phase) will follow AEP as soon as possible to support full modernized capabilities for the IIR-M and GPS IIF, and provide the foundation for GPS III. OCX will also support existing and new interfaces, and together with GPS III and Military GPS User Equipment (MGUE), will eliminate or mitigate existing shortfalls in the current GPS architecture.[1]

The United States Nuclear Detonation (NUDET) Detection System (USNDS) is a secondary mission aboard all GPS satellites. NDS is designed to detect, locate, and report NUDETs in a near real-time anywhere on or above the earth's surface. The system supports nuclear force management, integrated tactical warning and attack assessment, space control, and test ban treaty monitoring. Various USNDS payloads (or sensors) are hosted on GPS satellites and Defense Support Program (DSP) satellites. USNDS employs both fixed site and mobile ground processing to process and report information to various USNDS users and senior decision makers. More detailed descriptions of sensors hosted on GPS satellites are provided later.

U.S. NATIONAL SPACE-BASED PNT POLICY

A National Security Presidential Directive (NSPD) for Space-Based PNT was signed by the President in December 2004, replacing the 1996 Presidential

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[1] Originally termed Modernized User Equipment (MUE) for the prototype M-code capable receiver designs, future M-code capable receivers delivered for operational use will be referred to henceforth as MGUE.

Decision Directive, National Science and Technology Council, number six (PDD/NSTC-6). The new policy provides the departments of the USG updated guidance on the procurement, management, and protection of the GPS space, control, and user segments. This NSPD stresses that GPS is a national system with international implications that serves military and civilian/commercial needs. The NSPD also provides a framework to ensure compatibility or interoperability with other space-based PNT systems such as the existing Russian Global Navigation Satellite System (GLONASS), the Japanese Quazi-Zenith Satellite System (QZSS), and the planned European Union (EU) sponsored Galileo satellite constellation. Lastly, it established the National (Space-Based) PNT Executive Committee, or NPEC, which replaces the former Interagency GPS Executive Board. The NPEC is co-chaired by the Deputy Secretaries of Defense and Transportation.

The 2004 NSPD also established a National Coordinating Office (NCO) for Space-Based PNT to provide the NPEC with subject matter expertise, secretariat support, and to prepare a Five-Year National Space-Based PNT Plan. This plan, once created, will support future decisions on U.S. space-based PNT systems strategies, plans, and program implementations.

The NSPD provides six USG goals for maintaining, protecting and modernizing U.S. space-based PNT capabilities. Those six goals are: 1) provide uninterrupted availability of PNT services; 2) meet growing national, homeland, economic security, and civil requirements, and scientific and commercial demands; 3) remain the pre-eminent military space-based PNT service; 4) continue to provide civil services that exceed or are competitive with foreign civil space-based PNT services and augmentation systems; 5) remain essential components of internationally accepted PNT services; and 6) promote U.S. technological leadership in applications involving space-based PNT services.

Supporting these goals are other important policy documents produced by various federal departments. The DoD GPS Security Policy, the Chairman of the Joint Chiefs of Staff (CJCS) Master Positioning, Navigation and Timing Plan, and the Federal Radionavigation Plan (FRP) are three of the most prominent. Collectively, these documents provide direction and information to U.S and allied military users of GPS, as well as civil and commercial users. They identify the capabilities, directives, and restrictions of the two primary GPS services: the open Standard Positioning Service (SPS) and the secure Precise Positioning Service (PPS). They also provide information regarding the ongoing transformation of PNT services from a large mix of land, sea, and space-based PNT systems to a more prevalent use of space-based systems. These documents also provide policy on navigation aids, as well as wide-area and local-area augmentation systems, which can deliver significantly improved position accuracies in comparison to basic GPS service alone. Lastly, they establish guidelines for civil/military and U.S./foreign cooperation to ensure the various existing and planned PNT systems "do no harm" to one another.

SYSTEM CAPABILITIES AND REQUIREMENTS

The major space-based PNT goals of the DoD are: 1) sustain the current GPS space, control, and user segments; 2) acquire the necessary modernized space-based PNT capabilities to meet ever growing user requirements; and 3) eliminate or mitigate emerging threats. To meet these goals efficiently and effectively, the DoD and Department of Transportation (DOT) recommend the delivery of a mix of common-use (civil and military) radionavigation systems (including GPS) to: 1) meet diverse user requirements for accuracy, reliability, availability, integrity, coverage, operational utility, and cost; 2) maintain current services and performance while providing for future growth; and 3) eliminate unnecessary duplication of services.

Selecting the optimal future radionavigation system, or mix of systems, is a complex task because user requirements vary widely and change with time. While all users require PNT services that are safe, readily available, and easy to use, military requirements add unique defensive, offensive, and security capabilities (e.g., use in electronically and environmentally stressed conditions). Cost remains a major consideration that must be balanced against operational capabilities required by users.

The selection of optimal radionavigation systems involves operational, technical, institutional, international, and economic trade-offs. The Under Secretary of Transportation released the Radionavigation Capabilities Assessment Task Force Report on 5 January 2004, which recommended the best combination of radionavigation options to satisfy national PNT needs for the next ten years. The report also identified several technical evaluations that are being accomplished to determine if certain systems can meet cross-modal requirements in a cost-effective manner.

The "Standard Positioning Service Performance Standard," last updated and published by the DoD in 2001, establishes measures of minimum performance that civil users can expect from GPS. Since GPS first became operational, its performance has continued to improve and exceed performance standards by increasingly greater margins.

Military Requirements

The existing GPS constellation was originally designed to meet or exceed the requirements published in the 1990 System Operational Requirements Document (SORD). To support GPS Modernization (including GPS IIR-M, IIF and III) the Air Force developed, and the Joint Requirements Oversight Council (JROC) validated, the 2000 GPS Operational Requirements Document (ORD). Collective studies, test activities, and real-world experiences make a compelling case for improving the performance, robustness, and jam resistance of GPS even further. Broad military requirements and directives are published in the

DoD GPS Security Policy, and the CJCS Instructions 6130.01C and 6140.01A.[2] More specific statements of required capabilities to operate in stressed environments (including system limitations) are documented in two Capability Development Documents (CDDs). These CDDs will eventually replace the GPS SORD and ORD. A GPS III initial CDD was validated by the JROC on 4 August 2005 and the Military GPS User Equipment (MGUE) CDD will be coming before the JROC within a year. These documents specify a need to develop and acquire effective space, control, and user segment capabilities to protect U.S. and allied ability to utilize GPS in combat, and enable denial of hostile use of space-based PNT without unduly disrupting peaceful use outside an area of military operations.

