

*Defense Science Board
Task Force*

on

**The Future of the Global
Positioning System**



October 2005

**Office of the Under Secretary of Defense
For Acquisition, Technology, and Logistics
Washington, D.C. 20301-3140**

Report Documentation Page

*Form Approved
OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE OCT 2005	2. REPORT TYPE N/A	3. DATES COVERED -	
4. TITLE AND SUBTITLE Defense Science Board Task Force on: The Future of the Global Positioning System		5a. CONTRACT NUMBER	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)		5d. PROJECT NUMBER	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Office of the Secretary of Defense Acquisition and Technology and Logistics Washington, DC 20301-3140		8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited			
13. SUPPLEMENTARY NOTES The original document contains color images.			
14. ABSTRACT			
15. SUBJECT TERMS			
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified	SAR
			18. NUMBER OF PAGES 109
			19a. NAME OF RESPONSIBLE PERSON

This report is a product of the Defense Science Board (DSB).

The DSB is a Federal Advisory Committee established to provide independent advice to the Secretary of Defense. Statements, opinions, conclusions and recommendations in this report do not necessarily represent the official position of the Department of Defense.

This report is unclassified.



DEFENSE SCIENCE
BOARD

OFFICE OF THE SECRETARY OF DEFENSE
3140 DEFENSE PENTAGON
WASHINGTON, DC 20301-3140

28 October 2005

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE (ACQUISITION,
TECHNOLOGY & LOGISTICS)

SUBJECT: Final Report of the Defense Science Board (DSB) Task Force on the Future
of the Global Positioning System

I am pleased to forward the final report of the Defense Science Board Task Force on the Future of the Global Positioning System. In this report the task force assesses several key aspects of GPS military and commercial competitiveness and upgrade strategies and technical alternatives. The task force also examines the implications for GPS from a civil-commercial Galileo, the European Union's proposed Global Navigation Satellite System (GNSS).

The task force makes six principal recommendations for ensuring GPS retains its military and commercial advantage. These recommendations center on: improving the availability and accuracy of GPS satellites and services; improving the functionality and accelerating the attainment of improved capability of GPS control segment and satellite operations; accelerating the development of anti-jam capabilities for GPS military user equipment; improving anti-jam performance of the GPS signal-in-space; dealing with Galileo; and addressing organization and governance issues.

I endorse all the recommendations of the task force and encourage you to read their report.

A handwritten signature in black ink that reads "William Schneider, Jr." with a stylized flourish at the end.

William Schneider, Jr.
DSB Chairman

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OFFICE OF THE SECRETARY OF DEFENSE

3140 DEFENSE PENTAGON
WASHINGTON, DC 20301-3140

DEFENSE SCIENCE
BOARD

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Final Report of the Defense Science Board (DSB) Task Force on the Future of the Global Positioning System

The attached report responds to the April 9, 2004 terms of reference tasking to examine the future of the Global Positioning System (GPS). The request focused on the implications for GPS from Galileo, the European Union's proposed Global Navigation Satellite System, and several other aspects of GPS military and commercial competitiveness, upgrade strategies and technical alternatives.

Though GPS seems a healthy, successful program, nonetheless, our investigation of its operation and management reveals serious issues that affect its operational viability and require prompt leadership action to correct. These include issues of military effectiveness, civil performance and competitiveness, and governance. The task force makes six principal recommendations to address these issues.

Improving Availability and Accuracy of the GPS Satellite Constellation

The current schedule and future investment plan for GPS involves significant risk for sustaining a full constellation. The Air Force has committed for the long term to maintaining only a 24 satellite constellation. The task force recommends a 30 satellite, three-plane constellation for GPS III with satellite weight constraints to permit two satellites per launch. That will provide the cost control needed to achieve the 30 satellite constellation. The larger constellation not only increases robustness but is essential to improving GPS performance in the ground warfare environment where urban and mountainous terrain masks some of the satellite signals.

Improving functionality and accelerating capability of GPS Control Segment and Satellite Operations

In the face of continuing, intractable Operational Control Segment (OCS) development problems, the DoD should provide a near-term workaround to allow early and continuous operation of all new signals as they are present on-orbit. In addition, the Air Force should reevaluate the practice of a totally "blue-suit" operation at the Master Control Station. Outsourcing of part of the operational mission or insertion of selected contractor support personnel could aid in long-term operational continuity.

Accelerating anti-jam capability of GPS Military User Equipment

The task force does not recommend abandoning exclusivity but considers its rigid application to be constraining to potential signal reception benefits that can result from the future diverse signal mix. It recommends adjustments to current GPS receiver acquisition policies to permit more flexible procurement of GPS user equipment. The intention is to leave open the option for military commanders to use Blue jamming for key assets and key opportunities but enable the use of other signals for improved availability and to broaden the base of forces having PNT that will operate when there is no jamming. The task force also recommends including increased signal flexibility in the satellites to permit operational choices with regard to exclusivity in the longer run.

Improving Anti-Jam Performance

The ability for our military forces to be able to navigate and determine position and time in the presence of hostile jamming is essential. The principal vulnerability to be addressed is the threat of widely proliferated, mobile, inexpensive, relatively low-power jammers. The current program will not provide significant anti-jam capabilities in the field for approximately 15 years. The task force recommends the Department initiate an aggressive program to introduce anti-jam enhancements as soon as possible in appropriate military receivers and proceed with GPS III to increase signal-in-space power.

Dealing with Galileo

Galileo's role as a potential European counterpart or competitor to GPS has not yet been realized, and the EU has not fully established the financing necessary to bring it into sustainable operation. The task force recommendations include: remaining open to and promoting opportunities for cooperation under the recent U.S.-EU agreement; strongly promoting true civil interoperability; insisting on full disclosure of an open signal structure; and continuing purposeful implementation of a separate strategy to provide a superior military and an acceptable civil PNT capability for U.S. interests globally using the militarily supported GPS as the core capability. With the rapidly emerging prospect of an altered and competitive environment, the task force believes that the government should be prepared to consider alternative means of funding and governance structures better to sustain international support for GPS.

Organization and Governance

When this study was chartered, there was widespread concern about the governance of the national PNT area. During the study, a Presidential Directive was signed with the intention to strengthen the interagency management process, specifically requiring preparation and update of a 5-year space-based PNT Plan. The task force believes this provides an appropriate governance regime if implemented with discipline. Policy and operational responsibilities for GPS within the DoD have been also been diffused by various management decisions over the last several years. The task force recommends that GPS responsibilities within the Department be clearly assigned and described.

The task force feels that these recommendations are prudent and can serve as the basis for an improved GPS that will ensure U.S. military and civil preeminence in positioning, navigation, and timing services for many years to come.



Dr. James R. Schlesinger
Task Force Co-Chair



Dr. Robert J. Hermann
Task Force Co-Chair

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EXECUTIVE SUMMARY

TASK FORCE BACKGROUND AND APPROACH

On April 9, 2004, the acting USD (AT&L) and the ASD (NII) jointly requested that the Defense Science Board undertake a Task Force on the future of the Global Positioning System (GPS). The request focused on the implications for GPS from a civil-commercial Galileo, the European Union's proposed Global Navigation Satellite System (GNSS). The Terms of Reference also requested assessment of several other aspects of GPS military and commercial competitiveness and of upgrade strategies and technical alternatives.

The DSB empanelled a Task Force comprised of GPS experts with extensive public and private sector experience. Deliberations on relevant GPS topics were conducted primarily among the Task Force members with outside briefings limited to current activities affecting the program itself and other directly relevant topics.

During the course of the year several outside events significantly modified the issues of uncertainty that had existed when the Task Force was formed. Those events included the signing of a cooperative agreement on GPS and Galileo between the United States and the European Union in June 2004, a major study on GPS commercial viability as approved by the Deputy Secretary of Defense in October 2004 and signature by the President of an updated national policy on GPS and related systems in December 2004. While each of these events moderated specific areas of uncertainty that had been complicating GPS planning, each is still a work in progress that will require monitoring as leadership moves to address the still substantive issues facing GPS operation and evolution.

GPS BACKGROUND AND CURRENT ISSUES

Background

The GPS is a space-based positioning, navigation and timing (PNT) system developed by the DoD and currently managed by the U.S. government through an interagency process that seeks to fuse civilian and military interests. That process was the subject of the recently signed Presidential Directive. The U.S. Air Force finances and operates the system of 24+ GPS satellites (distributed in six orbital planes) and a control segment with associated ground monitoring stations located around the world. GPS signals permit simultaneous determination of both precise three-dimensional position and precise time. GPS was the first and remains the only global, three-dimensional radio navigation and timing system providing continuous operational service today. Its civil signal represents a commodity service, provided as a public good by the U.S. government (for safe navigation, improved quality of life and diverse economical purposes) and freely available to all without direct cost or other encumbrance. Its military signals are encrypted for exclusivity of access by U.S. and allied military forces.

GPS Pervades National Security and Economic Infrastructures – GPS is vital to the United States and to the DoD because, as a fundamental information system, it provides a common thread of precise position and time throughout our national security and economic infrastructures. This global, seamless service is invaluable for safe and efficient movement, measurement, and tracking of people, vehicles, and other objects anywhere from the earth's surface to geosynchronous orbit, as well as providing timing and synchronization for global communications, electronic transactions of all types, and power-distribution networks. GPS is used by national mapping agencies worldwide as a basic component of geographic information systems and for natural hazards mitigation (earthquakes, volcanoes, sea-level rise), climate monitoring, severe storm predictions, and in characterizing space weather (ionosphere). Scientific applications involving GPS on-board Low Earth orbiters are revolutionizing weather forecasting and gravity field determination from space.

GPS Quietly Underpins Quality of Life and Economic/Military Performance -- GPS represents a quintessential enabling technology – but one whose contributions are not always apparent, recognized or widely publicized. GPS services directly enable improved mobility, warfighting and communications and indirectly enable many other national infrastructure components to function more efficiently, safely and economically than they could in the absence of GPS. These infrastructure components interact to create quality of life for our citizens, enhance safety of life in our enterprises and produce efficiencies that sustain and enhance our economic performance and provide a critical advantage in military actions. Through its contributions, GPS has not only created its own service infrastructure that must be maintained at a high level of robustness and availability, it has also become an indispensable component of many other infrastructures on which our nation depends. These include telecommunications, electrical power distribution, banking and finance, transportation, emergency services, and military operations and involve hundreds of applications whose discrete contributions are virtually impossible to quantify.

GPS Brings Safety & Precision to Military Operations – Militarily, GPS provides a constant worldwide source for highly precise position and time, both of which are critical for the safe and efficient conduct of military operations and for a transformation to net-centric operations. GPS enhances interoperability in all aspects of military combat operations because of its common-datum, common-grid, and common-time capabilities. GPS has also been the catalyst for precision operations by increasing individual weapon effectiveness and minimizing collateral damage, a combination relevant to the new Air Force initiative of the Small Diameter Bomb. This new concept requires extremely precise target location and weapon delivery and, consequently, is particularly demanding of accuracy and availability from GPS.

GPS Becoming a Global Standard – Internationally, GPS provides significant benefits for civil and scientific users. GPS enables global georeferencing – tying all points to a common grid. Also, GPS observations dominate contributions to realizing the International Terrestrial Reference Frame (ITRF) - which even Galileo will adhere to.

Sustaining GPS Contributions Requires Prompt Leadership Attention -- From all outward appearances, GPS seems to be a healthy,

successful program. At its current level of performance, GPS is providing, on average, better than 5-meter horizontal accuracy, better than 10-meter vertical accuracy and absolute time within 0.1 microsecond of Universal Coordinated Time (UTC). With differential GPS techniques, local accuracies of 1-meter and better are routine. However, our investigation into various aspects of GPS operation and management reveals serious issues that affect its operational viability and require prompt leadership action to correct. These include issues of military effectiveness, civil performance and competitiveness, and governance.

A Vision for GPS

GPS has been implemented and operated to this point without benefit of a commonly accepted vision of its potential contributions. Even so, it has produced dramatic improvements both globally and for our nation that exceeded the expectations of its creators. Those achievements have occurred largely because of consistent support provided to GPS by the civilian leadership in the DoD and despite the fact that we may have forgone opportunities for more rapid improvement. For the future, post-2020, it should be apparent from our experience thus far that GPS can continue to improve quality of life and performance to the extent that opportunities for those improvements continue to be incorporated into its total system design within the global PNT architecture. GPS initiatives for the future should focus on proactive improvements to GPS service fidelity and robustness to continue expanding its performance benefits while protecting against possible asymmetric attacks directed at GPS enhanced infrastructure components.

Military Effectiveness Issues

Improvements Needed, Implementation Lacking - While GPS has proven itself technically effective in meeting military mission requirements in general, it is neither robust enough to overcome credible jamming threats nor are the military signals available in sufficient quantity to meet warfighter needs under many likely operational scenarios. Operational control and equipment acquisition strategies

now being executed are insufficient to address these deficits as rapidly as necessary. The warfighter leadership is becoming more aware of the extent to which GPS is integral to individual mission concepts of operation and operational architectures. However, this growing level of awareness has yet to translate into accelerated implementation, or even plans for implementation, of the GPS improvements necessary to effectively support those missions and architectures in the future. The Task Force finds this lack of improvement to be unsatisfactory, and has included recommendations to stimulate proactive planning for GPS improvements within the operational planning process.

Serious Delays Affecting Military Signals and Equipment -- Full operational availability of new military GPS signals, and the user equipment to receive them, is not forecast before 2013 (24 satellites), though the first new signals will be on GPS Block IIR-M satellites to be launched beginning in 2005. The GPS control segment has experienced significant problems over the last several years in activating new capabilities even as the GPS satellites have evolved, and those problems persist. There are also coverage gaps in the military GPS signal monitor network that have affected timely identification of satellite problems. The coverage problems will be mitigated to a large extent with the addition of data from six National Geospatial Intelligence Agency (NGA) monitor stations, improving the visibility of the constellation to the control segment. However, unanswered questions remain about use of additional global monitoring data collected by civil government and scientific organizations. To date the Air Force has not included the monitoring of the civil signals as an element of its mission of operating GPS. In consideration of its overall responsibilities for GPS operation, the Task Force included recommendations for the Air Force to add civil monitoring and performance measurement to its operational control mission.

Higher Anti-Jam Margins are Essential ASAP - Recent experience in Iraq has shown that the ability to maintain GPS service to our military forces in the presence of hostile jamming is essential. The principal vulnerability affecting that objective is the threat of proliferated, inexpensive, low-power jammers. Improved versions of these jammers are now being offered in the international arms market. Potential enemies are undoubtedly aware of GPS effectiveness, and will take

advantage of this jammer technology in future conflicts. It is imperative therefore that anti-jam margins for military GPS equipment be raised in order to mitigate the effect of these low power jammers. Additionally, the potential growth in the use of proliferated ultra-wideband networking and communications devices and its effect on the noise floor will likely make consistent reception of all GPS signals more challenging, particularly in metropolitan areas.

Anti-Jam Solutions are Known but Implementation Lags Need -

Two principal techniques are available to decrease vulnerability: more power in the GPS satellite signal, and improved technology in GPS user equipment. While increasing the delivered power of the transmitted satellite signal using a spot beam antenna is in the current GPS III plan, it will not be available for the full constellation until at least 2020. The current GPS program of record for user equipment will not field such anti-jam capability improvements in significant numbers for 10-15 years. Development of new user equipment capable of receiving all military GPS signals is underway. However, preproduction prototypes will not be available until at least 2008, and those will only represent two card designs, one for avionics and one for ground receivers. Obtaining modernized user equipment in other form factors for other platforms and weapons will require separate development efforts not presently planned or budgeted. Also, the current user equipment development program is focused on integrating the new military signal structure with existing GPS signals. Additional effort is needed to advance and integrate digital processing and antenna technologies that will provide sufficient anti-jam margin to defeat jammers already appearing on the international market. Because of the importance of these issues to the overall objective of achieving timely and affordable improvements in GPS anti-jam performance, the Task Force convened a separate subgroup to focus particular attention on them. Following that review, the Task Force concluded that schedule and cost risk in the GPS-III program are real and its very long procurement schedule leaves an intolerable window of jamming vulnerability. These concerns can be addressed by an approach that improves military receivers in the near term as the GPS-III program proceeds.