In response to the 1996 PDD/NSTC-6, and to fulfill validated requirements, the DoD initiated Navigation Warfare (Navwar) activities, which still remain a fundamental building block of the overall GPS modernization efforts. The GPS III and MGUE CDDs will document the capabilities-based requirements with threshold and objective values needed to support DoD missions.

Precise Positioning Service (PPS)

U.S. and allied militaries (and select federal government users of GPS) rely heavily on the PPS. The Air Force designs, develops, and funds GPS Modernization activities through the Global Positioning Systems Wing (formerly know as the GPS Joint Program Office) which also includes Army, Navy, NGA, and Civil personnel. The PPS is based on stringent military requirements and advanced cryptography developed by the National Security Agency (NSA) and the Air Force. These ensure the PPS User Equipment (UE) continues to operate under harsh electronic and environmental conditions. The cryptography ensures only authorized users get the most secure and robust GPS service. Although more secure and robust than commercial SPS receivers, the legacy PPS devices rely on older security modules and must be keyed with bulky key-loaders or classified crypto paper tapes. This is one reason many military GPS users chose to either not key their PPS receivers or forego using their PPS receivers altogether in favor of smaller/lighter commercial SPS receivers (with mapping capability and improved battery life). These tactics, unfortunately, increase military user vulnerability to jamming and spoofing.

In the mid-1990s, to improve functionality and security of PPS UE, the Joint Staff directed the Air Force, the National Security Agency (NSA) and trusted vendors to develop the Selective Availability/Anti-Spoofing Module (SAASM) security architecture. SAASM UE operates with unclassified keying material, lessening the probability of classified compromise. SAASM security, coupled with state of the art physical design, allows UE that is smaller, lighter, longer lasting, and more capable than legacy UE. The newest SAASM-based handheld receiver (the Defense Advanced GPS Receiver - DAGR) also includes mapping capability. Once the OCS AEP upgrade is complete, SAASM will enable the

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[2] Chairman of the Joint Chiefs of Staff instruction (CJCSI) 6130.01C is also known and the Master Positioning, Navigation and Timing Plan. CJCSI 6140.01A includes requirements and directives for the Selective Availability/Anti-Spoofing Module (SAASM) development program.

operations crews at Air Force Space Command to deliver crypto keying material "over-the-air" to SAASM users around the globe, greatly reducing the need to fabricate, account for, and deliver paper key tapes. There are currently thousands of SAASM receivers in the field, with tens of thousands more on order by the Services and allies for air, land, sea, and space applications. Lastly, SAASM provides a secure bridge from legacy GPS capability to even greater functions, flexibility, and security with the delivery of Military Code (M-code) signals, MGUE, and GPS III satellites.

Similar to the SPS Performance Standard, the DoD is publishing a "Precise Positioning Service (PPS) Performance Standard." This PPS Performance Standard will clearly identify the minimum performance levels that the U.S./allied military user communities can expect from secure GPS. The PPS Performance Standard is scheduled for release in 2007.

Initiatives To Improve Military Aviation

The Joint Precision Approach and Landing System, or JPALS, is an all-weather differential GPS (DGPS) system that will provide a rapidly deployable, mobile, day-night, and survivable precision approach and landing capability in adverse terrain to support military, civil, and multi-national PNT needs. The lead service for DoD JPALS implementation is the U.S. Navy.

JPALS is a key component that will enable U.S. military forces to be highly mobile and capable of "rapid response" on a global basis to a wide range of military scenarios. Similar in concept to a civil Local Area Augmentation System (LAAS), JPALS will be based on DGPS technology, and will consist of modular avionics and ground/shipboard components to provide a range of landing criteria and system configurations. JPALS must remain operational throughout a range of threat environments, and meet performance requirements tailored to support a highly mobile force in all areas, including austere forward operating locations.

The Air Force's Global Access, Navigation, and Safety (GANS) system is an umbrella avionics program that integrates GPS with: 1) navigation and safety equipment; 2) Navwar tactics, techniques, and procedures (TTPs); 3) avionics modernization; 4) military ground-based infrastructure; 5) Communications, Navigation, Surveillance/Air Traffic Management (CNS/ATM); and 6) JPALS.

Nuclear Detonation (NUDET) Detection System (NDS)

The U.S. NDS mission is shared by the Defense Support (satellite) Program (DSP) and GPS, each with its own supporting ground segment. NDS payloads are hosted on each GPS IIA, IIR, and IIR-M satellite. These payloads consist of optical, particle, EMP, and X-ray sensors, and associated on-board communications and processors. Collectively, these sensors detect, locate, and report NUDET events, and provide clarification regarding less critical non-NUDET events. Further NDS enhancements are planned on future IIF and GPS III satellites.

Similar to satellite navigation payload components, NDS equipment is subject to aging, damage, and degradation. As a result, not all NDS payloads are fully mission capable. Although NDS is considered secondary to the PNT mission, the NDS community is queried by AFSPC before launch decisions are made (and prior to any constellation configuration changes) to ensure the best possible global NDS coverage without adversely impacting PNT users. However, when necessary, some or all of the NDS payloads will be turned off to decrease the satellite's power load and extend the life of the satellite's PNT mission.

Civil Requirements

Federal Radionavigation Plan (FRP)
The 2005 FRP provides a consolidated statement of plans for USG-provided radionavigation systems. Although GPS is the centerpiece of the U.S. planned complement of radionavigation systems for the foreseeable future and has the capacity to meet or exceed the accuracy and coverage provided by many other radionavigation systems, the FRP acknowledges that GPS is not intended to satisfy the requirements of all radionavigation system applications. Consequently, the FRP describes both complementary radionavigation systems, as well as augmentations to GPS to meet the stringent needs of specific user groups.

Aviation Requirements
Aircraft requirements for navigation performance are dictated by: 1) an aircraft's design; 2) an aircraft's phase of flight and its relationship to terrain; 3) other aircraft that could be operating in the area; and 4) established air traffic control processes. Safety requirements for aviation navigation performance are dictated by the physical constraints imposed by the environment and the craft, as well as the need to avoid the hazards of collision, severe weather, or unnecessary grounding.