Exclusivity a Two-Edged Sword; Preserves Military Access but Limits Options - Since the inception of GPS, use of an exclusive military signal has been a guiding component of GPS security policy. A critical element of that security policy, navigation warfare (Navwar), is a set of

strategies and capabilities designed to preserve the asymmetric advantage afforded by GPS in the battlespace. Exclusive access to a military GPS signal set is one of the central tenets of Navwar. Maintaining such an asymmetric advantage in position determination, movement and timing over an adversary requires access to exclusive frequency spectrum and use of signal processing, encryption and physical protection measures that make military GPS receivers more complex and costly than comparable civilian receivers. Because of their complexity, and related security requirements, those measures also preclude early migration of GPS functions to “software-only” radio systems. Further, the pending advent of new civil and military signals presents opportunities for more diverse signal reception strategies that may increase service robustness in many situations. The Task Force does not recommend abandoning exclusivity or the capabilities afforded by Navwar. However, the Task Force considers the rigid application of exclusivity to be constraining to potential signal reception benefits that can result from the future diverse signal mix. Consequently, the Task Force recommends adjustments to current GPS receiver acquisition policies to permit more flexible procurement of GPS user equipment within approved military mission Information Assurance parameters. The Task Force also recommends including increased signal flexibility in the satellites to permit operational choices with regard to exclusivity in the longer run.

30 Satellites Enable 15 Degree Mask Angle and Urban/Mountain Coverage - There are no plans at present to manage the GPS constellation to provide continuous availability of more than 24 satellites on orbit, though at least 30 satellites are necessary to assure adequate signal coverage at a minimum 15 degree mask angle to support ground operations in mountainous terrain and urban environments. Trade studies show that a more realistic number of operational satellites would be in the 30 to 36 range, and the Task Force concurs that a 30 satellite constellation is necessary to provide the required service in challenged environments. A larger constellation should also be deployed in three planes vice the current six plane configuration.

GPS III Cost & Weight are Critical Issues - In this context, there is also a very high level of concern among the Task Force membership regarding projected growth in cost and weight of future generation GPS satellites. Affordability is a driving factor in operating and sustaining a

satellite constellation of this size, and the Task Force finds that the GPS III payload as currently envisioned will probably not be affordable in terms of satellite cost and weight. Both factors together determine payload-to-orbit costs, which, if not closely controlled, create an unacceptable budgetary environment in which to consider constellation size and replenishment rate decisions. History has shown that the Air Force has had chronic difficulty in adequately funding GPS, even in the absence of the more expensive GPS III satellites. If the Air Force continues to use its GPS investments as a funding source to offset other space/aircraft programs, then GPS service continuity will remain in jeopardy even without the more costly GPS III. The Task Force recommends that cost and weight of the GPS III satellites be key parameters in their design, and specifically recommends measures to limit GPS III weight to ensure two satellites may be launched aboard a medium-class launch vehicle.

Civil Performance and Competitiveness Issues

U.S. Should Take Leadership Role - As noted above, the economic and social value of a global PNT system based on GPS civil services is so compelling that the U.S. should lead the way in assuring that this global infrastructure is created and maintained. In this context, GPS service to civil users is confronted with a similar situation as that facing the military. Satellites to be launched beginning this year will contain the capability to transmit new civil signals that were announced by the U.S. Government several years ago but have been delayed. Even so, the capability to operationally control those signals will not be present in the GPS control segment until 2009 at the earliest, and that date is uncertain pending determination of a revised acquisition strategy for GPS control functions. With the FAA's supplemental WAAS system and the Coast Guard's NDGPS, GPS is now providing 1 to 2 meters of accuracy in the US. Similar European systems provide equivalent capability. Thus, civil expectations for GPS service fidelity are high and substantially surpass the official commitment to civil performance (SPS Signal Specification/Performance Standard) signed up to by the DoD beginning several years ago. Initiatives are underway to consider use of civil signal monitoring data by the GPS operational control system as an additional source of information regarding civil signal fidelity in conjunction with an updated civil service performance standard. The

Task Force felt it was important that the Air Force, in its operation of GPS, should seriously consider taking advantage of well-established global monitoring capabilities operated by civil and scientific organizations.

EU's Galileo Presents Challenges & Opportunities - The emergence of Galileo as a potential European counterpart or competitor to GPS heightens the importance of GPS civil performance. The Europeans have offered both security and economic reasons to justify creation of a Galileo system in parallel with GPS. European entry into this arena has changed the world's perspective on the composition of a global PNT system. The projected business models for Galileo may impact the use of GPS; however, it is too early to project how Galileo will be implemented, and the EU has not yet fully established the financing necessary to bring it into sustainable operation.

Final Galileo Form Remains Uncertain, but Discussions Offer Promise - The June 2004 U.S.-EU agreement on GPS/Galileo cooperation is encouraging in that it appears to have resolved several technical compatibility issues and establishes an environment for further cooperation. Diverse perceptions that arose during negotiation of the agreement regarding comparability of service between the two systems remain to be resolved as cooperative discussions proceed under the agreement. Even with the agreement in place, uncertainty remains regarding the eventual form Galileo will take as well as regarding European resolve to bring it into full operation. In this context, the recently signed Presidential directive establishes as a goal that U.S.-provided civil GPS services and augmentations remain competitive with foreign civil systems. If/when Galileo is fully operational, its additional satellites should increase signal availability and overall system integrity for dual mode civil GPS-Galileo receivers. This should be particularly useful for users in urban "canyons" and other obstructed areas. In more open environments a single receiver may see a sufficient number of satellites to enable signal integrity verification within the receiver itself. The cooperative discussions now envisioned with the EU should have such improvements as an objective. From a military perspective, Galileo's eventual form could present additional challenges with potential effects on Navwar implementation in the NATO environment. As Galileo evolution and adoption proceeds, the DoD must be prepared

to address its possible use by one or more NATO nations or for NATO purposes.

Governance Issues

GPS Serves Broad & Crucial National Purposes - GPS has become a truly “national” program of critical importance to essentially all aspects of U.S. life and well beyond the scope of any single Department. The burden of justifying the capabilities appropriate for GPS and the resources to implement those capabilities falls on the DoD, which has an easily identifiable worldwide need for the system. Civil, commercial and scientific users around the world who are now dependent on GPS are not institutionally organized to justify and pay for any system characteristics peculiar to their needs that exceed those of the military.

Perception of Military Dominance in Governance - Even though the current interdepartmental governance structure seeks to support the needs of civil and military users without prejudice, there is a perception that the military exerts undue influence in decisions affecting civil GPS. This perception has been used as a principal argument by those who would seek to advance competing technologies or services to supplant or ‘augment’ GPS, in some cases where technical or economic justification falls short. It has also provided potential underpinning for various initiatives to commercialize GPS in order to improve its financial base and to generate non-defense resources for system operation and improvement.

Need to Assess Viability of Alternative Governance Structures - Over the past two years, studies have been authorized by the Deputy Secretary of Defense to investigate the viability of alternative governance structures for managing and financing GPS to both sustain and enhance its services for its full complement of domestic and international users. The studies to date have found that such a strategy could be feasible; however, much additional work would be necessary before any such changes could or would be implemented. The Task Force believes that any substantive change in GPS governance would require extensive cooperation and support among the Executive and Legislative Branches of U.S. Government, as well as commercial acceptance by GPS users.

Comprehensive National Strategy has been Lacking – In its implementation and operation of GPS thus far, the U.S. Government has not made use of a comprehensive strategy accounting for all the national equities at stake in the resolution of issues affecting acquisition and operation of the system. Similarly, there has not been a systematically constructed and commonly accepted architecture to foster consensus among the various agencies responsible for implementation of GPS and its components and complements. The recently signed Presidential Directive is intended to strengthen the interagency management process and requires the preparation and update of a 5-year space-based PNT Plan which could provide the basis for such a strategy.

Responsibilities & Authorities for GPS in DoD Need Clarification – Within the DoD, policy and operational responsibilities for GPS have been diffused by various management decisions over the last several years. The sometimes overlapping, sometimes disconnected roles of the OSD staff components, the Joint Staff, the U.S. Strategic Command (STRATCOM) and the Air Force, as DoD Executive Agent for Space, in the management of GPS have created some confusion over where responsibility actually rests. This sense of confusion has also impacted civil and international perceptions of the importance the U.S. places on GPS and the commitment of the U.S. to GPS sustainment and evolution. It is incumbent on the DoD to redefine lines of authority and responsibility for the system and to reestablish its position of leadership for GPS as the heart of the space-based PNT infrastructure both domestically and internationally. The Task Force recommends that the DoD remain the steward for all GPS satellite services and considers it vitally important that GPS responsibilities within the Department be clearly assigned and described. The Task Force recommends that the Secretary of Defense provide such clear guidance applicable to the full range of military and civil GPS signal services in the future.

TASK FORCE RECOMMENDATIONS

Before detailing our recommendations, it is important to delineate priorities for GPS customers: the worldwide military, civil, commercial and scientific users who benefit from and rely on its services.

GPS User Priorities:

As shown in the following table, GPS user priorities are generally common.

User Priority	Military GPS User	Civil, Commercial, Scientific GPS User
Availability (Short and long term and despite interference)	✓	✓
Accuracy	✓	✓
Bounded inaccuracy	✓ (Minimize collateral damage)	✓ (Assure service integrity)
Denial of PNT sources to hostile parties	✓	
A substantive role in determining system configuration (Governance)	✓	✓
Compatibility with like services (e.g., Galileo, QZSS, GLONASS)	✓	✓

Table 1. GPS User Priorities

SYSTEM AND PROGRAM RECOMMENDATIONS**GPS Satellites and Constellation (Improve Availability and Accuracy)**

- Commit to sustaining a 30-satellite constellation (vice the current 24).

- Increases tolerable mask angle from 5 degrees to 15 degrees to improve performance in mountainous terrain and urban environments.
- Configure the constellation in three planes with 10 satellites per plane (this will simplify constellation sustainment, enabling dual satellite launches to be conducted more efficiently than for a six-plane, five-satellite per plane configuration).
 - Begin transition from the current six-plane constellation as soon as possible rather than waiting until GPS III launches begin.
- Limit GPS III satellite weight to permit launch of two satellites on a single mid-size EELV
 - If the satellite exceeds weight or power thresholds that would compromise dual-manifest (maintain sufficient margin for each through development), the removal of secondary payloads must be evaluated. In this instance, NDS mission modifications and alternatives must be explored.
 - A regional signal (broader beam) should be considered as a lighter-weight and less complex alternative to the narrow spot beam planned for GPS III.
- Continue to acquire high fidelity space-based clocks and navigation payloads to enable direct, high-reliability military accuracy in the range of 2-4 meters for precise targeting and weapons delivery (ensure that the industrial base for this technology is assured).
- As a part of the acquisition strategy for GPS III, include the option to procure higher power earth coverage satellites without non-GPS payloads to permit operation of a mixed constellation of higher-cost, high functionality satellites and lower-cost, utility satellites, increasing signal robustness and availability while lowering overall constellation life cycle costs. This will

also provide significant global mitigation for GPS against both intentional and unintentional interference.

- Incorporate a fully reprogrammable Navigation Payload aboard GPS satellites as soon as practicable to enable future flexibility in signal structure and content.

GPS Control Segment and Satellite Operations (Improve functionality, Accelerate Capability)

- In the face of continuing, intractable Operational Control Segment (OCS) development problems, provide a near-term workaround to allow early and continuous operation of all new signals as they are present on-orbit (M-code, L2C, L5 and, eventually, L1C).
 - Use of the new civil signals will be on an “at-risk” basis, pending declaration by the AF of full operational status.
- As a solution to long-standing OCS development problems, conduct a parallel development of OCS functionality based on layered control engineering principles with clearly defined application programming interfaces between software components rather than the current heavily patched software engineering methodology that has proven unworkable.
 - This recommendation is consistent with that contained in a tasking conveyed to the Air Force by the ASD (NII) in DoD PNT Executive Committee meetings during early-mid 2003.
- Modify the operational concept for satellite operations.
 - Air Force personnel continue to provide guidance and direction to satellite operations.
 - As a means of mitigating the disruptions caused by personnel turnover and to provide an experienced cadre of GPS operators, selectively integrate contractor technical personnel into positions involving direct satellite system

monitoring and execution of commands. In addition to its other benefits, implementing this practice should result in operational cost savings for the Air Force as well as freeing uniformed billets for other assignments.

- Implement direct, independent and continuous monitoring of both military and civil operational capability. This should include projections of capability to meet user needs in both normal and stressed environments as well as historical data to provide assessments of past performance, as necessary.
 - For military assessments and projections, complete the addition of remaining National Geospatial-Intelligence Agency monitor station data into the OCS.
 - Include a direct connection to the WAAS monitoring system. This would provide very high fidelity continuous sampling of GPS availability, integrity and accuracy in the U.S.
 - For civil assessments and projections, consider use of existing worldwide civil, commercial and scientific GPS monitoring networks.
 - As a means of improving GPS global competitiveness, the GPS Civil Performance Standard should be updated to more closely reflect system performance improvements.
 - Establish an independent “civil report card” based on the WAAS monitoring network. This should be included in the weekly assessment of GPS performance.

GPS Military User Equipment Acquisition and Installation (Accelerate Anti-Jam Capability)

- Each Service should fund its own R&D program to best ensure position and timing information is integrated

into equipment and operational capabilities, following a STRATCOM-developed roadmap for joint, integrated, seamless, precision operations and to ensure operation in accordance with a STRATCOM established PPS performance standard.

- Continue fielding Selective Availability Anti-Spoofing Module (SAASM) GPS equipment for missions and applications where access to exclusive GPS military signals is necessary pending production and operational availability of user equipment incorporating the M-Code and other modernization features (see below).
- Evolve GPS user equipment from SAASM to YMCA configurations as rapidly as possible.
 - Change policy guidelines for procuring future GPS user equipment to permit at least three levels of performance and protection.
 - Full capability to operate with “military exclusive” GPS signal(s).
 - Full capability to operate with “military exclusive” GPS signal(s) with the additional capability to receive and exploit other civil and foreign satellite navigation signals.
 - User equipment not configured for exclusive military signals but which can receive and exploit the full range of accessible signals to enable less expensive operations in more benign interference environments.
- In parallel with development of YMCA and M-Code user equipment, invest in complementary technologies that promise significant improvements in anti-jam performance. Integrate these features into SAASM and YMCA receiver designs at the earliest opportunity. Such technologies include, but are not limited to:
 - Adaptive multi-beam steering to counter proliferated mobile jammers
 - Digital antenna processing
 - Narrow-band adaptive filters

- Vector delay lock tracking
- Deep inertial coupling
- Network assist for acquisition/better platform handoffs
- All-in-view
- Chip-scale atomic clocks
- Carefully plan for early integration of anti-jam receiver technology into high priority/high payoff weapon systems.
 - Develop a silver-bullet force comprised of specific delivery platform types equipped with upgraded GPS-aided munitions capable of operating in hostile jamming environments.
 - Ensure mission concepts of operation and system architectures accurately reflect GPS contributions and relevant concepts of operation are updated to define workable employment concepts for silver-bullet resources.
- Continue efforts to evolve the current security architecture to the more diversified and robust PRONAV security architecture.
- One decision that the Task Force considers essential to improving opportunities for future flexibility in GPS satellites and user equipment is to permanently eliminate the requirement for Selective Availability in all future equipment designs with the objective of deleting the hardware and software overhead for its implementation from throughout the future system.

Improving Anti-Jam Performance

- Initiate an aggressive program to introduce anti-jam enhancements soon in appropriate military receivers, namely:

- Receivers that are being redesigned to accommodate M-code
- Receivers in new weapon systems being developed
- Selected "silver-bullet" subsets of receivers in munitions
- Proceed with GPS III with a firm resolve and process to control satellite weight such that two satellites can be launched on a single booster, namely:
 - Control "requirements creep" through consistent program oversight exercised by the ASD(NII) and USD(AT&L)
 - Maintain sufficient weight and power margins through development
 - Be prepared to off-load portions or all of other payloads such as NDS if necessary.

Dealing with Galileo

- Remain open to and promote opportunities for cooperation under the recent U.S.-EU agreement and in accordance with the recent Presidential Directive.
- Strongly promote true civil interoperability - well defined geodetic and time transformations that can be easily implemented in user equipment.
- Insist on full disclosure of the open signal structure.
- Continue purposeful implementation of a separate strategy to provide a superior military and an acceptable civil PNT capability for U.S. interests globally using the militarily supported GPS as the core capability.
- Maintain a PNT system configuration that will permit Galileo assets to increase the capability presented by the combination of both systems for civil users.

- Prepare for discussions within the NATO environment regarding possible use of Galileo services for military purposes by NATO member nations.
- Explore with the Europeans a collaborative approach that maintains the sovereign independence of both parties while permitting the creation of greater capability at lower cost than either could achieve alone for commercial benefit.
- Explore cooperative exchange of monitoring information.

Organization and Governance

- The recently signed Presidential Directive on Space-Based PNT affords an opportunity for all stakeholders to correct deficiencies of the former Interagency GPS Executive Board. The following recommendations address the effectiveness of the new structure.
 - If Deputies do not routinely participate, then designated representatives to the National Space-Based PNT Executive Committee (NPEC) must be formally empowered to speak for and act on behalf of their respective Deputies for all matters coming before the NPEC.
 - Strengthen the effectiveness of the full-time National Space-Based PNT Coordination Office (NPCO) by formally designating senior technical focal points within each department who will keep the NPEC principals fully apprised of all PNT matters being developed by the NPCO for executive level consideration and action.
 - Stakeholders can use this forum to investigate the viability of alternative methodologies for managing and financing GPS to address current issues and more effectively sustain and enhance services for its full complement of domestic and international users into the future.

- The Secretary of Defense should also clarify lines of authority and responsibility within the Department to eliminate ambiguity regarding GPS responsibilities that hinders decision making internally and that perpetuates the perception externally that the DoD has lost sight of its GPS stewardship responsibilities.
 - Designate a single focal point within the Office of the Secretary of Defense responsible for all GPS policy and oversight matters including clearly defined relationships with the Joint Staff and Services (including the Air Force) regarding GPS operations and acquisition, respectively.
 - Use the DoD PNT Executive Committee process to conduct a top-to-bottom review and develop recommendations regarding organizational structure(s) for DoD PNT role.
 - Sponsor and lead an interagency effort to develop a comprehensive national PNT architecture to guide future investment and implementation decisions regarding GPS and complementary systems and technologies.
 - The Secretary of Defense should reemphasize in writing the criticality of GPS operations, similar to the emphasis he has previously issued for GPS acquisition.
 - Commander STRATCOM can quickly demonstrate improved operations through support of Commander 14th AF tasking to stand up a Joint GPS Service Support Center (as part of the Joint Space Operations Center). The center's primary operational task would be improved position and time services to military users, achieving this initially through the collection and assessment of GPS monitor information from reliable, independent global sources and in the longer term by providing operational guidance for updating the control segment software. The center could also provide a source of information on all foreign GNSS

available (GLONASS, Galileo, other systems), for space situation awareness.

- In fulfilling its stewardship obligation for providing civil and military space-based PNT, the Commander, STRATCOM should be directed by the Secretary of Defense to develop and maintain a roadmap for achieving joint, integrated, seamless, precision military operations, to coordinate Service-developed user equipment roadmaps for compatibility and to establish and maintain SPS and PPS performance standards. STRATCOM could then task its component (Air Force Space Command) to implement standards and reporting criteria in accordance with routine joint system performance reporting instructions.
- Include designated representatives from STRATCOM on all DoD and interagency executive committees and working groups involved with management and operation of GPS.
- Ensure that the concept of stewardship for GPS operations as passed from the Secretary of Defense to STRATCOM includes responsibility for being aware of and meeting civil service performance needs as mutually agreed between the DoD and civil users and reflected in the GPS Civil Performance Standard.

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CHAPTER 1. INTRODUCTION

1.1 TASK FORCE APPROACH

This Task Force on the future of the Global Positioning System (GPS) was originally empanelled to assess the implications for GPS from a civil-commercial Galileo, the European Union's proposed Global Navigation Satellite System (GNSS). The Terms of Reference (Appendix A) also requested assessment of several other aspects of GPS military and commercial competitiveness and of upgrade strategies and technical alternatives.

The Task Force was comprised of acknowledged GPS experts with extensive public and private sector experience (Appendix B). Assessments of the various issues before the Task Force were obtained through the insights and extensive experience of the members. Use of outside briefings was minimized, and those presented to the group (Appendix C) were focused primarily on updating current program activities bearing on specific issues under consideration.

1.2 GPS DESCRIPTION

GPS is a space-based positioning, navigation and timing system developed by the U.S. Department of Defense (DoD). It emerged in the late 1960s and early 1970s as a merger of synergistic Navy and Air Force programs for timing and space-based navigation, respectively. The U.S. Air Force currently finances and operates the basic system of 24+ satellites and associated ground monitoring stations located around the world. GPS is widely characterized as a satellite navigation or a satellite positioning system, providing signals for geolocation and for safe and efficient movement, measurement, and tracking of people, vehicles, and other objects anywhere from the earth's surface to geosynchronous orbit in space. A less-known element omitted from many GPS descriptions is the embedded timing that serves an essential role in its navigation services. The precise time and stable frequency signals available from

GPS are at least equal in importance to its navigation and velocity determination functions. They serve as synchronization sources for global communications, electronic transactions of all types, power-distribution networks and innumerable other applications.

From its beginning, the GPS architecture was designed to minimize military navigation and timing vulnerability by moving the vital electronic processing and transmitting equipment into space to make them extremely difficult to reach. From there, GPS signals provide a multi-mission force multiplier service for an unlimited number of U.S. and allied military users. Though many believe civil applications only came along much later, in fact, GPS scope was expanded early in its development to include complementary civil capabilities as well.

Simplistically, GPS implements a time-difference-of-arrival concept using precise satellite position and on-board atomic clocks to generate navigation messages that are continuously broadcast from each of the GPS satellites. These messages can be received and processed by users anywhere in the world to determine position and time accurate to within a few meters and a few nanoseconds, respectively (Figure 1).

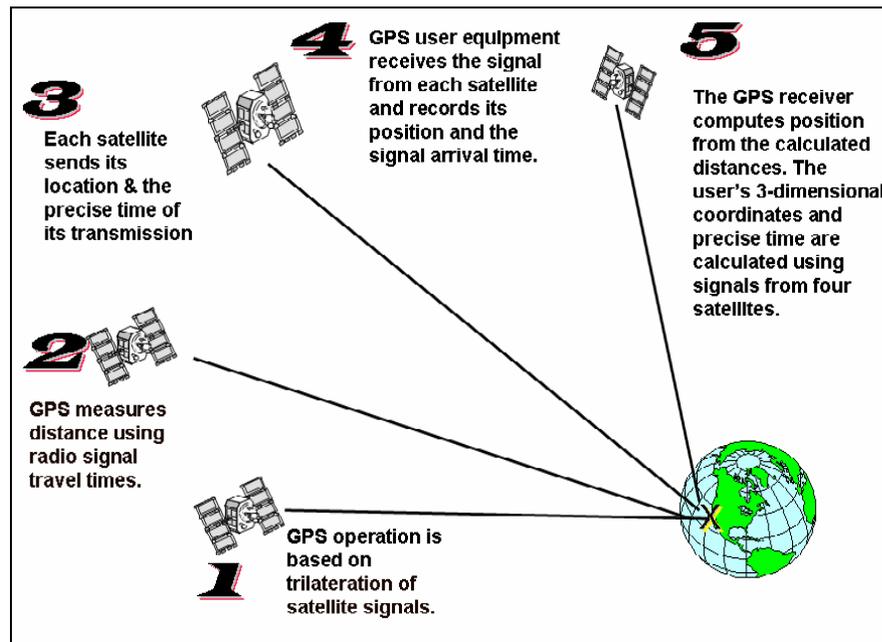
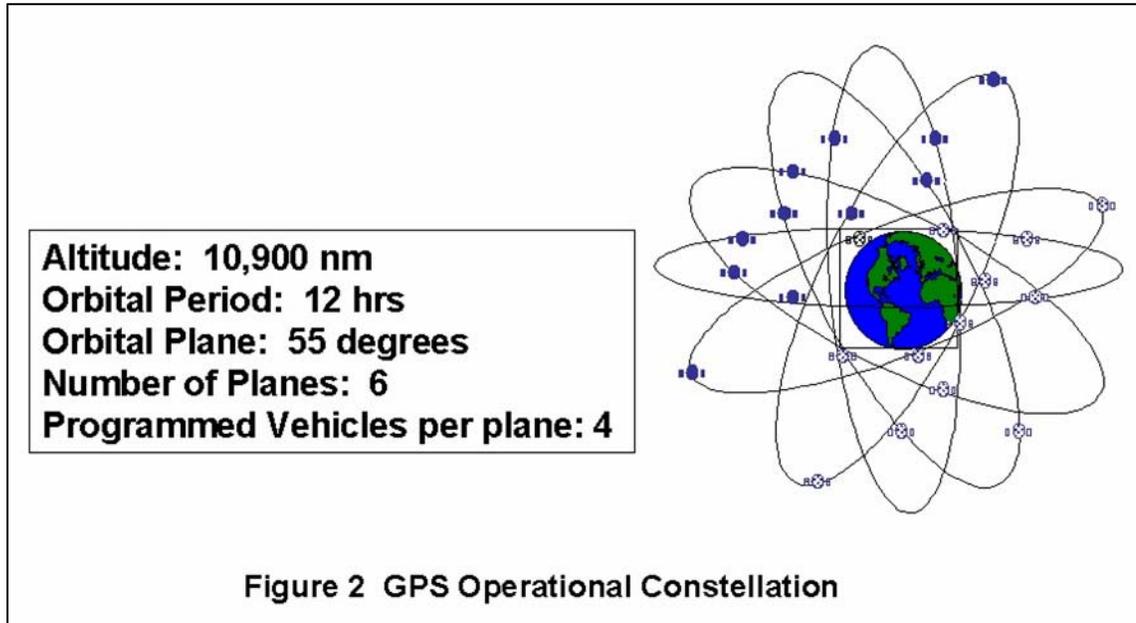


Figure 1 How GPS Works

Each GPS satellite on-board computer and navigation message generator knows its own orbital location and system time very precisely. A global network of monitor stations keeps constant track of these parameters. Corrections are uploaded to each satellite at least daily by the worldwide operational control segment with Master Control Station at Schriever Air Force Base near Colorado Springs, Colorado. The uploads include orbit position projections for each satellite in the constellation, based on sophisticated models and effective for several weeks, as well as corrections to on-board satellite clocks. All GPS satellite capabilities are enabled by control segment software. New capabilities designed into the satellites require corresponding control software to be developed, tested and validated for operational use before those capabilities can be declared operationally available for GPS users.

System time is maintained aboard each satellite by Cesium and Rubidium atomic frequency standards. In general, these on-board clocks are accurate to within a few nanoseconds of global coordinated time (UTC) as maintained by the Master Clock at the U.S. Naval Observatory and are individually stable to a few parts in 10^{13} or better. Early GPS satellites contain two Cesium and two Rubidium standards each, later versions have all Rubidium standards. Only one standard is operational aboard each satellite at any given time.

To produce accurate positions in three dimensions, a user must be able to see four GPS satellites, separated sufficiently and geometrically oriented in three-dimensional space so that processing will define a precise signal intersection. After much analysis, this basic requirement for simultaneous multi-satellite global coverage resulted in a constellation design comprising at least 24 satellites at semi-synchronous altitude (about 11,000 nautical miles). The system was originally designed with eight satellites in each of three orbital planes, inclined at 63 degrees; however, as a result of budget fluctuations during system development, as well as a plan to launch GPS on the Space Shuttle (later abandoned), the current operational constellation was implemented in six orbital planes, each of which is inclined at 55 degrees (Figure 2).



Each GPS satellite transmits the navigation messages in military and civil signals in the L-band at L1 (1575.42 MHz) and military only signals at L2 (1227.6 MHz). A new civil signal will be added to L2 beginning in 2005 and an additional frequency will be added for civil use in late 2006 at L5 (1176.45 MHz). The GPS receiver uses the position and time information, broadcast in the navigation messages and traveling at the speed of light, to calculate approximate ranges to each of the satellites within line of sight to its antenna. These approximate ranges are called pseudoranges, since biases in the user receiver clocks prevent the precise individual ranges from being measured directly. The pseudorange from each individual satellite for a specific but unknown value of user clock error defines a sphere on which a user may be located in three-dimensional space. The intersection of three spheres defines a point, though the intersection is imprecise due to the aforementioned biases in the receiver clock (which in nearly all cases is not an atomic clock) and to effects of ionosphere and atmosphere on the signal transit time. Addition of a pseudorange from a fourth satellite allows calculation of the user receiver clock error and permits computation of the three physical dimensions of the precise intersection, as well as precise time. GPS operates within an Earth-Centered-Earth-Fixed (ECEF) reference frame, so position determinations are essentially independent of the local topography, which must be accommodated by geodetic models within the GPS receivers. The

baseline geodetic reference for GPS is World Geodetic System 1984 (WGS-84), though many other geodetic references are included in most GPS receivers.

1.3 INTRODUCTION OF THE ISSUES

The GPS comprises the core component of a broader, worldwide PNT system-of-systems that is important for the U.S. military, for the U.S. economy and infrastructure, for military allies and coalition partners of the U.S and for the world's economy and infrastructure. The PNT system-of-systems consists of both local-area and space-based (wide-area) augmentation services designed to enhance GPS accuracy and/or availability. It also includes complementary stand-alone systems such as inertial measurement units and electronic clocks that work in close connection with GPS, which serves to mitigate the natural drift of stand-alone systems. There is also a reverse benefit from GPS-inertial coupling, as the inertial aids the GPS processors to maintain dynamic tracking in the presence of high accelerations.

As a direct result of its integral functions in the global PNT system-of-systems, we as a nation have become critically dependent on GPS. This point requires emphasis because the extent of our dependence on GPS, derived from its effectiveness and pervasive availability, amounts to a new paradigm which military and civilian decision makers must take into account. Efficiencies in positioning, movement and timing derived from the ubiquitous GPS signals have already quietly permeated virtually every level of our national infrastructure to the extent that, in many cases, there is no going back to earlier ways of doing things without tremendous but unrecognized penalties. All of the domains, missions and infrastructure components addressed by this Task Force are already affected to a greater or lesser degree by this dependency, and we believe the effects will only become more pronounced over time.

From outward appearances, GPS seems a healthy, successful program. At its current level of performance and with nearly thirty satellites in the constellation, GPS is providing, on average, better than 5-meter horizontal accuracy, better than 10-meter vertical accuracy and absolute time within 0.1 microsecond of Universal Coordinated Time (UTC). With differential

GPS techniques, local accuracies of 1-meter and better are routine. However, our investigation into various aspects of GPS operation and management reveals serious issues that affect its operational viability and require prompt leadership action to correct. These include issues of military effectiveness, civil performance and competitiveness, and governance.

In the ongoing transformation of military capabilities, assurance of precision affords a basis for new military operational concepts, and GPS provides the core infrastructure component for precision. Many of these new operational concepts have as essential elements small conventional munitions that enable tailoring of attack effects while minimizing collateral damage. These new concepts are particularly demanding of accuracy in both target location and weapon delivery and of precision signal service availability. New paradigms such as the Air Force's small diameter bomb (see Appendix D), the Navy's Extended Range Guided Munition (ERGM) and the Army's Excalibur XM982 GPS-guided artillery projectile epitomize these new miniaturized munitions. The consequences for future military requirements of using these smaller munitions will be felt in areas of accuracy and of anti-jam signal and receiver performance.

Within this context, from a military perspective, the Task Force considered the following issues:

- The potential of constrained investment leading to below minimum required number of satellites on orbit.
- Inadequate numbers of satellites for many applications in the longer run.
- Availability of anti-jam capability and the threat of increasingly more potent and possibly mobile jammers.
- Control and User segment schedules do not match satellite availability.
- The value of military signal exclusivity and its attendant costs.
- The state of the Operational Control Segment relative to monitoring GPS signal fidelity and operating the satellite constellation.
- The status of GPS III and the factors affecting cost and weight of proposed GPS III satellites.

- GPS has also become a critical element of infrastructure for positioning, navigation and timing for a wide variety of civil applications and for countless commercial applications. PNT is a big business and growing. A variety of government and private sector studies have projected multi-billion dollar annual markets for civil and commercial GPS-enabled products and services continuing into the future. These studies focus on projected sales and do not project the multi-sector cost savings attendant on the ubiquitous use of GPS and the attendant efficiencies in operations and safety it affords affecting both the U.S. and international economies.
- Within this context, from the perspective of civil and commercial applications, the Task Force considered the following issues:
 - The potential of constrained investment leading to below minimum number of satellites on orbit.
 - Inadequate numbers of satellites for many applications in the longer run.
 - The perception in the civil/commercial sector and the international community that the U.S. military dominates decisions about the system and is not responsive to their needs and concerns.
 - The potential effects of the European Galileo system on the U.S. leadership position with respect to global PNT.

The economic and social values of a global PNT infrastructure based on GPS-like systems for both military and civilian purposes are compelling. The U.S. should take a position of leadership in assuring that this global infrastructure is created and maintained. Within this context, the Task Force considered the following issues:

- The strategic value to the United States of GPS as a central component in a coherent, global PNT system.

- Assuring availability of GPS to U.S. military forces in times of stress and conflict.
- Providing confidence to the civil, commercial and international communities that they can depend on GPS as a long term part of their PNT infrastructure.
- Necessary actions to achieve these objectives (capability, resources and schedules).
- Appropriate operations, management and governance structures.