GPS SPS meets the requirements for oceanic en route air navigation, as well as navigation used for more remote regions of the National Airspace System (NAS); therefore, it has been approved as a primary means of navigation for these areas. GPS SPS does not meet the more stringent availability and integrity requirements to act as a primary system for NAS domestic en route navigation through non-precision approach and is approved only as a supplemental system for those purposes.

Augmented GPS SPS can meet Federal Aviation Administration (FAA) requirements for a primary navigation system in the NAS. The Wide Area Augmentation System (WAAS) operated by the FAA meets the integrity, availability, and accuracy requirements, as specified in the FRP, for en route navigation through near-Category I precision approach.[3] The FAA commissioned WAAS for public use in September 2003 and the U.S. continues to implement ways to make it more effective. Local Area Augmentation Systems (LAAS) are undergoing research by the FAA for Category I precision approaches. Other studies are currently underway to determine whether LAAS meets the

[3] Category I: An instrument landing approach procedure that provides for approach to a height above touchdown of not less than 200 feet.

requirements for Category II[4] and III[5] precision approach operations. Aviation users are interested in obtaining navigation services using systems that best meet their requirements and business case needs, with stable advanced planning of any necessary transitions.

Land Requirements
Contrary to the air and maritime communities, distinct phases of land navigation are not as well defined. Radionavigation requirements are more easily categorized in terms of applications. Civil land navigation applications for transportation fall into three basic categories; highway, rail, and transit applications:

- Highway accuracy requirements range from 10 centimeters for safety warning to 30 meters for vehicle monitoring. Real-world GPS SPS performance (without augmentation) consistently meets 10 - 30 meter highway user accuracy requirements, but cannot provide the necessary integrity to warn users when signal integrity is in question. Augmentations are required to meet more stringent accuracy and integrity requirements.
- Rail accuracy requirements range from one meter for positive train control to 10 - 30 meters for position location. As with highway accuracy, unaugmented GPS SPS consistently meets 10 - 30 meter rail user requirements, but augmentations are required to meet more stringent accuracy requirements (i.e., positive train control and rail yard operations).
- Transit accuracy requirements range up to: five meters for data collection and automated bus/train station information annunciation; 50 meters for vehicle command and control; and 100 meters for Emergency Response. Unaugmented GPS SPS can meet the requirements for Emergency Response and vehicle command and control, but is less reliable to support applications requiring five-meter accuracy.

An improved Nationwide DGPS (NDGPS) system provided by the U.S. Coast Guard (USCG) and the U.S. Army Corps of Engineers will ultimately provide accuracies from one to three meters on a consistent basis, and sub-meter accuracy for select applications. This national augmentation system, due for completion by 2009, will meet most land and maritime PNT requirements.

Maritime Requirements
GPS SPS can meet the navigation requirements for the open-ocean and coastal phases of navigation, but does not meet the requirements for the Harbor Entrance and Approach phase without augmentations. The NDGPS system does meet Harbor Entrance and Approach phase requirements. It provides PNT service for coastal coverage of the continental U.S., the Great Lakes, Puerto Rico, portions of Hawaii and Alaska, and sections of the Mississippi River Basin

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[4] Category II: An instrument landing approach procedure that provides for approach to a height above touchdown of not less than 100 feet.
[5] Category III: An instrument landing approach procedure that provides for approach without a minimum height above touchdown.

with accuracy consistently better than six meters, an availability of 99.9%, and integrity broadcasts when the system should not be used for navigation.

The USCG is exploring accuracy enhancements and the integration of the NDGPS with other navigation sensors. Particular emphasis is placed upon the integration of NDGPS with inertial navigation systems (INS). Efforts are underway to determine the ability of INS to enhance GPS/DGPS systems, and to provide heading information for Electronic Chart Display and Information System use. Work is being conducted within Radio Technical Commission for Maritime Services (RTCM), Special Committee 104, in developing new high accuracy messages, including ones optimized for use with GPS Selective Availability set to zero.[6] This work includes the development of corrections for ranging signals broadcast from geo-stationary WAAS satellites.

Greater numbers of GPS WAAS receivers continue to emerge in the public marketplace and are being increasingly used in maritime environments. As a result, comprehensive testing and evaluation of WAAS accuracy, availability, and integrity is being conducted to see if WAAS does indeed meet more stringent user requirements (e.g., buoy positioning, Harbor Entrance and Approach, and inland waters navigation). This testing and evaluation involves a combination of shore and vessel data collection, as well as WAAS modeling and simulation.

Space Requirements

The GPS signals-in-space are key enablers for a multitude of DoD, civil, and commercial space users. GPS provides the necessary location accuracy to better track and command many DoD, National Aeronautics and Space Administration (NASA), allied, and commercial satellites in low-earth orbit. From an engineering perspective, NASA uses GPS signals for the full spectrum of research missions including the International Space Station, the Space Shuttle, Earth/Space Science satellites, research balloons, high-altitude Unmanned Aerial Vehicles (UAVs), and other NASA research aircraft. Capabilities include precise navigation (to centimeter level), attitude determination and control, unprecedented timing measurements, and space and air vehicle formation flying. These capabilities allow NASA and other spaceflight developers to engineer systems that are lower in cost and higher in performance than non-GPS alternatives.

NASA and the DoD are also investigating the use of GPS to track space vehicles in orbits higher than the GPS constellation (above 20,200 kilometers). This emerging technology application will allow closer spacing of satellites in geostationary orbits, providing a more dense satellite population over crucial areas of the world. It will also improve space vehicle autonomy, thereby reducing mission costs. NASA also hopes that this "weak signal" research,

[6] Selective Availability, or SA, involved the purposeful degradation of (civil) GPS SPS to deliver SPS accuracy and performance significantly worse than that provided to authorized (military) PPS users. SA was ordered "set to zero" by the President in May 2000. Since then, SPS users in benign environments have enjoyed virtually the same performance and accuracy as PPS users.

coupled with the upcoming advancements of GPS, will pave the way for the use of GPS and GPS-like augmentations in support of future missions to the Moon. As part of their new exploration initiative, NASA envisions that GPS technology and its augmentations will accompany our future space explorers as they venture to Mars and into the far reaches of space.