CHAPTER 2. GPS ROLE IN MILITARY MISSIONS AND THE NATIONAL INFRASTRUCTURE

2.1 NATIONAL SECURITY INFRASTRUCTURE (DOMAINS AND MISSIONS)

For military missions, GPS provides an unparalleled force-enhancement tool. GPS aids in all aspects of military combat operations because of its common-datum, common-grid, common-time capabilities. GPS is unique in its ability to establish an unambiguous correlation in four dimensions between a target and a dynamic weapon system aimed at that target – all the time, anywhere on the earth, and under any conditions of light, weather, or other source of target obscuration. This translates directly into increased probability of kill for any particular weapon, increased force employment efficiency for military mission planners, and overall lower risk for the individual military members and units that must execute the missions. To the extent that a target point is defined and a weapon is guided by precise GPS signals, the probability that the target will be hit despite any other circumstances that exist is significantly higher with GPS than with any other combination of targeting and positioning technologies. Further, since GPS requires no electronic transmissions for access, it enables safe, efficient and precise operations in situations where complete radio silence is required. Because of those performance features, both the DoD and Congress have long mandated GPS for military operations. Its functionality has been or is being installed and integrated into virtually every significant operational warfighting and support system operated by the DoD, including communications and data systems.

The following summarizes the Task Force assessment of GPS contributions to diverse military missions.

2.1.1 Air Operations

GPS enables global precision air operations in all categories of manned and unmanned air platforms. It permits point-to-point air navigation anywhere in the world without reliance on ground-based navigation aids or ground control through all phases of flight up to precision approach and

landing. GPS works best in aircraft applications when coupled with an inertial navigation unit. In this coupled configuration, GPS provides initialization for the inertial system and compensates for inertial drift, and the inertial system improves GPS tracking in the presence of high acceleration and changes in direction. In many applications, use of GPS allows lower cost inertial systems than would otherwise be required if the inertial were stand-alone. GPS positions relayed across Joint Tactical Information Distribution System (JTIDS) communications networks afford air commanders a continuous precise picture of the three-dimensional disposition of air assets. Both aircraft and weapons carried aboard aircraft employ GPS. However, only a few aircraft types provide the data transfer capability to directly initialize onboard GPS weapons so that they may rapidly acquire and track GPS signals once they are released from under the wing or from the bomb bay, thereby reducing their effectiveness.

2.1.2 Naval Operations

GPS enables seamless global maritime navigation on the open ocean, littoral waters, harbors and inland waterways. It has replaced two former radionavigation systems used for open ocean navigation by naval vessels and submarines. It has eliminated the need for high-power radio transmissions formerly needed for open ocean aircraft recovery in carrier operations. It also improves safety of close proximity operations at night and in limited visibility conditions.

2.1.3 Land Operations

GPS enables efficient and safe land operations globally. Use of GPS with properly gridded maps enables ground forces to conduct coordinated operations in featureless terrain and, when coupled with laser range finders, to precisely determine target coordinates from a distance for attack by GPS guided munitions. Integrated with tactical secure communications devices, GPS enables commanders to maintain continuous awareness of force location and movement for more effective operations and to mitigate fratricide. Unique constraints imposed on GPS by land operations in forests, mountainous terrain and urban areas can be mitigated by increasing military signal strength and by raising the mask angle below which signal reception from the satellites is blocked to at least 15 degrees.

2.1.4 Space Operations

GPS enables highly precise and continuous determination of satellite orbits out to at least geosynchronous earth orbit (GEO – about 22,000 mi). For this purpose, GPS acts in place of ground-based radars, which must be scheduled and cannot track individual satellites continuously, and many of which are located on foreign soil. The GPS constellation orbits at about 11,000 nmi (medium earth orbit – MEO). For satellites orbiting below about 4,000 nmi (and low earth orbits are well below this altitude), continuous point positioning is possible, as with aircraft navigation. Satellites at or above MEO track GPS signals coming past the edge of the earth from the other side of the GPS constellation, and use serial data collection techniques for orbit determination. Use of GPS by MEO and GEO systems requires that GPS signals directed toward the earth be broadcast such that sufficient signal energy can be received by satellites on the other side of the earth so they can perform orbit determination calculations.

2.1.5 Weapons Delivery

GPS enables all-weather, day/night precision weapons delivery anywhere in the world. GPS has improved employment efficiency and accuracy of all types of bombs, cruise missiles and artillery systems. It affords improved safety for aircrews by enabling weapon release at increased stand-off ranges from targets. It affords wider ranges of employment options for cruise missiles in cases where lack of terrain features or shortage of mission planning material would have otherwise precluded a mission. It affords improved safety for ground support of forces in close contact with adversaries by enabling precise GPS-guided bombing or artillery fires against GPS-designated target coordinates (see discussion on spatial uniformity – Appendix E).

2.1.6 Targeting

Target location error (TLE) is the single largest contributor to total system error in the employment of GPS-guided munitions against fixed targets. To the extent that GPS is used in the determination of target coordinates, the ability to attack those coordinates with precision is significantly enhanced. GPS is used in conjunction with laser range finders

by ground forces and forward air controllers. GPS is also used in conjunction with synthetic aperture radar aboard aircraft to obtain precise targeting information relative to the aircraft's position (see discussion on spatial uniformity - Appendix E).

2.1.7 Special Operations

In addition to its contributions to land, sea and air navigation, targeting and weapons delivery as they apply to special operations, GPS enables covert and precise day/night rendezvous on land, sea and air under all weather conditions. The combination of precise position and timing information provides the capability to rendezvous without the need for radio transmissions or other displays which might attract unwanted attention.

2.1.8 Logistics Operations

GPS enhances safety and efficiency of all types of logistics and supply operations. It enables pre-positioning of military supplies in covert locations for planned operations as well as precise delivery of needed supplies when pre-positioning is unfeasible. In sea-based resupply/refueling and air refueling operations, it allows precise, covert day/night rendezvous under all weather conditions.

2.1.9 Mine Clearing/Explosive Ordinance Disposal (EOD)

GPS, augmented by differential techniques, enables precise charting of mine fields in land or water for construction of safe lanes and for improving safety of EOD operations.

2.1.10 Search & Rescue

GPS enables precise location of downed aircrew members and improves the probability for a successful rescue. GPS is combined with low probability of intercept/low probability of detection (LPI/LPD) over-the-horizon and direct communications in Combat Survivor/Evader Locator (CSEL) handsets now in production.

2.1.11 Communications

GPS provides timing and frequency synchronization for wired and wireless communications and data networks. Synchronization is necessary for encrypted communications and data transmissions, in particular, and for maintaining efficient throughput at connection nodes between different networks. The U.S. Naval Observatory (USNO) is the official timekeeper for the DoD. As a part of its mission, the USNO maintains its Alternate Master Clock at the GPS Master Control Station and provides the data necessary to steer GPS time directly to the USNO standard. The timing signal from the GPS satellite constellation represents the transmitted version of USNO time and has been designated in JCS publications as the official time source for military operations.

2.1.12 Intelligence, Surveillance and Reconnaissance (ISR)

GPS enables increased efficiency in geo-referencing ISR data and provides the precise timing information used in ISR systems of all types.

2.1.13 Net-Centric Operations

GPS provides the timing and synchronization necessary for effective net-centric operations for both support and attack activities. It also enables precise short- or long-duration navigation for all types of unattended vehicles that may be employed in net-centric operations.

2.1.14 Battlespace Awareness

GPS enables the spatial and communications components underlying effective battlespace awareness. Spatial information relayed through tactical comm/nav networks such as JTIDS and Enhanced Position Location Reporting System (EPLRS), among others, provide the foundation for continuous battlespace awareness at all command levels. Precise spatial and timing information are also important components of Blue Force Tracking and Joint Blue Force Situational Awareness capabilities that contribute to reduced fratricide and coordinated operations.

2.2 NATIONAL ECONOMIC INFRASTRUCTURE

As an information resource, GPS provides an essential linkage between the largely locationless electronic/communications environment and the physical world. Even the best overhead images and maps must be accurately geo-referenced in order to be useful for precise navigation and GPS provides that direct connection. GPS also provides primary timing and synchronization for most of our national telecommunications and data networks. In addition to its economic and scientific contributions, GPS is also integral to enabling speed and precision in domestic emergency response operations of all types. DoD and Department of Homeland Security officials responsible for protection of our national infrastructures must be aware of the contributions GPS makes to their daily operation. In executing their responsibilities for ensuring homeland security, federal, State, and local agencies will have to be able to respond quickly in the real world to warning and attack information from a variety of sources. GPS is integral to making that information immediately and uniformly useful.

The following summarizes the Task Force assessment of GPS contributions to national infrastructure elements.

2.2.1 Civil Telecommunications

Beginning even before GPS became fully operational, global timing and communications infrastructures began adopting GPS as the primary distribution mechanism for time and frequency synchronization. The USNO maintains its Alternate Master Clock at the GPS Master Control Station and provides the data necessary to steer GPS time directly to the USNO standard. As a direct result, the timing signal from the GPS satellite constellation is being used internationally as a continuous, globally available source of UTC. Additionally, major national and international telecommunications service providers, including both wireless and wireline technologies, have recognized the value of using the freely accessible GPS timing signals. Beginning in the late 1980s, many have largely replaced their complements of ground-based atomic frequency standards in favor of receiving continuous precise time and frequency signals from GPS. With its signals providing a principal source of timing synchronization and frequency syntonization at the Stratum 1 (Primary Reference Source) level,

GPS has become an essential component in the flow of digital data between multiple service providers, relevant to both Internet operations and diversified telecommunications networks. GPS has also become an essential, and largely transparent, enabling technology for the economical operation of cellular telephone and other wireless media nationwide and around the world.

2.2.2 Electrical Power Distribution

Nationwide, many electric power companies have begun to use GPS timing and frequency services to improve the economy and efficiency of their operations. They primarily use GPS signals for monitoring stability of line frequencies, frequency synchronizing or “syntonizing” services with adjacent power company networks, and isolating faults in transmission networks. The fidelity of service provided by GPS exceeds the routine needs of power companies, but its ready, free availability makes it very appealing, and the precise timing signal is extremely useful in isolating damage in remote lines to within a single tower span. GPS is also the technology of choice for maintaining phase differences to very tight standards when loads are transferred among substations, as would happen as a consequence of a major power perturbation. Use of GPS has enabled load transfers to be accomplished in a few hours where previous techniques required days. As electrical service deregulation spreads across the country while the nation faces a real new threat of intentional power grid disruptions, interoperability dependencies between individual service providers heighten the importance of GPS as companies must respond to widespread load variations and to system surges created by environmental effects such as solar storms or potentially by hostile actions of terrorists.

2.2.3 Electronic Commerce and Finance

Many banking and financial firms employ GPS timing for synchronization of their encrypted computer networks, though this function is in most cases buried within contracted telecommunications services and transparent to management. Also, computer transactions are routinely time-tagged, and with the advent of Internet trading, the precise timing of transactions is becoming more important. Presently, both the USNO and the National Institute of Standards and Technology (NIST) are

legally certified time stamping services for the purpose of determining financial transaction sequences. The mechanism for distribution of the precise timing signals across the Internet is GPS. As e-commerce and e-trading expand in the U.S. and internationally, the importance of precise time stamping will continue to increase.

2.2.4 Transportation

Since GPS reached operational status in the early 1990s, its consistently high-quality performance and low cost of use have created dramatic changes in the civil and commercial transportation infrastructure. Two federal agencies, the U.S. Coast Guard and the Federal Aviation Administration (FAA), have both embraced GPS and have initiated programs to augment GPS accuracy. The Coast Guard initially began with a differential augmentation service to provide sub-10 meter accuracy using marine radio-beacons around the contiguous US coastline (Maine-Texas and California-Alaska), the Great Lakes and St. Lawrence Seaway, and the Mississippi and Missouri River watersheds. That service is now fully operational at an actual precision of 1-2 meters. The service has also been expanded to interior land applications in the last several years in a cooperative venture with the Federal Railroad Administration and the Air Force and called Nationwide Differential GPS (NDGPS). NDGPS is transmitting augmentation signals to provide one-meter accuracy to rail and other land users across the U.S. using Low Frequency signals from the obsolete AF Ground Wave Emergency Network which is being dismantled. This service was originally intended to support positive train control, but has service implications far beyond railways.

At the same time, the FAA has implemented a multi-billion dollar program called the Wide-Area Augmentation System (WAAS) to increase the accuracy, reliability and availability of GPS-based services for aviation users by transmitting special augmentation signals over satellite communications links. The FAA has also begun a companion project called the Local Area Augmentation System (LAAS) wherein signals are transmitted in the area of an airport to aid instrument landings and ground operations. The WAAS is a model for international civil aviation ventures in Europe and Japan to provide seamless global augmentation to GPS. Japan is also planning a complementary space-based adjunct to GPS, transmitting civil GPS signals, called the Quazi-Zenith Satellite System (QZSS). The QZSS comprises a small number of satellites in an orbital

arrangement configured to increase the number of civil GPS signals over Japan to improve availability in dense urban areas. In addition to these activities, foreign differential GPS services, mostly (but not all) government-sponsored, are widely available to serve a diverse range of positioning (Geographic Information Systems) and transportation needs. Together, these international activities reflect a growing commitment to satellite navigation services, and specifically to GPS.

Though not directly related to transportation, another service called Global Differential GPS (GDGPS) uses a worldwide network of civil reference stations to develop differential GPS corrections. The GDGPS service was originally developed for NASA by the Jet Propulsion Laboratory and is now additionally offered through commercial vendors to enable precision agriculture. The GDGPS also provides a valuable source of monitoring information for civil GPS signals as will be addressed in Section 3 of this report.

A common thread through all this activity is that each represents an augmentation to the core service provided by the GPS satellites – and none will operate on its own without the presence of the basic GPS signals. In most cases, the augmentations serve as checks on the quality of the basic signals, but together, they will soon represent an absolutely critical component of transportation economy and public safety.

2.2.5 Emergency Services

Closely related to GPS contributions to both communications and transportation are its contributions to the emergency services infrastructure of police, fire, and ambulance providers and other emergency responders. Use of GPS is growing significantly among regional ambulance providers as a means of managing fleets of emergency vehicles. As its use increases in automobiles, it is becoming a significant factor in E-911-type situations, where emergency vehicles are dispatched to accident locations by activation of a GPS location keyed to activation of an air bag. Further, GPS-derived positions are now being included in planning for E-911 capabilities required by legislation from cellular telephone service providers. GPS has also proven its value to fire departments operating in devastated parts of the California hills after the Oakland fire of several years ago, to the diverse

government emergency response teams dealing with the aftermath of hurricanes in the Southeast and with flooding in the Midwest. GPS use is growing in this sector and its incorporation in E-911 situations and in improving spatial interoperability among multi-jurisdictional response organizations will increase its importance in the future. Those improvements would be hastened even more by Federal Government leadership in promoting education regarding GPS benefits and training in the uniform application of its services to all participants in emergency response at federal, State and local levels (see discussion on spatial uniformity - Appendix E). This type of institutionalized spatial coordination will be especially important to rapid and efficient response in the case of an unpredictable widespread disaster resulting from terrorist or other hostile activity involving biological agents or nuclear devices.

CHAPTER 3. SYSTEM AND PROGRAM ISSUES

3.1 LACK OF BALANCE AMONG THE GPS SEGMENTS

As discussed in Section 1.2, GPS is comprised of three distinct, but closely related, segments. The space segment (satellites) provides the signals that are received and processed by the user segment, and the quality and content of the signals, as well as the health of the satellites, is maintained by the control segment. In order for the system to perform optimally and provide the best possible service to users, the capabilities of all three segments must evolve in synchronization. As new signal capabilities are added to new satellites, the capability to activate, monitor and operate those new signal capabilities must be designed, tested and incorporated into the operational control segment. This must be done such that the continuing operation of legacy services by the control segment is not degraded or affected in any way. At the same time, new user segment receivers/chipsets must be developed put into production and installed/integrated into user systems so they will be able to process and exploit the new signal capabilities when they are present in sufficient quantities in on-orbit satellites and they are activated and then declared operational by the control segment.

While those factors were synchronized during the initial stages of GPS operation, the program is now out of balance in several respects and that threatens to delay availability of needed operational capabilities. The out of balance situation has occurred for a variety of reasons, primarily related to technical issues and funding. Since the satellites are the critical signal sources and even new satellites can be operated by the existing control segment to maintain legacy services, they have taken priority when technical problems arise that endanger future launch schedules. In some cases, those problems have required diversion of funding from the other segments, causing delays in their improvement and evolution. One operational capability that has been particularly affected has been anti-jamming performance, which requires both control and user segment improvements to take advantage of new satellite signals. Additionally, diversion of funding from user equipment development delays other

improvements in signal processing that can provide anti-jam improvements independent of new satellite signals.

3.2 GPS SATELLITES & THE GPS CONSTELLATION

GPS satellites presently come in five vintages, Block II/IIA (manufactured by Rockwell), Block IIR/IIR-M (Lockheed-Martin – formerly GE) and Block IIF (Boeing – formerly Rockwell). As of 15 Apr 05, the current constellation is comprised of one Block II, fifteen Block IIA and twelve Block IIR satellites. Of the twenty-eight satellites on orbit, a significant number are operating in a single-string condition. Still in the pipeline are eight Block IIR satellites and nineteen Block IIF satellites. All Block II-vintage satellites carry a sensor payload set supporting the Nuclear Detonation (NUDET) Detection System, or NDS. The NDS payload was designed to detect and characterize NUDET bursts for the DoD and other agencies, and based on global coverage afforded by GPS, replaced similar sensors that had been performing this function on other systems. All Block II-class satellites also employ UHF crosslink antennas, used to transmit information around the GPS constellation. With the growth of UHF ground-based communications activity in recent years, signal interference on the crosslinks is becoming more prevalent, and future GPS satellites will adopt higher frequency crosslinks in spectrum bands protected for space-to-space use. The next generation GPS satellite intended to replace the Block II versions is a part of the GPS III overall system upgrade.

3.2.1 Block IIR/IIR-M

The Block IIR satellites duplicated the signal configuration of the Block II/IIA satellites and incorporated additional capabilities for extended operation and crosslink ranging. A total of twenty-one Block IIR satellites were procured via multi-year contract. One was destroyed on launch due to booster failure. Up to eight of the remaining twenty Block IIR satellites will be modified to add a second civil code (L2C) at the L2 frequency and a new military code (M-code) at both L1 and L2. The modification will also allow the ability (called flex power) to shift power between the M-code and the P(Y)-code for increased anti-jam protection. Flex power allows for a potential increase in P(Y)-code power by turning M-code off. Alternatively, turning off the P(Y)-code will only slightly increase M-code power, which

will likely not provide operational benefit because backward compatibility will be lost in that case. Despite this limitation, flex power represents a first significant step toward improving system anti-jam performance by providing a means to increase delivered power of the legacy P(Y)-code to the user. The modified satellites will be designated as Block IIR-M versions. The addition of new signals to the Block IIR satellites was a FY 01 budget action that had been pending since 1998 and was finally directed via OMB pass-back action. The first Block IIR-M satellite was to have been launched in 2003, and ten to twelve were originally considered for modification; however, decision delays and a subsequent problem with space qualified electronics that affected the entire satellite fleet pushed schedules out. The first Block IIR-M satellite is now scheduled for launch in 2005. The original unit cost of Block IIR satellites in quantity of twenty-one was on the order of \$35-40 million. Unit cost of the eight upgraded Block IIR-M satellites will be about \$70-75 million.

3.2.2 Block IIF

The first six Block IIF satellites were procured in FY97/98 as the first multi-year block of a 33-satellite buy. Subsequently, the Air Force decided not to exercise an option for the second multi-year buy of fifteen satellites but to procure the satellites via annual procurements of three satellites each. Since that decision, thirteen additional Block IIF satellites have been procured. Also, an FY02 budget action included funding to upgrade all Block IIF satellites by adding civil and military signals and flex power capability as on the Block IIR-M vehicles, and, in addition, a third civil signal designed for civil aviation use at a new frequency, L5 (1175.42 MHz). Originally scheduled for late 2005, the first Block IIF satellite launch is now planned in early 2007. The original unit cost of Block IIF satellites, predicated on the expected 33-satellite buy, was on the order of \$30 million. Unit cost of the upgraded satellites is now in the range of \$70-80 million.

3.2.3 GPS III Satellite

The GPS III satellite is still undergoing design by two contractor teams (led by Boeing and Lockheed-Martin/Spectrum Astro). Block III satellites will incorporate improved electronics, high data rate crosslinks (high

frequency/narrow beam) providing continuous contact among satellites, and a high power spot beam (“theater” size) for anti-jam improvement. The spot beam is intended to meet the JROC-endorsed anti-jam requirement for +20 dB signal strength improvement by providing additional power directly from the satellites in lieu of making substantial changes to user equipment antennas and processing technology. First launch for the GPS III satellite was originally planned for FY09 with fully populated constellation by 2016/17; however, go-ahead delays and funding shortages elsewhere in the program have delayed the first launch until at least FY13.

The new capabilities, when added to the existing primary and secondary payloads, represent additional cost and weight for the GPS III satellites. Original GPS Block II-version satellites cost on the order of \$30+ million. With improvements to signal structure and power (taking account of effects of sole source contracts and low quantities) Block IIR-M and Block IIF satellites now cost on the order of \$60-80 million. Even at those prices, the Air Force has experienced difficulty in procuring sufficient satellites and medium-lift boosters to assure the 24-satellite constellation can be sustained at a high level of probability into the future. Block III satellites are anticipated to cost on the order of \$100-150 million. Based on these projections, the Task Force considers it essential that the Air Force investigate alternatives to lower total constellation on-orbit costs. Such alternatives include deletion of secondary payloads with significant weight and power needs from some or all GPS satellites and operating a mix of spot-beam satellites and higher power earth coverage “utility” satellites with lower relative cost/complexity.

The cost of the boosters to launch the various GPS configurations is a significant consideration as well. Currently, the Delta II booster used for remaining Block IIR and IIR-M satellites costs nearly \$60 million, and the medium-lift Evolved Expendable Launch Vehicle (EELV) that will launch Block IIF satellites is projected to cost \$65-70 million. GPS III is programmed for the medium EELV as well, and the Task Force strongly recommends that GPS III weight be tightly managed to enable two satellites to be launched on a single booster. Achieving dual-launch capability using a medium EELV, or even an intermediate EELV (projected cost \$90-95 million) will dramatically lower on-orbit costs for the GPS III constellation compared to a single satellite launch strategy.

3.2.4 GPS Satellite Constellation

Based on the forgoing, the current schedule and future investment plan for GPS involves significant risk of sustaining sufficient satellites for a full constellation. The current on-orbit inventory is 28 satellites; however, with expected failures, the AF Space Command December 2004 PNT Functional Availability Report reflects a nominal probability between 5 – 20 percent and a worst-case probability between 20-40 percent that the constellation will fall to fewer than 24 satellites in the 2007-2012 period based on current satellite replacement schedules.

The Air Force has committed for the long term to maintaining only a 24 satellite constellation. While this may be satisfactory for aviation and open-ocean maritime missions, the Task Force does not consider it sufficient to support missions in confined urban areas and mountainous regions of the world. The nominal 24-satellite constellation only ensures consistent four-satellite coverage with mask angles (angle to horizon which cuts off GPS reception) above five degrees elevation, a value the Task Force finds to be inadequate for surface operations. For missions involving land operations, assuring availability of four satellites above a fifteen-degree mask angle will provide adequate signals to support operations in urban and mountainous areas. To achieve at least four satellite coverage above fifteen degrees elevation requires at least a thirty satellite constellation. The Task Force considers this to be vitally important to obtaining the broadest military utility from GPS for future operations and a major factor in system design decisions for GPS III.

Considerations for 30-satellite GPS III constellation configurations include adding one satellite to each of the existing six planes or changing the constellation to a three-plane configuration with ten satellites per plane. The Task Force is aware that many studies have been performed and computer simulations conducted relative to GPS constellation design over the past three decades. While the studies show relative strengths and weaknesses for both three- and six-plane configurations, on balance, the Task Force consensus is that a three-plane constellation is the more effective design. Further, if GPS III satellite weight can be constrained to permit two satellites at a time to be launched on a medium-lift booster, the three plane configuration will be more economical to sustain than six-planes. Recall from Section 1.2 that the original GPS constellation design was a three-plane

configuration; the six plane design was only adopted when the satellite count dropped to 18 and coverage had to be spread more thinly.

3.3 SYSTEM OPERATIONS, SIGNAL MONITORING AND PERFORMANCE ASSESSMENT

3.3.1 System Operations

The GPS Operational Control Segment (OCS) consists of a software-intensive Master Control Station (MCS) at Schriever AFB, CO connected to a global network of six monitor stations (Schriever, Cape Canaveral, Hawaii, Kwajalein Atoll, Diego Garcia and Ascension Is.) and uplink antennas at Kwajalein, Diego Garcia, Ascension Is. and Cape Canaveral. Additional antennas can be used if necessary, though access for GPS use must be separately scheduled. The MCS is operated by the Air Force 2nd Satellite Operations Squadron (2SOPS). Monitor stations are unmanned and maintained by contractor personnel. With Air Force acquisition attention in recent years focused on GPS satellites and signal structure, the Task force believes the control segment has been seriously neglected.

As the system was becoming operational in 1993-1995, delays in control segment software deliveries (IBM Federal Systems - Loral - Lockheed-Martin) began to be a problem. Since that time, the problems have been sporadically addressed but never really solved. The Block IIF contract placed responsibility for both the Block IIF space segment and control segment under the prime; however delivery delays continued, and coordination between BlockII/IIR and Block IIF software was an additional problem. A further change of contractor responsibility called the Single Prime Initiative was supposed to bring improvement, but it was accompanied by additional software delivery segmentation and capability deferrals - necessary to maintain baseline system performance. The control segment currently operates with a combination of Commercial Off-The-Shelf (COTS) and uniquely modified COTS products that are minimally adequate for maintaining system integrity.

In addition to the chronic software problems, Air Force Space Command has routinely deferred equipment maintenance and modernization of the monitor stations and ground antennas. As of today, the control segment is operating the GPS constellation of Block IIA and Block IIR satellites

basically as Block IIA satellites. Activations of improved signal processing capabilities already in space in the baseline Block IIR satellites have been deferred for up to 7 years, and attention is focused on delivery and test of operational software necessary to minimally operate the new versions of Block IIR-M and Block IIF that will be in space beginning in 2005 and 2007, respectively.

Over the last several months, funding shortages have forced the Air Force to terminate work already on contract for Versions 6.0 and 6.1 of OCS software. These software versions are necessary to permit operation of all the new signals being launched on Block IIR-M and Block IIF satellites. Version 6.0 allows operational control of L2C and L5, and Version 6.1 allows operational control of the military M-Code. Version 6.0 was also intended to implement the flex-power initiative and permit power shifting among the available signals as dictated by operational priorities. Delivery of both versions had recently slipped to 2009 and 2010, respectively, and new delivery dates are now forecast in 2010-2011. With termination of those elements of control software from the current contract, the Task Force considers it essential that new signals be activated on launch of each Block IIR-M and Block IIF satellite and made available at the users' risk for testing and other applications, even if they cannot be declared operational until some time in the future.

Based on this history of chronic problems, the intent of the GPS III effort is to replace rather than upgrade the existing control infrastructure. However, even when GPS III satellites eventually begin to replace the Block II versions, experience indicates that legacy satellites will likely require operational support well beyond 2020.

The ability of the control segment to absorb further new requirements and implement additional operational changes is non-existent within current resources. The Task Force believes new approaches are necessary as soon as possible to enable consistent and timely operation of improved in-space capabilities. In this regard, the Air Force should also reevaluate the practice of a totally blue-suit operation at the MCS. Outsourcing of part of the operations mission or insertion of selected contractor support personnel could both aid in long-term operations continuity as well as in supporting consistent operation of new signal capabilities in advance of a "fully operational" declaration.

3.3.2 Monitoring and Performance Assessment

3.3.2.1 DoD Monitoring Networks

The MCS receives continuous information regarding GPS military signal fidelity through a global network of six dedicated monitor stations, identified above. Each monitor station receives the Y-Code signals from whichever satellites are in view, and most of the constellation is in view of at least one monitor station at all times. The exception is that satellites whose orbits take them below the equator in the eastern South Pacific may be out of view by any monitor station or uplink antenna for 20 minutes or more. An initiative was undertaken in 1995 to mitigate this situation by incorporating data from monitor stations operated by the National Geospatial-Intelligence Agency (NGA) at locations that would fill the gap and augment other observations. However, funding for this effort, called the Accuracy Improvement Initiative (AII), was insufficient to integrate the NGA data into MCS software until this year when data from an initial six NGA stations will be incorporated. Data from five more NGS stations is planned to be incorporated in 2006 (Figure 3).

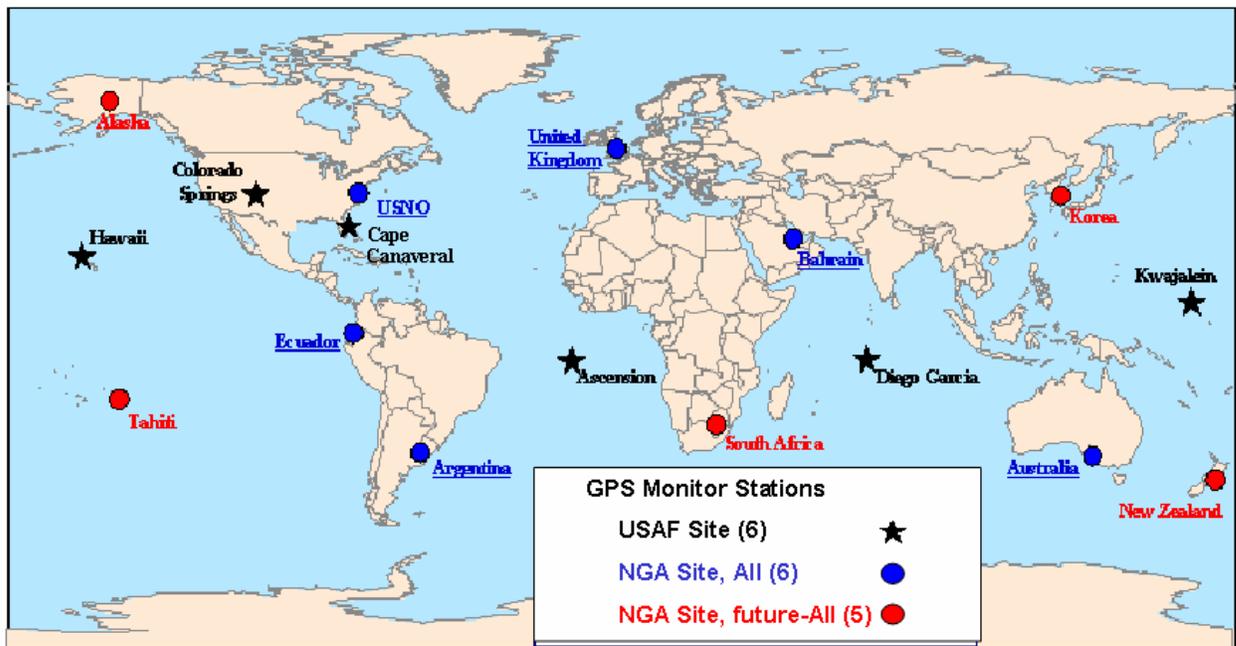


Figure 3. DoD Monitor Stations

3.3.2.2 Civil Monitoring Networks

In addition to monitor stations operated by the DoD, there are separate regional and global networks of civil signal (C/A-Code) monitor stations operated by government and scientific organizations. Global networks include the Global Differential GPS (GDGPS) System and the International GPS Service (IGS).

The GDGPS is operated by the Jet Propulsion Laboratory (JPL) with funding from NASA and others and gathers data from over 60 worldwide monitoring stations (see Figure 4). Raw data from the GDGPS provide the basis for a value-added commercial differential GPS service called GreenStar, offered by John Deere and furnishing high precision GPS augmentation for precision farming. The GDGPS System is completely independent of the GPS OCS infrastructure, thus increasing the probability of detecting an anomaly. The system has demonstrated extremely high reliability since its inception in early 2000. An integrity monitoring prototype based on the GDGPS System was developed in collaboration between JPL and the Aerospace Corporation, and was launched in May 2003. It provides secure internet access to authorized users, including 2SOPS operators from the MCS floor as well as from their homes. The developers at NASA/JPL and Aerospace are now in the process of implementing end-to-end secure data authentication, and automated alarms with 4 second latency. Feedback from the MCS indicates that the system is a very valuable tool.