NASA's Jet Propulsion Laboratory (JPL) has developed a high accuracy GPS augmentation system to support the demanding real-time positioning, timing, and orbit determination requirements for NASA science missions. The Global Differential GPS (GDGPS) system enables 10 – 20 centimeter real-time positioning accuracy for users with newer dual-frequency GPS receivers anywhere on the ground, in the air, and in space. Also, NASA is continuing its development of augmentation for the Tracking and Data Relay Satellite System (TDRSS). Named TASS, or TDRSS Augmentation Service for Satellites, it disseminates the GDGPS real-time differential correction messages to orbiting satellites, enabling precise autonomous orbit determination, science processing, and planning operations in Earth orbit. The JPL is working with NASA and the Air Force to fully utilize the unique GPS monitoring capability of the GDGPS system.

Non-Navigation Requirements

The use of GPS for non-navigation activities is large and diverse. Some non-navigational activities include surveying, mapping, tracking, geophysical applications, meteorology, communications, power grid management, and timing. Real-time accuracy requirements range down to one centimeter or less than one nanosecond. Post-processed accuracy requirements extend to the sub-centimeter level. GPS SPS augmentations are currently used to meet many of these requirements. Unaugmented GPS SPS continues to meet non-navigation requirements in the 10 – 100 meter (30 nanosecond or higher) accuracy range.

Users who require centimeter-level positioning are able to use a nationwide network of GPS Continuously Operating Reference Stations (National CORS). The National CORS is a GPS augmentation managed by the Department of Commerce (DOC) via the National Oceanic and Atmospheric Administration (NOAA) that supports non-navigation, post-processing applications. This network provides local users with ties to the NOAA-managed National Spatial Reference System, for accurate, three-dimensional, post-mission positioning. Typical uses of National CORS include land management, coastal monitoring, civil engineering, boundary determination, mapping, geographical information systems, geophysical/infrastructure monitoring, and future improvements to weather predicting and climate monitoring. The NOAA Height Modernization program is currently making it more affordable to determine precise heights by using over 900 sites in the National CORS network. Moreover, this network is growing at a rate of about ten sites per month. The CORS program is a multi-purpose cooperative endeavor involving more than 130 government, academic, and private organizations – each of which operates at least one site. In particular, it includes all existing NDGPS/DGPS sites and all existing FAA/WAAS ground sites.

New GPS-based Earth science investigations are improving our knowledge of the Earth and its environment. For example, Earth science atmospheric and ionospheric limb soundings and ocean reflection measurements using GPS are improving our understanding of atmospheric makeup, ionosphere structure and dynamics, and sea surface winds, all of which are crucial to better understand the environment in which we live. GPS has also enabled Earth scientists to better understand the geodetic nature of the Earth. For example, subtleties in the Earth's rotation and polar motion and deformation of the Earth's crust are routinely measured using GPS.

GPS Timing and the U.S. Naval Observatory

The U.S. Naval Observatory (USNO) Master Clock is ***the*** timing standard for DoD and, as such, GPS. Coordinated Universal Time (UTC) as realized by the U.S. Naval Observatory Master Clock is known as UTC(USNO), and is the most precise time in the world. The standard international reference for timing is UTC. UTC is not a real time source, but is a "paper clock" derived once a month by combining input from approximately 50 timing centers around the world, including the USNO and the National Institute of Science and Technology (NIST) in Boulder, Colorado. The largest single contribution to international UTC (approximately 40%) comes from the frequency standards (or atomic clocks) maintained at USNO. GPS is the primary method (and the best method) to deliver UTC(USNO) to users worldwide. This precise UTC time is transmitted in the GPS signal-in-space and utilized globally for various applications (e.g., telecommunications, network synchronization, secure military communications, power grids, transportation systems, and the tracking of banking transactions) which support the national infrastructures of the U.S. and numerous other countries. Additionally, GPS utilizes atomic clocks at each dedicated Monitor Station and on-board each satellite to keep its own internal system time used for navigation purposes. Maintaining accurate atomic clocks is essential because the accuracy of GPS time relates directly to the location accuracy used for positioning and navigation. For instance, a user incurs approximately one added meter of location error for every three additional nanoseconds of timing error.

The USNO continues to improve its baseline timing capabilities and performance with new physics and software packages applied to atomic frequency standards and technologies. The addition of Rubidium Fountain clocks will aid in improving future time accuracy and general GPS performance.

PROGRESS IN MODERNIZING GPS

The DoD is continuing a significant investment to modernize GPS and enhance its ability to meet growing military and civil PNT needs.

The FRP summarizes the objectives of the GPS Modernization effort as improving position and timing accuracy, availability, integrity monitoring support capability, and enhancing the GPS operational control system to ensure a robust, highly dependable navigation and timing source for all users. The incorporation of data from eight NGA monitor stations into the OCS was a significant step toward these objectives and provides benefits for space operators at the MCS, as well as, all GPS users. Data from additional NGA monitor stations should be incorporated within a year.[7]

The ongoing GPS Modernization Program is modifying all remaining IIR satellites (re-designated as IIR-M) by adding the new M-code military signal at L1 and L2 and a second civil signal at L2 (known as L2C).[8] The first IIR-M satellite was launched in September 2005. The second IIR-M was just launched in September 2006.

For civil SPS users, L2C will deliver dual frequency capabilities which will diminish errors caused by the ionosphere. For military users, M-code will provide significant performance improvement for those operating with keyed M-code capable user equipment. M-code will provide a robust encrypted signal which is spectrally separated from the existing GPS signals, which makes it considerably less vulnerable to jammers designed to target SPS users. An advanced security architecture applied to M-code also makes it less vulnerable to spoofing. To utilize M-code and its capabilities, the DoD has directed the GPS Wing (formerly known as the GPS Joint Program Office) to design, and the Services to procure, M-code capable user equipment at the earliest opportunity. Existing legacy and SAASM PPS UE cannot process M-code.