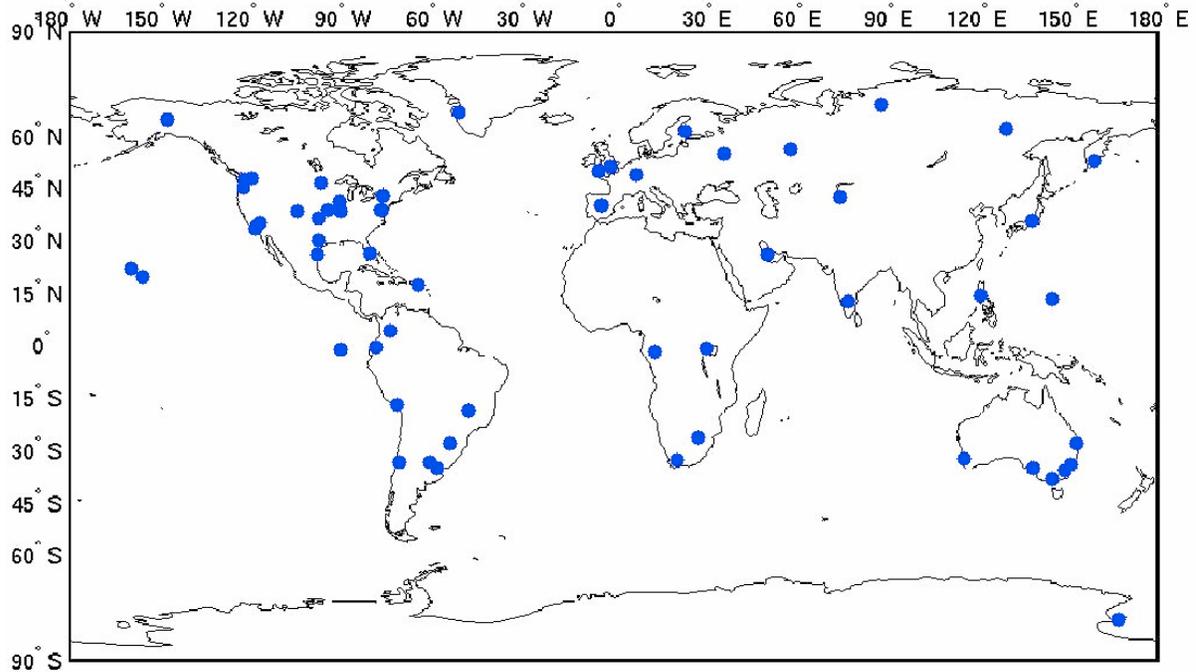


Figure 4. 62-Station GDGPS Reference Network

The IGS was established by the International Association of Geodesy and includes over 350 monitoring stations and ten analysis centers operated by various national and scientific geodetic organizations around the world (see Figure 5). NASA funds the coordinating office for this organization, called the Central Bureau and also located at the JPL. The IGS maintains over a decade of data and products from its global network. Resulting products are the most accurate and precise available. The IGS is often contacted after the fact for information on anomalies or failures, but this arrangement is very ad hoc.

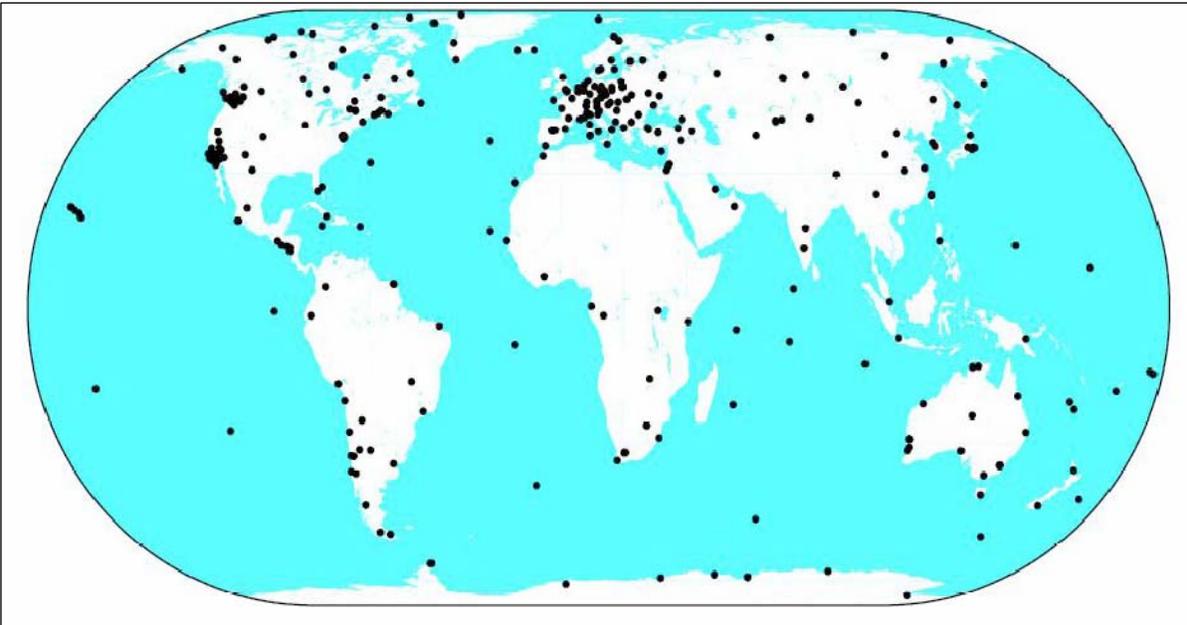


Figure 5. IGS Network - 2004

Historically, the practice of the Air Force to use 'trusted data sources only' has led to the dismissal of monitoring information from civilian sources because the integrity and fidelity of each individual source could not be continuously verified, and intentional errors could be introduced that would corrupt the process. However, given the fact that it has taken years for integration of the NGA station network and data into the OCS, the Task Force recommends the Air Force reevaluate this 'trusted source' practice for the added value such independent performance measurements could bring to GPS operations in addition to data from the 16 DoD stations. The Task Force recognized that such additional information would require special measures to assure its integrity and that a point of diminishing returns would likely apply as additional data is added; however, on balance, we believe the Air Force should actively seek to gain as much value as possible from these available resources. Further, even if the trusted resource argument does not allow the use of these additional monitor units in the upload calculations, they should be used as part of an overall performance monitoring capability.

3.3.2.3 Performance Assessment

Assessing the performance of a satellite or satellite system necessitates detailed requirements for collection of measurement data, functional

requirements for system operation, and measurable performance parameters which provide the framework for monitor and control. Given the availability of monitoring stations and measurement data, it is also necessary to maintain performance standards against which to measure results. Such a performance standard has been in place for many years for the civil Standard Positioning Service (SPS). It was originally authored by AF Space Command and approved by the ASD(C3I) in the early 1990's as the SPS Signal Specification, and has since been revised and reissued under the auspices of the GPS Joint Program Office (JPO) as the SPS Performance Standard. This standard provides measurement metrics for a globally averaged signal in space for civil applications. However, it is important to note that the GPS OCS does not collect SPS measurement data through the GPS or NGA monitor stations for assessing SPS performance against this standard. The OCS does monitor the military Precise Positioning Service (PPS) signals and measure their performance against satellite transmission and PPS accuracy specifications; however there is not at present a global PPS performance standard equivalent to the SPS standard. The Task Force recommends that consistent capabilities for performance measurement and assessment be established covering both the SPS and PPS. Development and maintenance of SPS and PPS standards for such performance assessment in the future should be the responsibility of the operational organizations representing GPS users, and we recommend STRATCOM as the organization to oversee those activities as part of its GPS stewardship responsibilities on behalf of the DoD.

3.4 USER EQUIPMENT & IMPROVEMENTS IN ANTI-JAM PERFORMANCE

3.4.1 Military GPS User Equipment

Military GPS user equipment has steadily evolved since the first family of operational equipment, classified when keyed, was approved for production in the late 1980's. During the 1980's and early 1990's the GPS JPO was the principal source of receiver development and platform integration activity in the DoD. Over the last decade, however, the JPO has de-emphasized its role in development, and even more so in production, of user equipment for diverse DoD applications. The evolutionary path for GPS user equipment has been on a track from box to card to module form with emphasis on standard interfaces and decentralized procurements. The

Selective Availability/Anti-Spoofing Module (SAASM), conceived in the early 1990's, was intended to replace previous classified hardware receivers and PPS Security Module/Auxiliary Output Chip (PPS-SM/AOC) components in more affordable and standardized packages. However, funding shortages and changing production requirements delayed availability of working SAASM designs for several years. Currently SAASM is required in all new GPS equipment fielded after 1 October 2006. Legacy applications (PPS-SM/AOC) are required to be part of a roadmap for SAASM transition in order to continue to receive GPS JPO procurement support after that date.

To date SAASM has been seen as expensive and power-hungry to some; however, production and cost data presented to the Task Force did not indicate SAASM costs to be excessive. There is strong Service resistance to SAASM in some quarters, and many believed initially there were readily available software-based solutions that would meet any reasonable threat and that would be much more affordable. However, subsequent and intensive discussions between the GPS JPO and Joint Tactical Radio System (JTRS) designers identified significant limitations in current software-based technology related to both GPS security requirements and software-based processing capacity that do not make that technology appealing for military GPS implementations in the near term.

As presently envisioned, SAASM is a receiver implementation for legacy military signals only. The new M-code that will appear in space with the first Block IIR-M launch this year will involve a different security implementation, incorporating Protection of Navigation (PRONAV) features that are part of a new Information Assurance (IA) architecture (see Section 3.5). Original plans were to develop and deploy M-code only receivers and to retire legacy receivers that utilized the C/A- and P(Y)-Codes. However, because of cost and synchronization issues, those plans were modified to first develop and deploy user equipment capable of receiving legacy signals (P(Y) and C/A) as well as the new M-Code. These new equipment items are termed YMCA receivers. A two-phase development effort is now underway at the JPO that will result in production-ready versions of two YMCA receiver form factors, one for aviation use and one for ground applications. The JPO will not take those receivers to production, however. The Services will be expected to individually procure YMCA cards to meet their requirements for upgraded

GPS receivers. The Task Force is concerned that, even though the M-Code signals will be present in space beginning in 2005, current user equipment development and production schedules will not produce the production-ready YMCA receiver cards until early 2009, and actual production and installation of the improved GPS equipment could take much longer.

In the fifteen-plus years that Service advisory boards and the DSB have been looking into GPS vulnerability, GPS user equipment has been recognized as providing the quickest path to system robustness. In comparison to satellites, user equipment is accessible, capable of rapid modification (antennas, processing technology, etc.), and more flexible from a signal-jammer geometry standpoint. Though increased power from space is important as well, satellite-only solutions are hampered by long lead times and signal power disadvantages that favor the jammer. However, for the last several years most of the attention and money allocated to improving GPS robustness has been devoted to signal structure and satellites. Unfortunately, full availability of such satellites cannot be expected prior to 2018 at the earliest, and budget pressures could reduce the number of satellites deployed. For many users this would have the same effect as jamming, as fewer satellites limit availability of signals to users whose missions require operations in locations where signal reception is masked by terrain or buildings.

3.4.2 Military Anti-jam Capability

The ability for our military forces to be able to navigate and determine positions in the presence of hostile jamming is essential. The principal vulnerability to be addressed is the threat of widely proliferated, mobile, inexpensive, relatively low-power jammers. The optimal configuration for such jammers is in an extensive array, in which the jammers blink on and off. Worldwide, we can foresee GPS jammers available in the 100 Watt size. This size jammer is relatively easy to manufacture and can be widely proliferated.

While we have demonstrated the technology to cope with distributed fields of jammers of this size, we have not put in place a program to field this user equipment on a reasonable scale. It has been shown to be cost-prohibitive and impractical for scheduling reasons to contemplate DoD or Service-wide replacement of GPS user equipment. However, it is not impractical to consider installation of more sophisticated anti-jam GPS

receivers on selected platforms with critical, high precision missions. The best technique for GPS user equipment to defeat such jammers is to employ beam steering antennas. GPS research efforts have successfully developed prototypes. This technology is readily available to be incorporated into YMCA production equipment by 2008.

This Task Force supports an anti-jam strategy designed to steadily force adversaries to increase the required offensive jamming power needed to attack the navigation and timing service so that:

- It will be more expensive and more difficult to attack improved GPS receivers with a proliferation of relatively cheap and low-power jammers.
- The higher power jammers will be easier to locate and attack.
- Full visibility of this strategy as announced and executed will deter some from wasting their resources on jamming capabilities.

We are concerned, however that the current program will not provide significant anti-jam operating capabilities in the field for approximately 15 years.

The chart at Figure 6 demonstrates the trade between anti-jam capability (expressed in dB), jammer power, and effective jammer range. Current military GPS user equipment is expected to be jammed at ranges of 5 to 50 kilometers by a 10-watt jammer. In fact, Army ground users are seeking to use civil GPS equipment that will be jammed at far greater ranges by the same 10-watt jammer.

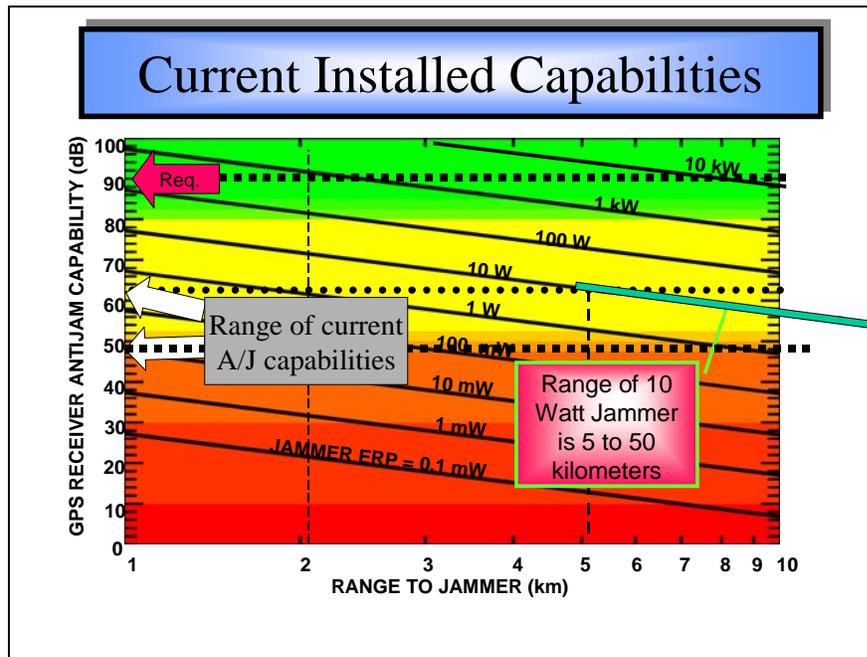


Figure 6. Current Capabilities

A reasonable expectation is that future conflicts will encounter distributed and possibly mobile jammers of 100 watts or more. We therefore believe that the requirement for user equipment jamming resistance should, as a minimum, be set at 90dB. This would provide a minimum acceptable level of protection for users who can be expected to operate in the range of enemy jammers. As can be seen (Figure 7) this would render 1 kilowatt jammers ineffective beyond a range of 3 kilometers.

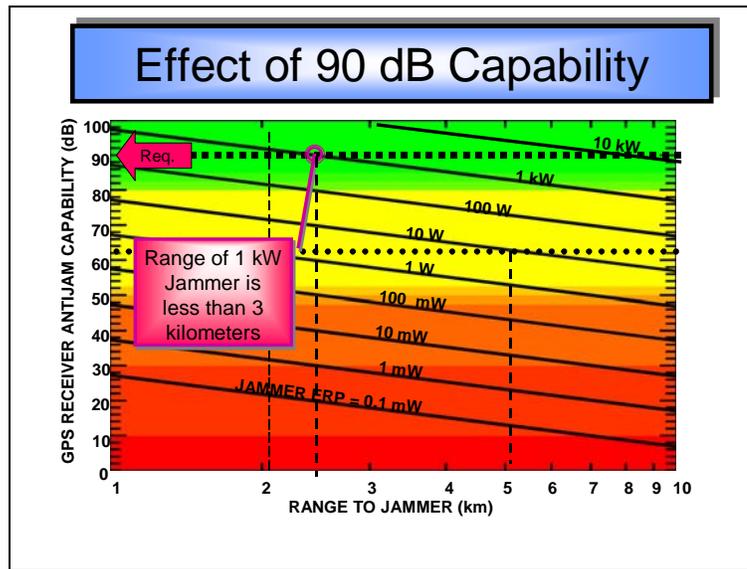


Figure 7. Improvements Possible

3.4.2.1 User Equipment

User equipment improvements can be brought on line years earlier than any satellite improvements (though the contributions of flex power (section 3.2.1) and subsequent increases in transmitted power from the satellites remain important). As mentioned, many of these improvements have already been conceived and demonstrated. As a first step, implementation of YMCA receivers will facilitate the initial transition to the new, more robust military signal structure. Jam resistance is the most important goal of the possible improvements. Improved Jam resistance will provide assured availability of GPS for the many precision operations that are required by our modern armed forces. Done properly, these capabilities will defeat the effects of enemy jammers. Potential improvements are both long term (where a steady investment in R&D is essential), and short term (ready for procurement and operation in the next few years). The Task Force believes the DoD should vigorously support these improvements with both budget and direction. Our recommendations include the following specific examples:

Near Term (immediate and next several years)

- Integrated, Network-Capable receivers that ensure host systems can hand off both time and position to GPS-equipped munitions. An example is the F-16 host handing off four-dimensional coordinates to Joint Direct Attack Munitions. This will allow faster acquisition, more accurate positions, and greater ability to operate under hostile jamming operations. There are many more examples, especially for Army users where rapid acquisition will help reduce power and improve responsiveness.
- “All-in-view” receivers that will lock on and use all satellites that are not masked. This will improve accuracy, integrity and availability.

Medium Term (3 to 5 years)

- GPS receivers should be designed to receive all GPS signals, both civil and military.
- Deep integration with inertial components that will significantly increase resistance to jamming as well as improve system accuracy during periods when the GPS receiver is being jammed.
- Inexpensive beam-steering antennas can provide very significant improvements in jam resistance. Faster and cheaper digital electronics will make these devices more inexpensive and hence more appealing to the high-volume military users.
- Smart all-in-view receivers can adaptively process all GPS signals and reject or attenuate any that are degraded or jammed.

Longer Term (5 to 10 years)

- Chip Scale Atomic Clocks that will allow better knowledge of time during acquisition and hence make initial acquisition faster and more reliable. These small, low-

power clocks will also provide better short-term accuracy. In turn, when coupled with the new Lm signal, the short-term clock accuracy will allow more averaging, and hence more jamming resistance.

3.4.2.2 Satellite Spot-Beam

The principal DoD plan to reduce GPS jamming vulnerability is to increase satellite power for GPS military signals, and in particular for the next generation signal called the M-Code. The GPS III plan involves a large, high-gain antenna added to the normal earth-coverage antenna. This may be a deployable reflector antenna or a phased-array antenna; the contractor and the particular mechanization have not yet been selected. The large antenna can produce a factor of one hundred or higher signal strength in a limited region or “spot” on the earth at least 1000 kilometers in diameter. All M-Code GPS receivers in this “+ 20 dB spot” would benefit from the increased signal power. The current plan would achieve a full constellation in the CY2019 era if no further delays occur.

The Task Force notes the following advantages and concerns with the GPS III spot-beam approach:

Advantages

- All authorized, M-code GPS users in an area of conflict benefit from the substantially increased signal power density.
- This GPS system enhancement involves only one major program versus the need to deal with a multiplicity of GPS individual programs which would be necessary in order to upgrade operational military GPS receivers

Concerns

- The GPS III schedule is long and likely to get even longer leaving an unacceptably long window of vulnerability for GPS users if spot-beam is the only option to improve anti-jam performance.

- The complexity and cost of the GPS III satellite is likely to grow due to the inevitable growth in “requirements”.
- The weight of the satellites may grow such that two satellites cannot be launched on a single medium-lift booster, dramatically escalating constellation sustainment costs.
- The 1000 km diameter spot may be too small to cover major areas of conflict.

3.4.2.3 Augmenting the Spot-Beam

The actual size of the spot beam on the earth has not yet been finalized. There are tradeoffs between spot size (antenna gain) and radiated RF power. A “fatter” beam with a larger spot on the earth would alleviate the coverage concern and it is a configuration to consider in the GPS III system tradeoffs.

However, the main concern identified by the Task Force is the extended schedule for GPS III and its included spot beam approach. The long window of jamming vulnerability must be addressed by some augmentation, and the best way to do this is to upgrade individual GPS receivers with anti-jam enhancements, some of which are noted above. Such techniques are available today and they can be installed in a few years. The timing is propitious because weapon system managers will soon begin a major change-out of their receivers to accommodate the M-Code signal. One concern noted above is the cost of upgrading on the order of a million military receivers. However, most military receivers are in munitions and it is not necessary, for example, to upgrade all of the 230,000 Joint Direct Attack Munitions (JDAMs) being planned. Rather, the Task Force recommends upgrading 50,000 JDAMs to provide an inventory of “silver-bullet” munitions to use in the event jamming is encountered. Such an upgrade of selected military GPS receivers could cost in the vicinity of \$1 billion as detailed in Appendix F. This is a significant cost but not exceedingly high in the context of major GPS satellite upgrades.

The Task Force concludes that the risk in the GPS III program is real and its extended procurement schedule leaves an intolerable window of jamming vulnerability. These concerns can be addressed by an approach that improves military receivers in the near term as the GPS-III program

proceeds. Adding anti-jam enhancements to individual receivers will buffer the overall program by providing critical early anti-jam capability, a risk reduction function, and a backup if the GPS III program is further delayed or fails to survive. Over the long term with some form of GPS III “spot” online and the individual receiver enhancements recommended above, the 40 to 60 dB of additional anti-jam capability will make GPS jamming a relatively hopeless tactic for an enemy.

3.5 SECURITY POLICY – PROTECTION & EXCLUSIVITY

GPS has been described as “like air on the battlefield.” However, unlike air, current GPS services are not available equally to everyone on the battlefield. Military GPS signals, the Precise Positioning Service or PPS, are intended for the exclusive use of U.S. and allied/friendly forces. They are intended to be receivable by only those forces for joint interoperability and also to be the only signals that remain available should the generally available civil equivalent services be denied by navigation warfare (Navwar) measures in a theater of conflict. Most importantly, they currently provide up to 100 times more resistance to interference than do the civil GPS signals, and with planned improvements, will provide 1,000 to 10,000 times more resistance in the future. Maintaining this asymmetric advantage in position, movement and timing over an adversary requires access to exclusive frequency spectrum and use of signal processing, encryption and physical protection measures that make military GPS receivers appear more complex and costly than comparable civilian receivers. The concept of exclusivity has underpinned GPS system and signal design and security policy decisions for the last two decades. A critical element of that security policy, navigation warfare (Navwar), is a set of strategies and capabilities designed to preserve the asymmetric advantage afforded by GPS in the battlespace. Exclusive access to a military GPS signal set is one of the central tenets of Navwar, whose importance to the DoD and to national security has been emphasized over the past year in Deputy Secretary of Defense direction and in the recent GPS national policy directive signed by the President.

The next generation military GPS signal, called M-Code, will significantly improve exclusivity of access because, in addition to being encrypted, it will be spectrally separate from civilian signals. The M-Code

will permit higher power operation than the present signal design and will facilitate localized tactical denial of GPS civil signals to prevent their use by hostile forces. As described in the Section 3.4, military GPS receivers, when tracking the encrypted military signals, are much more resistant to interference than commercial GPS equipment. Many platforms also employ adaptive nulling antennas to deal with jamming. The newest generation of military GPS receivers that can access military GPS signals directly are even more resistant to interference; however, future improvements in signal availability and receiver performance (i.e., advanced processing, digital beam forming antennas) will continue to be necessary, as supported by our recommendations.

These new military GPS receivers will operate under an equally new security paradigm known as Protection of Navigation (PRONAV). PRONAV is being implemented by the GPS JPO to incorporate concepts of Information Assurance (IA) and receiver performance to address the two central components of GPS IA, military integrity and military exclusivity. Military integrity assures that authorized users can access and utilize the authentic modernized GPS signal-in-space in all environments for which the system has been specified to provide position, velocity and timing service integrity monitoring. As described above, military exclusivity protects against unauthorized exploitation and assures that the authentic modernized military GPS signal-in-space is exploited only by authorized users. PRONAV does not replace former techniques such as encryption or use of tamper resistant technology, but expands on the options for service integrity and fidelity that are available to GPS operators and users and provides for more flexible implementations according to mission-specific IA requirements. Improvements to GPS functionality resulting from PRONAV are shown in Figure 8.

	Requirements*	GPS COMSEC	PRONAV (IA)
Cryptography	Monitoring/Termination	5	5
	Key Loading	5	6
	Zeroization	5	7
	Self-Checks	5	5
	Fail-Safe Design Features	5	6
	Anti-Tamper/Reverse Engineering	5	5
Navigation-specific IA Features	Availability - J/S	1	6
	Availability Blue Force Jamming	1	5
	Data Integrity	5	7
	Signal Integrity	1	6
	Reasonableness	1	5
	Consistency	1	5
	External Aiding	1	5
	Authentication	5	7

Figure 8. Comparison of GPS Performance in COMSEC vs. PRONAV Architecture (Scale 1 – 7, 1 is the lowest level of assurance, 7 is highest)

In this environment, the pending advent of new civil signals, in combination with military performance improvements described, presents opportunities for more diverse signal reception strategies that may increase service robustness in many situations. The Task Force does not recommend abandoning exclusivity or the capabilities afforded by Navwar. However, the Task Force considers the rigid application of exclusivity to be constraining to potential signal reception benefits that can result from the future diverse signal mix. Consequently, the Task Force recommends adjustments to current GPS receiver acquisition policies to permit more flexible procurement of GPS user equipment within approved military mission Information Assurance parameters. The Task Force also recommends including increased signal flexibility in the satellites to permit operational choices with regard to exclusivity in the longer run. One decision that the Task Force considers essential to improving opportunities for future flexibility in GPS satellites and user equipment is to permanently eliminate the requirement for Selective Availability and to delete the

hardware and software overhead for its implementation from throughout the system.

CHAPTER 4. COMPETITION, GOVERNANCE AND OPERATIONAL MANAGEMENT

4.1 *GPS AND THE GLOBAL MARKETPLACE*

In many ways, GPS is analogous to autos and horse-drawn carriages or to calculators and slide rules. However, in those cases, evolving market-driven product lines provided steadily increasing functionality over previous alternatives. Acceptance in the marketplace was achieved and replacement and upgrade decisions for users was encouraged because awareness of value had been well-established through advertising and improvements were both marketed by manufacturers and sought by customers. GPS, on the other hand, offers multi-use applications derived by diverse users from a set of radio signals provided by the government for national security and as a public good. The applications create a market of national security and civil/commercial/scientific capabilities; however, broad market awareness is lacking, and application evolution is constrained for both domains by the willingness and ability of the government to improve or add to the signal set. The continued availability and improvement of that signal set are subject to annual budgetary decisions at several levels among different government agencies and from various committees of the Congress. At the same time, however, efficiencies in positioning, movement and timing derived from the ubiquitous GPS signals have already quietly permeated virtually every level of our national infrastructures to the extent that, in many cases, there is no going back to earlier ways of doing things without tremendous but unrecognized penalties. All of the domains, missions and infrastructure components addressed by this Task Force are already affected to a greater or lesser degree by this dependency, and we believe the effects will only become more pronounced over time. The dilemma that results is peculiar to GPS. Our widespread dependency on it demands strong advocacy by military and civilian leaders for its continued evolution and improvement. However, the executive and legislative environment where such decisions must be made is skeptical of advocacy, absent a strong message from the market (operational users),

and so such decisions are delayed because of fiscal constraints and competing priorities. This situation is a direct result of institutional decisions regarding GPS operation and governance that guided its original design and implementation. However, now that GPS has become operational and has established dependencies because of its value, the structures created for its initial implementation should be reassessed. The internal conflicts affecting GPS in the national security arena and global marketplace must be understood and mitigated by government leaders responsible for GPS at all levels because those decisions have real and far-ranging effects for our national security and economic competitiveness.

4.2 *ADVENT OF EUROPEAN UNION'S GALILEO*

Since the inception of GPS, the civil and commercial sectors as well as the international community have been uneasy about an apparent military dominance in GPS decisions. Even though Secretaries of Defense and Transportation, the President, and the Congress have produced policies and legislation emphasizing multi-agency management of GPS and its multi-use applications, the fact remains that GPS is primarily financed by the Department of Defense and is a critical component of U.S. National Military Strategy. That reality underlies the perception that the U.S. military could “take away” GPS from other users at any time, and enables detractors of GPS to create the misimpression that the U.S. or the military would do so arbitrarily. In this climate, the emergence of Galileo, a system similar to GPS planned by the European Union (EU), has created motivation for a reevaluation of U.S. policies and practices with regard to GPS. Fundamental to these are the organization and governance structures by which the U.S. manages and operates GPS as a “national” program and as part of a “national and international” PNT infrastructure.

The Europeans have offered both security and economic reasons to justify creation of a Galileo system in parallel with GPS. One fundamental reason advanced is concern over European dependence on an infrastructure critical to their society that is totally controlled by the United States. In that context, European entry into this arena has changed the world’s perspective on the composition of a global PNT system. Clearly the Europeans intend to operate Galileo as a revenue generating enterprise, and its projected business models for both civil and military applications may impact the use of GPS internationally. Galileo’s

eventual role as a potential European counterpart or competitor to GPS has yet to become apparent, but even at this stage of its development it heightens the importance of evolving GPS civil performance. In the military arena, an initiative is also underway to take up possible joint use of GPS and Galileo among the NATO partners. With that being said, it is too early to project how Galileo will be implemented, and the EU still has not yet fully established the financing necessary to bring it into sustainable operation.

The June 2004 U.S.-EU agreement on GPS/Galileo cooperation is encouraging in that it appears to have resolved several technical compatibility issues and establishes an environment for further cooperation. Diverse perceptions that arose during negotiation of the agreement regarding comparability of service between the two systems remain to be resolved as cooperative discussions proceed under the agreement. Even with the agreement in place, uncertainty remains regarding the eventual form Galileo will take as well as regarding European resolve to bring it into full operation. In this context, the recently signed Presidential directive establishes as a goal that U.S.-provided civil GPS services and augmentations remain competitive with foreign civil systems. If/when Galileo is fully operational, its additional satellites should increase signal availability and overall system integrity for dual mode GPS-Galileo receivers. This should be particularly useful for users in urban “canyons” and other obstructed areas. In more open environments a single receiver may see sufficient satellites to enable signal integrity verification within the receiver itself. The cooperative discussions now envisioned with the EU should have such improvements as an objective.

All of these issues compel the U.S. to take a proactive role with Europe and the rest of the world to assure a favorable outcome that protects U.S. goals and objectives for GPS while contributing positively to our international relationships. While it is useful for extending dialog on mutual technical interests, the 2004 Agreement does not provide a mechanism to achieve this outcome.

4.3 NATIONAL GOVERNANCE OF GPS AND THE PNT INFRASTRUCTURE

GPS has become a truly “national” program of critical importance to essentially all aspects of U.S. life and well beyond the scope of any single Department. However, the burden of justifying the capabilities appropriate for GPS and the resources to implement those capabilities has historically fallen on the DoD, which has an easily identifiable worldwide need for the system. Civil, commercial and scientific users around the world who are now dependent on GPS are not institutionally organized to justify and pay for any system characteristics peculiar to their needs that exceed those of the military. Further, to date, there has been no institutional mechanism to effectively exercise management authority more broadly than has been exercised by the DoD.

For the past several years, various recommendations have been advanced to provide a more comprehensive and authoritative structure for dealing with the major PNT infrastructure issues of the nation. Even though the current interdepartmental governance structure seeks to support the needs of civil and military users without prejudice, there is a perception that the military exerts undue influence in decisions affecting civil GPS. This perception has been used as a principal argument by those who would seek to advance competing technologies or services to supplant or ‘augment’ GPS, in some cases where technical or economic justification falls short. It has also provided potential underpinning for various initiatives to commercialize GPS in order to improve its financial base and to generate non-defense resources for system operation and improvement.

Over the past two years, two separate studies were authorized by the Deputy Secretary of Defense to investigate the viability of alternative governance structures for managing and financing GPS to both sustain and enhance its services for its full complement of domestic and international users. The Task Force received a briefing on a preliminary phase of the study, termed Project Atlas, which had looked at generic concepts of financing applicable to GPS. A subsequent study, termed Project Herakles, was concluded in April 2005 and focused in detail on a more specific set of alternatives. Both studies indicated that alternative governance strategies could be feasible; however, additional work is

necessary before any changes could or would be implemented. Any substantive change in GPS governance would of course require extensive cooperation and support among the Executive and Legislative Branches of U.S. Government. Yet, given the end of the “natural monopoly” for GPS, and with the rapidly emerging prospect of an altered and competitive environment, the Task Force believes that the government should remain open-minded on the governance issues highlighted by Project Herakles.