Currently forecast for first launch in FY2009, GPS IIF satellites will incorporate the same improvements as the IIR-M, as well as an additional civil signal (known as L5) designed for safety of life applications.[9] Also, in response to existing and emerging threats, the IIR-M and IIF satellites include a "Flex Power" capability which will allow satellite power to be "swapped" between the legacy military signals and M-code to provide increased protection in an interference or jamming environment. Corresponding improvements to the GPS OCS/OCX infrastructure will also be implemented to fully support existing and future satellites.

The final stage of the planned GPS Modernization includes the development and fielding of the next generation GPS satellite, GPS III. GPS III, when combined with OCX control segment upgrades and MGUE, will provide improved anti-jam capability, accuracy, availability, and integrity. This combination is intended to satisfy growing military and civil requirements. Target date for launch of the first GPS III satellite is 2013.

One of DoD's challenges throughout modernization will be facilitating the numerous requests from military and civil users to add payloads which would increase the size, weight, and power requirements for future GPS satellites to support these requests. Such payloads will receive intense scrutiny from a

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[7] The standard global coordinate system (World Geodetic System 1984, or WGS-84) is defined by NGA based largely on the precise GPS-derived positions of the combined network of Air Force and NGA monitor stations.

[8] L1 is located at 1575.42 MHz in the L-Band spectrum. L2 resides at 1227.60 MHz.

[9] L5 will be located at 1176.45 MHz in the L-Band spectrum.

cost/benefit perspective as they could present a financial burden for the DoD, and place added cost and schedule burdens on satellite and booster vendors.

Congressional Concerns Regarding GPS

Due to the overwhelming positive results of the first use of GPS in combat (during Desert Storm in the early 1990s), Congress directed in 1994 that all DoD aircraft, ships, armored vehicles or indirect firing weapon systems be GPS-equipped by 1 October 2000. Due to technical, fiscal and programmatic challenges, an extension of this suspense has been approved by Congress through 1 October 2007. Overall, the Services project they will meet the updated suspense with only a few exceptions highlighted by the Air Force. A full report will be submitted to Congress in 2007.

The House Armed Services Committee has also recognized the significance of GPS to both the civil and military communities and is concerned with increasingly sophisticated threats against GPS. In early 2006, the committee directed the Air Force to explore the merit of truncating the planned purchase of 19 GPS IIF satellites and accelerating the introduction of GPS III.[10] The Air Force has sponsored studies and analyses which have resulted in an increase to the Mean Life Estimate of existing (IIR) satellites. Based on this increased estimate, the Air Force reported back to Congress its potential plan to decrease the number of IIF purchases from the planned 19 satellites to 12, but also warned that any acceleration of GPS III should take place via a strategy that lowers risk and raises probability of success. To ensure the protection of this critical space-based PNT asset, the Air Force potential plan also included incremental delivery of GPS III capabilities. This would allow the DoD to maintain constellation health while promoting future space-based PNT mission success.

INTERNATIONAL COOPERATION AND CHALLENGES

Civil, Commercial, and Scientific Activities

Federal departments and agencies are working with their respective foreign counterparts to encourage acceptance and integration of GPS into civil, commercial, and scientific applications worldwide to promote cooperation in using GPS for peaceful purposes. International discussions focus on establishing GPS as a core component of any future Global Navigation Satellite System (GNSS) and developing the necessary infrastructure to support a global seamless space-based PNT architecture. Political, institutional, and technical issues are being addressed and must be resolved before this architecture is realized. The U.S. continues to be an active initiator, participant, and facilitator internationally in defining the future GNSS architecture.

The U.S. and Japan continue to enjoy an excellent working relationship with respect to GPS cooperation. U.S. and Japanese experts have engaged in technical discussions since 1998 to ensure that GPS and the proposed Japanese space-based GPS augmentation known as the Quasi-Zenith Satellite

[10] Fiscal Year 2006 House Armed Services Committee report 109-89 to House Resolution 1815.

System (QZSS) complement each other and increase utility for civil PNT users in the Pacific Rim.

The U.S. has also been meeting with Russian PNT experts to discuss areas of mutual interest regarding space-based PNT. These ongoing consultations, regarding potential cooperation in future civil signal structure design, could resolve compatibility and interoperability issues with GPS and GLONASS.

India has recently joined the countries aspiring to a national satellite-based PNT service by announcing their intention to launch the Indian Regional Navigation System (IRNS), code named GAGAN. Continued U.S./India discussions are planned to ensure cooperation and compatibility with GPS and any future Indian space-based PNT system.

NASA is engaged in international cooperative programs to apply innovative (GPS-based) Earth observation techniques. Most notable among these are GPS remote sensing platforms such as the COSMIC, GRACE, SAC-C, and CHAMP satellites that utilize advanced techniques to measure atmospheric and ionospheric weather and climate variability. The GPS-based GRACE mission (a collaboration of NASA and the German Aerospace Center) is demonstrating a new revolutionary capability to measure gravity and the transport of mass within the Earth system. Germany, Argentina, and Taiwan are cooperating in these missions. NASA also provides considerable support to the International GNSS Service for cooperative international research and products such as precise GPS orbits and the promotion of new GPS-related activities such as the African Geodetic Reference Network project.

GPS and Galileo

On June 26, 2004, the U.S. and the EU member states signed a cooperation agreement for GPS and the European satellite navigation system known as Galileo. After years of intensive negotiations, this agreement protects our national security interests related to the use of GPS M-code signals in a Navwar environment. In addition, per the agreement, all parties agreed to pursue nondiscriminatory approaches to trade in the provision of future space-based (civil) PNT services. The agreement also lays the foundation for a common civil signal to be broadcast by both Galileo and the GPS III constellation.

Defense Activities

The DoD has agreements with 40+ allies and friendly nations to enable their access to GPS PPS as a primary source of military PNT information. Such agreements significantly contribute to improved interoperability and situational awareness when those nations join with U.S. forces in allied and coalition operations.

There is concern, however, that adversaries and allies could use emerging satellite navigation systems for future military operations once those systems are fully operational. From an allied standpoint, this could be an impediment to the increased interoperability already achieved through the integration of GPS in numerous U.S. and allied systems and platforms. From an adversarial standpoint, these emerging satellite systems could provide hostile nations increased force enhancement value and allow them precise positioning, navigation and timing similar to that enjoyed by the U.S. today. In accordance with the 2005 "International Cooperation Guidance (ICG) for GPS and Navwar," various agencies of the USG continue to work in joint and international fora to track these issues and mitigate any operational or political impacts they might cause.

International Standards

Radionavigation services and systems address the needs of diverse international groups. The goals of performance, standardization, and cost minimization of user equipment influence the search for an international consensus on a selection of radionavigation systems. For civil aviation, the International Civil Aviation Organization (ICAO) establishes standards and recommended practices for international use of radionavigation systems. The International Maritime Organization (IMO) plays a similar role for the international maritime community. Consistent with the goal of advocating the acceptance of GPS and USG augmentations as standards for international use, the FAA and USCG offered GPS SPS to ICAO and IMO, respectively, as a candidate for the future GNSS that is envisioned to create a seamless PNT for all civil users around the world. ICAO and IMO have accepted these offers.

The FAA took a leadership role in organizing the original ICAO GNSS Panel in 1993 (which is now known as the Navigation Systems Panel – NSP). As a result, GPS and its augmentations were adopted by ICAO as the international GNSS standard. At present, foreign Space-Based and Ground-Based Augmentation Systems (SBAS and GBAS) conform to ICAO standards. Additionally, the USG continues cooperative activities with Japan, Brazil, Canada, China, India, Mexico, and Russia to promote and assist in the implementation of GPS and its augmentations, and supports regional PNT initiatives and working groups in North America, South America, Europe, and Southeast Asia.

The USCG remains an active participant in two international forums, the International Association of (Marine Aids to Navigation) and Lighthouse Authorities (IALA) and the IMO. The USCG-operated Nationwide DGPS system has been adopted by more than 40 countries as the standard to meet their maritime navigation and positioning needs. The USCG has supported IALA in establishing technical workshops for maritime nations interested in developing DGPS systems.

An agreement was signed between the U.S. and Canadian Coast Guards to establish a "seamless DGPS service" between our common borders. From the user perspective, this service combines the two national systems into one. It increases signal availability by scheduling off-air maintenance between providers and gives the users the status of all available signals, not just those operated by one nation.

Economic Competitiveness of U.S. Industry

The GPS industry continues to experience the same healthy growth it has in years past. GPS has become a household name among the general population, as evidenced by the proliferation of television and print advertisements touting it as a feature in new cars, telephones, and even soft drink cans used for promotional sweepstakes.

In a 2001 USG study, the DOC report on "Trends in Space Commerce," conservatively estimated double digit market growth in global sales of GPS equipment to drive the market to nearly $10 billion annually by 2008. More recent studies by commercial technology (market research) firms have reflected an even more robust picture of market growth. One New York firm with extensive experience in market research and technology intelligence on the wireless, automotive, electronics, broadband, and energy industries projected a worldwide GPS market worth over $22 billion annually by 2008[11].

At present, roughly half of the worldwide GPS market consists of sales of automotive and asset-tracking equipment. These segments are expected to continue to grow faster than the overall, broader market for GPS equipment. In addition to the strength of these markets, new segments are constantly emerging for GPS applications and are projected to continue to drive demand for gear as diverse as personal (or animal) tracking devices and DGPS services used on golf courses.

U.S. companies excel at integrating GPS receivers into innovative form factors, with embedded GPS applications likely to appear in an ever-increasing range of devices. While total GPS revenues will continue to grow, per unit revenue is not expected to be as strong as unit growth, due mainly to pricing pressure. Growing sales, particularly in consumer application products such as car navigation and recreational handhelds, are expected to enable GPS manufacturers to remain profitable for the next several years. In the more distant future, continued product innovation should enable U.S. manufacturers to maintain profitability as the accuracy and capabilities of GPS products improve.

User equipment sales represent only a portion of the economic growth potential from GPS applications. As with personal computers, the true value of GPS is not in the cost of the equipment, but in the productivity and growth it enables. U.S. industry has created new services and enhanced existing products by accessing GPS capabilities. In 2006, the Departments of Commerce and Transportation released the results of an economic study quantifying the benefits of GPS modernization in terms of the productivity gains enjoyed by civilian users, not just increases in GPS-related equipment sales. The study focused on the second civilian GPS signal (called "L2C"), which was specifically designed to enhance the commercial utility of GPS. Under the most likely scenario, the study concluded that L2C could enable over $5 billion in economic productivity benefits through 2030. Also in 2006, the Department of Commerce sponsored a public forum at the U.S. Chamber of Commerce where business

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[11] Allied Business Intelligence, Inc., *GPS World Markets: Opportunities for Equipment and IC Suppliers*, Oyster Bay, NY, 2003.

leaders from across U.S. economy celebrated the arrival of the L2C signal and described how it will benefit their industries.[12]

PROGRESS IN PROTECTING GPS FROM INTERFERENCE

Unintentional and Intentional Interference

In September 2001, the DOT's Volpe National Transportation Systems Center released a study indicating that GPS is susceptible to unintentional disruption from such causes as atmospheric effects, signal blockage from buildings, interference from communications equipment, and also susceptible to intentional disruption by those with hostile intent. The Volpe study contained a number of recommendations to address the possibility of disruption and ensure the safety of the national transportation infrastructure.

The DOT continues to implement an action plan based on the Volpe report including the following initiatives for maintaining the viability of the transportation infrastructure: 1) ensure that adequate backup systems are maintained; 2) maintain the partnership with the DoD to continue modernizing GPS with the implementation of new civil signals; 3) facilitate transfer of appropriate anti-jam technology from the military for civil use; 4) conduct industry outreach to develop receiver performance standards; and 5) emphasize and promote education programs with state and local departments of transportation that advise users about GPS vulnerabilities.

Whether aiding air traffic control, navigating harbors and restricted waterways, maintaining timing and frequency for critical communications infrastructure, or supporting emergency responders, some critical PNT applications require backups or other robust/viable alternatives.

Most safety-critical transportation applications that use GPS currently have adequate backup systems in place. In looking to the future, however, the radionavigation system mix may need to change in response to changing requirements or emerging threats. For example, to ensure essential radionavigation services continue unabated, additional actions will be required to build redundancy into critical transportation systems under development (e.g., Intelligent Transportation Systems).

Infrastructure protection is an ongoing concern in the US. The Department of Homeland Security (DHS) and the DOT continually assess the adequacy of backup systems for vital transportation functions that rely on GPS. Their action plans ensure the vulnerabilities identified in the Volpe report do not affect the safety and security of U.S. transportation systems as the USG works to ensure that GPS fulfills its responsibilities as a key element of the nation's transportation infrastructure. Backup systems for safety-critical uses of GPS may also serve security functions. For instance, innovative products based on GPS technology will substantially improve the way we track unmanned container shipments.

[12] L2C is being included along with M-code in all IIR-M, IIF and GPS III satellites.

The FAA continues to operate national air and ground assets that detect and isolate GPS interference sources. DHS (USCG), DOT (FAA), and DoD (Air Force Space Command) also maintain 24-hour operations centers to receive interference reports, as well as any other important GPS-related information that could impact users around the globe. These three ops centers have established a Memorandum of Agreement (MOA) to ensure all pertinent GPS constellation health and performance information is shared in real or near-real time.

Spectrum Management

Potential interference to GPS signals at L1, L2, and L5 (and subsequent service disruptions) must be addressed through the appropriate regulation of the radio frequency spectrum used by GPS. To this end, the GPS community was insistent on appropriate emissions limits to protect GPS users from potentially harmful interference from Ultra-Wide Band (UWB) transmission systems. Under rules approved by the Federal Communications Commission (FCC) in consultation with the National Telecommunications and Information Administration (NTIA), certain unlicensed UWB devices (e.g., ground penetrating radars and wireless personal area networks) will be allowed to intentionally emit (for specific limited purposes) in the Radio-Navigation Satellite Service (RNSS) bands used by GPS. The emissions of these devices will be limited to levels that provide adequate protection to GPS users. However, if these emission limits are relaxed, or not enforced, they will hamper the ability to protect GPS from interference despite the modernization efforts of the DoD and the interference mitigation efforts of the DOT mentioned earlier.

Approximately 93 percent of all spectrum use takes place in less than one percent of the total available spectrum (below 3 GHz). The portion of the electro-magnetic spectrum useful for RF communications is a finite and heavily burdened resource. That narrow region of the spectrum is popular in part because of favorable technical characteristics and its related suitability for various kinds of services. As a result, the protection of the portion of spectrum used by GPS is of critical importance to both existing GPS, as well as the planned GPS modernization.

To protect the future high-power M-code at L2, the U.S. opposed at the last World Radio Conference (WRC-03) any unnecessary power limits for RNSS systems operating in the 1215-1260 MHz band. A resolution was suppressed by opponents and deemed not worthy of further study. The U.S. also acknowledged the need to protect the 1164-1215 MHz band (where the planned GPS L5 signal will reside). The next WRC and future spectrum debates are scheduled for 2007.

MILITARY SYSTEM EFFECTIVENESS

National Security Operations

The DoD clearly recognizes the need to protect GPS from disruption and interference. Indeed, one of the three primary goals of the Department's

Navwar activities is to enhance the robustness of GPS through a combination of increased power from space, investment in MGUE, and selectively upgraded high-priority surface, air, and space platforms with additional anti-jam features. Other Navwar goals include preventing adversary exploitation of GPS without unduly disrupting peaceful use of GPS outside an area of military operations and finding/neutralizing hostile GPS jamming sources. As discussed in many forums, the DoD's program to modernize GPS is already underway with: 1) the addition of flex-powered military signals; 2) PPS UE with advanced antenna electronics and enhanced anti-jam designs; and 3) M-code that is spectrally separated from civil signals.

GPS continues to be a major force enhancement tool in the modernization and upgrade of military weapon systems and combat support platforms, not only in this country, but throughout the world. At the same time, the scientific, economic, and industrial infrastructure of the U.S. and friendly nations are continuing to expand the uses and applications of GPS. Transportation, telecommunications, banking, agriculture, mining, forestry, emergency response services, and search and rescue, are just a few of the industries that rely on GPS positioning and timing accuracy. As a result, the protection, sustainment, and modernization of GPS must remain critical national security objectives. In addition, the continued exploitation of GPS by potential adversaries necessitates the development and employment of capabilities to counter this threat. The DoD continues to address this need through its Navwar development activities.

Impact to Military Operations
AFSPC, at the request of U.S. Central Command (USCENTCOM), recently completed field surveys to evaluate the growing impacts of Electro-Magnetic Interference (EMI) in Afghanistan and Iraq. AFSPC determined that many GPS-impacting interference events were unintentional and self-inflicted, and had a significant impact on commercial (SPS) GPS receivers in theater. Keyed military PPS receivers were not observed to be impacted by this unintentional interference. To mitigate this problem, AFSPC recommended that field commanders enforce the use of keyed military PPS devices for combat and combat support operations. It also advised that USCENTCOM update any EMI-related CONOPs and expand the duties of their centralized spectrum management office to better track and troubleshoot negative impacts to GPS in the region's increasingly crowded electro-magnetic spectrum. To address these and other EMI issues, USCENTOM established the Combined Theater Electronic Warfare Coordination Cell.

These real-world experiences highlight the importance of: 1) keyed PPS user equipment for military operations (versus using SPS receivers or unkeyed PPS receivers); 2) the continued development of Navwar Electronic Protection (EP) hardware, software, CONOPs and TTPs; and 3) timely delivery of M-code, MGUE, and GPS III (with supporting OCX) capabilities.

The DoD also took an important step in 2005 with the activation of the Joint Navigation Warfare Center (JNWC). By direction from the Deputy Secretary of Defense, the JNWC supports the integration of Navwar activities across the DoD and is aligned with U.S. Strategic Command (USSTRATCOM). The Air Force, as Executive Agent for Space, was directed by the DepSecDef to prioritize budget resources to establish the JNWC. The JNWC is located at Kirtland AFB, New Mexico to achieve synergies with existing test and evaluation organizations. The JNWC will continue Navwar testing and analysis begun by the Joint GPS Combat Effectiveness organization in the late-90s, and will expand this mission to include Navwar-related modeling and simulation activities in support of warfighter applications. In addition to its test and evaluation responsibilities, the JNWC will also collect and analyze intelligence and threat data, spearhead advanced Navwar development efforts, participate in Navwar-related Crisis Action Planning, and inform/educate the Services, Combatant Commands (COCOMs), and our allies to: 1) minimize reliance on commercial GPS receivers; 2) highlight the importance of protecting our use of PPS; 3) prevent hostile use of space-based PNT when necessary; and 4) not unduly disrupt peaceful PNT use outside an area of operations. As owner of the overall Navwar mission, USSTRATCOM will also ensure the JNWC remains linked to appropriate intelligence sources that aid in the detection and location of hostile GPS jamming sources. As soon as more Navwar capabilities are implemented, U.S. national and regional security objectives supported by GPS will be better maintained. Until then, such GPS-related interests and capabilities remain vulnerable to disruption.

GPS continues to enhance military operations globally. In OPERATION IRAQI FREEDOM (OIF), the U.S. military used approximately 20,000 precision munitions versus just over 9,000 non-precision munitions. Of the precision munitions used, nearly 57% were GPS-aided, including those used to accomplish the time-sensitive striking of critical targets (the other 43% of precision munitions used included INS-guided, laser-guided, etc). In future conflicts, DoD expects to see even higher percentages of GPS-aided munitions.

To enhance GPS performance for users in one theater or region, AFSPC implements a tactic known as GPS Enhanced Theater Support (GETS). By providing satellites with orbit and clock updates immediately prior to "passing over" CENTCOM, AFSPC operators at the GPS Master Control Station (MCS) provide PPS users with increased confidence that GPS will operate as advertised, and that position and timing errors will be minimized during critical operations.

OIF also saw the introduction of enemy GPS jamming, as Iraqi forces tried to disrupt GPS signals. From the onset of coalition air strikes until U.S. forces entered Baghdad, the Iraqis executed a concept of operations using jammers intended to interfere with GPS signals. While U.S. TTPs were implemented to overcome the Iraqi jamming efforts, the fact that attempts were made to deny U.S. and coalition forces GPS capability must be viewed with concern.

New and improved jammers and employment concepts are expected to emerge as potential adversaries come to recognize and appreciate the asymmetric advantage U.S. and coalition forces now enjoy through the use of GPS. Several countries have openly concluded that GPS jamming is an effective means of disrupting U.S./allied operations. Some manufacturers are even marketing

GPS jammers on the internet and in trade magazines. This is another reason why continued Navwar development and implementation is so important.

In the near-term, however, one of the most effective methods against jamming and interference is the use of keyed PPS user equipment in hostile areas and stressed environments. Dual frequency, 12-channel PPS UE is proving to be more jam resistant than older single frequency, 4-channel legacy UE, and significantly more resistant than civil/commercial SPS receivers. SAASM, which includes dual frequency/12-channel capability, is providing the necessary bridge from yesterday's legacy GPS capability to tomorrow's M-code, MGUE, and GPS III capabilities.

INDEPENDENT REVIEW OF MILITARY GPS PROGRAM

Defense Science Board (DSB) Task Force

On April 9, 2004, the acting Under Secretary of Defense for Acquisition, Technology and Logistics (USD/AT&L) and the Assistant Secretary of Defense for Networks and Information Integration (ASD/NII) jointly requested that the DSB empanel a task force to study the future of GPS. The initial request focused on the implications for GPS of the EU-sponsored Galileo system and included assessment of several other aspects of GPS military and commercial competitiveness, including modernization strategies and advanced technical alternatives.

The task force represented a significant confluence of GPS knowledge, including experts in GPS design, in military, civilian, and scientific applications of GPS, and in the inner workings of military, government, and industry operations. Co-chaired by Dr. James Schlesinger and Dr. Robert Hermann, the task force brought a unique combination of experience and personal credibility. Activities examined by the DSB include international negotiations and agreements, national policy discussions on GPS management, and considerations affecting future GPS governance.

During the course of the study, several outside events significantly modified the issues of uncertainty that had existed when the task force was formed. Those events included: 1) the signing of a cooperative agreement on GPS and Galileo between the U.S. and the EU; 2) a major study on GPS commercial viability as approved by the Deputy Secretary of Defense; and 3) release of the President's NSPD on space-based PNT systems. While each of these events moderated specific areas of uncertainty that had been complicating GPS sustainment and modernization, each is still "a work in progress" that will require monitoring as USG leaders move to address the still substantive issues facing GPS operation and evolution.

In October 2005, the DSB task force released its report on the "Future of the Global Positioning System." This final report illuminates the critical role GPS plays in the world. As an opening premise, proved throughout the report, it notes that "GPS is vital to the United States and to the DoD because, as a fundamental information system, it provides a common thread of precise positioning and timing throughout our national security and economic infrastructures." The task force stressed the importance of USG senior leadership awareness of critical national infrastructure issues relating to GPS, and need for leadership to address the sustainment and modernization challenges.

SUMMARY

Since the last report to the Congress in 2004, GPS has continued to expand its applications in: 1) the national security and economic infrastructures; 2) the future U.S. and allied military operations; and 3) increasing scientific and commercial industries and venues. Both traditional and nontraditional applications of GPS continue to materialize. The DoD's bottomline goal is to keep overall program risk to a minimum, while delivering modernized space-based PNT capabilities to millions of users worldwide.

NASA and the Departments of Transportation, Homeland Security, State, and Commerce continue to support the Department of Defense in establishing GPS as an integral component of the 21st century global marketplace and maintaining U.S. preeminence in satellite PNT technologies and services. If successful, the USG will ensure GPS remains the world's "gold standard" for space-based PNT.

The continued acceptance and widespread application of GPS will present new challenges to our ability to maintain a decisive competitive edge in the battlespace of the future. To meet these challenges, DoD Navwar activities have included demonstrations of existing and emerging capabilities, and provided new tactics, techniques and procedures for the warfighter. Plans to expand the use of GPS anti-jam technologies and develop methods to access alternative sources of PNT information are paramount to DoD mission success. To be fully effective, the procurement and fielding of advanced Navwar and PNT capabilities requires the necessary resources and continued senior leadership support in both the executive and legislative branches of the USG.

While GPS currently enjoys unprecedented acceptance throughout the world, new threats to GPS are emerging and competitive foreign satellite navigation systems are on the horizon. The DoD is well on the way to an incremental/ systematic upgrade to a number of space, control, and user features through the GPS Modernization Program. Maintaining GPS at the forefront of the world's space-based positioning, navigation, and timing technology can only be achieved through a continued national commitment to GPS and Navwar accompanied by adequate and stable funding throughout their lifecycles.