In its implementation and operation of GPS thus far, the U.S. Government has not made use of a comprehensive and commonly accepted strategy accounting for all the national equities at stake in the resolution of issues affecting acquisition and operation of the system. Similarly, there has not been a systematically constructed and commonly accepted architecture to foster consensus among the various agencies responsible for implementation of GPS and its components and complements. The recently signed Presidential Directive is intended to strengthen the interagency management process and requires the preparation and update of a 5-year space-based PNT Plan which could provide the basis for such a strategy. Unfortunately, the Task Force notes that the implementation of the new management structure by all the Departments involved appears to be significantly lagging the schedules as defined in the Directive.

4.4 EXECUTION OF GPS MANAGEMENT RESPONSIBILITIES IN THE DOD

Program Execution Responsibilities

Since the inception of GPS, the Secretary of Defense has been the effective Executive Agent for acquiring and operating GPS for all represented interests of the United States. Also, the Air Force, in various capacities over the life of the program, has been designated as Executive Agent for acquisition and operation of GPS for the Department of Defense. On behalf of the Secretary of Defense, the Commander, STRATCOM is also responsible for ensuring that required GPS services are available for all intended users and is separately accountable for

exploiting GPS for Department of Defense missions. Other Departments and Agencies are separately accountable for exploiting GPS for their unique missions.

Even in consideration of this specific definition of accountability and responsibility, policy and operational responsibilities for GPS within the DoD have been diffused by various management decisions over the last several years. The sometimes overlapping, sometimes disconnected roles of the Office of the Secretary of Defense staff components, the Joint Staff and the Air Force in the management of GPS have created considerable confusion over where responsibility for GPS actually rests.

This sense of confusion has also impacted civil and international perceptions of the importance the U.S. places on GPS and the commitment of the U.S. to GPS sustainment and evolution. It is incumbent on the Secretary of Defense to redefine lines of authority and responsibility for the system and to reestablish the DoD position of leadership for GPS as the heart of the space-based PNT infrastructure both domestically and internationally. The Task Force recommends that the DoD remain the steward for all GPS satellite services and considers it vitally important that GPS responsibilities within the Department be clearly assigned and described. The Task Force recommends that the Secretary of Defense provide such clear guidance applicable to the full range of military and civil GPS signal services in the future.

CHAPTER 5. RECOMMENDATIONS

Before detailing our recommendations, it is important to delineate priorities for GPS customers: the worldwide military, civil, commercial and scientific users who benefit from and rely on its services.

5.1 GPS USER PRIORITIES

As shown in the following table, GPS user priorities are generally common.

User Priority	Military GPS User	Civil, Commercial, Scientific GPS User
Availability (Short and long term and despite interference)	✓	✓
Accuracy	✓	✓
Bounded inaccuracy	✓ (Minimize collateral damage)	✓ (Assure service integrity)
Denial of PNT sources to hostile parties	✓	
A substantive role in determining system configuration (Governance)	✓	✓
Compatibility with like services (e.g., Galileo, QZSS, GLONASS)	✓	✓

Table 2. GPS User Priorities

5.2 SYSTEM AND PROGRAM RECOMMENDATIONS

5.2.1 GPS Satellites and Constellation (Improve Availability and Accuracy)

- Commit to sustaining a 30-satellite constellation (vice the current 24).
 - Increases tolerable mask angle from 5 degrees to 15 degrees to improve performance in mountainous terrain and urban environments.
- Configure the constellation in three planes with 10 satellites per plane (this will simplify constellation sustainment, enabling dual satellite launches to be conducted more efficiently than for a six-plane, five-satellite per plane configuration).
 - Begin transition from the current six-plane constellation as soon as possible rather than waiting until GPS III launches begin.
- Limit GPS III satellite weight to permit launch of two satellites on a single mid-size EELV
 - If the satellite exceeds weight or power thresholds that would compromise dual-manifest (maintain sufficient margin for each through development), the removal of secondary payloads must be evaluated. In this instance, NDS mission modifications and alternatives must be explored.
 - A regional signal (broader beam) should be considered as a lighter-weight and less complex alternative to the narrow spot beam planned for GPS III.
- Continue to acquire high fidelity space-based clocks and navigation payloads to enable direct, high-reliability military accuracy in the range of 2-4 meters for precise targeting and weapons delivery (ensure that the industrial base for this technology is assured).

- As a part of the acquisition strategy for GPS III, include the option to procure higher power earth coverage satellites without non-GPS payloads to permit operation of a mixed constellation of higher-cost, high functionality satellites and lower-cost, utility satellites, increasing signal robustness and availability while lowering overall constellation life cycle costs. This will also provide significant global mitigation for GPS against both intentional and unintentional interference.
- Incorporate a fully reprogrammable Navigation Payload aboard GPS satellites as soon as practicable to enable future flexibility in signal structure and content.

5.2.2 GPS Control Segment and Satellite Operations (Improve functionality, Accelerate Capability)

- In the face of continuing, intractable Operational Control Segment (OCS) development problems, provide a near-term workaround to allow early and continuous operation of all new signals as they are present on-orbit (M-code, L2C, L5 and, eventually, L1C).
 - Use of the new civil signals will be on an “at-risk” basis, pending declaration by the AF of full operational status.
- As a solution to long-standing OCS development problems, conduct a parallel development of OCS functionality based on layered control engineering principles with clearly defined application programming interfaces between software components rather than the current heavily patched software engineering methodology that has proven unworkable.
 - This recommendation is consistent with that contained in a tasking conveyed to the Air Force by the ASD(NII) in DoD PNT Executive Committee meetings during early-mid 2003.
- Modify the operational concept for satellite operations.

- Air Force personnel continue to provide guidance and direction to satellite operations.
- As a means of mitigating the disruptions caused by personnel turnover and to provide an experienced cadre of GPS operators, selectively integrate contractor technical personnel into positions involving direct satellite system monitoring and execution of commands. In addition to its other benefits, implementing this practice should result in operational cost savings for the Air Force as well as freeing uniformed billets for other assignments.
- Implement direct, independent and continuous monitoring of both military and civil operational capability. This should include projections of capability to meet user needs in both normal and stressed environments as well as historical data to provide assessments of past performance, as necessary.
 - For military assessments and projections, complete the addition of remaining National Geospatial-Intelligence Agency monitor station data into the OCS.
 - Include a direct connection to the WAAS monitoring system. This would provide very high fidelity continuous sampling of GPS availability, integrity and accuracy in the U.S.
 - For civil assessments and projections, consider use of existing worldwide civil, commercial and scientific GPS monitoring networks.
 - As a means of improving GPS global competitiveness, the GPS Civil Performance Standard should be updated to more closely reflect system performance improvements.
 - Establish an independent “civil report card” based on the WAAS monitoring network. This should be included in the weekly assessment of GPS performance.

5.2.3 GPS Military User Equipment Acquisition and Installation (Accelerate Anti-Jam Capability)

- Each Service should fund its own R&D program to best ensure position and timing information is integrated into equipment and operational capabilities, following a STRATCOM-developed roadmap for joint, integrated, seamless, precision operations and to ensure operation in accordance with a STRATCOM established PPS performance standard.
- Continue fielding Selective Availability Anti-Spoofing Module (SAASM) GPS equipment for missions and applications where access to exclusive GPS military signals is necessary pending production and operational availability of user equipment incorporating the M-Code and other modernization features (see below).
- Evolve GPS user equipment from SAASM to YMCA configurations as rapidly as possible.
 - Change policy guidelines for procuring future GPS user equipment to permit at least three levels of performance and protection.
 - Full capability to operate with “military exclusive” GPS signal(s).
 - Full capability to operate with “military exclusive” GPS signal(s) with the additional capability to receive and exploit other civil and foreign satellite navigation signals.
 - User equipment not configured for exclusive military signals but which can receive and exploit the full range of accessible signals to enable less expensive operations in more benign interference environments.
- In parallel with development of YMCA and M-Code user equipment, invest in complementary technologies that promise significant improvements in anti-jam performance. Integrate these features into SAASM and YMCA receiver designs at the earliest opportunity. Such technologies include, but are not limited to:
 - Adaptive multi-beam steering to counter proliferated mobile jammers

- Digital antenna processing
- Narrow-band adaptive filters
- Vector delay lock tracking
- Deep inertial coupling
- Network assist for acquisition/better platform handoffs
- All-in-view
- Chip-scale atomic clocks
- Carefully plan for early integration of anti-jam receiver technology into high priority/high payoff weapon systems.
 - Develop a silver-bullet force comprised of specific delivery platform types equipped with upgraded GPS-aided munitions capable of operating in hostile jamming environments.
 - Ensure mission concepts of operation and system architectures accurately reflect GPS contributions and relevant concepts of operation are updated to define workable employment concepts for silver-bullet resources.
- Continue efforts to evolve the current security architecture to the more diversified and robust PRONAV security architecture.
- One decision that the Task Force considers essential to improving opportunities for future flexibility in GPS satellites and user equipment is to permanently eliminate the requirement for Selective Availability in all future equipment designs with the objective of deleting the hardware and software overhead for its implementation from throughout the future system.

5.2.4 Improving Anti-Jam Performance

- Initiate an aggressive program to introduce anti-jam enhancements soon in appropriate military receivers, namely:

- Receivers that are being redesigned to accommodate M-code
- Receivers in new weapon systems being developed
- Selected “silver-bullet” subsets of receivers in munitions
- Proceed with GPS III with a firm resolve and process to control satellite weight such that two satellites can be launched on a single booster, namely:
 - Control “requirements creep” through consistent program oversight exercised by the ASD(NII) and USD(AT&L)
 - Maintain sufficient weight and power margins through development
 - Be prepared to off-load portions or all of other payloads such as NDS if necessary.

5.2.5 Dealing with Galileo

- Remain open to and promote opportunities for cooperation under the recent U.S.-EU agreement and in accordance with the recent Presidential Directive.
- Strongly promote true civil interoperability – well defined geodetic and time transformations that can be easily implemented in user equipment.
- Insist on full disclosure of the open signal structure.
- Continue purposeful implementation of a separate strategy to provide a superior military and an acceptable civil PNT capability for U.S. interests globally using the militarily supported GPS as the core capability.
- Maintain a PNT system configuration that will permit Galileo assets to increase the capability presented by the combination of both systems for civil users.
- Prepare for discussions within the NATO environment regarding possible use of Galileo services for military purposes by NATO member nations.

- Explore with the Europeans a collaborative approach that maintains the sovereign independence of both parties while permitting the creation of greater capability at lower cost than either could achieve alone for commercial benefit.
- Explore cooperative exchange of monitoring information.

5.2.6 Organization and Governance

- The recently signed Presidential Directive on Space-Based PNT affords an opportunity for all stakeholders to correct deficiencies of the former Interagency GPS Executive Board. The following recommendations address the effectiveness of the new structure.
 - If Deputies do not routinely participate, then designated representatives to the National Space-Based PNT Executive Committee (NPEC) must be formally empowered to speak for and act on behalf of their respective Deputies for all matters coming before the NPEC.
 - Strengthen the effectiveness of the full-time National Space-Based PNT Coordination Office (NPCO) by formally designating senior technical focal points within each department who will keep the NPEC principals fully apprised of all PNT matters being developed by the NPCO for executive level consideration and action.
 - Stakeholders can use this forum to investigate the viability of alternative methodologies for managing and financing GPS to address current issues and more effectively sustain and enhance services for its full complement of domestic and international users into the future.
- The Secretary of Defense should also clarify lines of authority and responsibility within the Department to eliminate ambiguity regarding GPS responsibilities that hinders decision making internally and that perpetuates the

perception externally that the DoD has lost sight of its GPS stewardship responsibilities.

- Designate a single focal point within the Office of the Secretary of Defense responsible for all GPS policy and oversight matters including clearly defined relationships with the Joint Staff and Services (including the Air Force) regarding GPS operations and acquisition, respectively.
- Use the DoD PNT Executive Committee process to conduct a top-to-bottom review and develop recommendations regarding organizational structure(s) for DoD PNT role.
- Sponsor and lead an interagency effort to develop a comprehensive national PNT architecture to guide future investment and implementation decisions regarding GPS and complementary systems and technologies.
- The Secretary of Defense should reemphasize in writing the criticality of GPS operations, similar to the emphasis he has previously issued for GPS acquisition.
 - Commander STRATCOM can quickly demonstrate improved operations through support of Commander 14th AF tasking to stand up a Joint GPS Service Support Center (as part of the Joint Space Operations Center). The center’s primary operational task would be improved position and time services to military users, achieving this initially through the collection and assessment of GPS monitor information from reliable, independent global sources and in the longer term by providing operational guidance for updating the control segment software. The center could also provide a source of information on all foreign GNSS available (GLONASS, Galileo, other systems), for space situation awareness.
- In fulfilling its stewardship obligation for providing civil and military space-based PNT, the Commander, STRATCOM should be directed by the Secretary of Defense to develop and maintain a roadmap for

achieving joint, integrated, seamless, precision military operations, to coordinate Service-developed user equipment roadmaps for compatibility and to establish and maintain SPS and PPS performance standards. STRATCOM could then task its component (Air Force Space Command) to implement standards and reporting criteria in accordance with routine joint system performance reporting instructions.

- Include designated representatives from STRATCOM on all DoD and interagency executive committees and working groups involved with management and operation of GPS.
- Ensure that the concept of stewardship for GPS operations as passed from the Secretary of Defense to STRATCOM includes responsibility for being aware of and meeting civil service performance needs as mutually agreed between the DoD and civil users and reflected in the GPS Civil Performance Standard.

APPENDIX A. TERMS OF REFERENCE

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ACQUISITION,
TECHNOLOGY
AND LOGISTICS

THE UNDER SECRETARY OF DEFENSE

3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

APR 9 2004

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference -- Defense Science Board Task Force on the Future of the Global Positioning System

You are requested to form a Defense Science Board (DSB) Task Force on Future of the Global Positioning System (GPS).

As the current global radio navigation system de facto standard, GPS currently dominates commercial and military applications. The European Union's proposed development of Galileo, a global radio navigation satellite system (GRNSS), under civilian operation and control places DoD at a crossroads with respect to the Global Positioning System. The commercial sector's exposure to GPS has whetted its appetite for precision time standards and positioning data; and their demand for robust, persistent, and continuous precision time and position capabilities implies significant growth in the commercial area as new applications are developed.

Without significant DoD movement on GPS, the introduction of Galileo may marginalize GPS to an expensive military use only system. The commercial market now provides significant cost savings to DoD as it develops GPS applications for its customers. However, significant future costs may be incurred by DoD to develop and maintain GPS receivers and other system components if the commercial market spawned by a Galileo product grows to its envisioned size and commercial companies abandon GPS as a niche market.

There is also a blurring of military and civil applications related to homeland security. GRNSS is increasingly critical to infrastructure operations such as power control, energy pipelines, communications, and transportation. Therefore, the operation, control, and robustness of GRNSS are not only a concern for the military but a national security issue for the critical infrastructure as well. If Galileo or some other GRNSS becomes deployed and its penetration of the worldwide civil market proceeds as planned, some of the critical infrastructure functions could be enabled by a GRNSS which is potentially outside US control and influence.



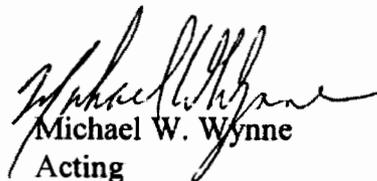
The Task Force should assess the range of issues dealing with Galileo (or some other future radio navigation satellite system) and provide recommendations to address these issues. The assessment should address the following:

- a. Provision of capabilities and services within GPS to ensure its viability in commercial markets. The range of strategic options for the US related to GPS and Galileo range from co-existence to cooperation to competition. This range of options may include moving the management and development of GPS to another government agency;
- b. The impact on frequency spectrum use, signal waveforms and power management;
- c. Access and denial issues throughout the spectrum of conflict;
- d. Possible alternatives to a global radio navigation system including the development of small compact timing devices and/or navigation units. This assessment must include an estimate of the financial impact of incorporating these new devices into legacy weapons and weapon systems;
- e. Vulnerabilities and upgrade strategies for all GRNSS.

The Task Force should assess areas in which DoD should seek strong partnering relationships outside DoD, both within government and industry. It should also recommend research and development areas that are uniquely in DoD interest and might not be accomplished by the private sector.

The study will be co-sponsored by me as the acting USD(AT&L) and the ASD(NII). Dr. James Schlesinger and Dr. Robert Hermann will serve as co-chairs of the Task Force. Mr. Ray Swider, OSD(NII), will serve as Executive Secretary and Lt Col Dave Robertson, USAF, will serve as the Defense Science Board Secretariat representative.

The Task Force will operate in accordance with the provisions of P.L. 92-463, the "Federal Advisory Committee Act," and DoD Directive 5105.4, the "DoD Federal Advisory Committee Management Program." It is not anticipated that this Task Force will need to go into any "particular matters" within the meaning of section 208 of Title 18, U.S. Code, nor will it cause any member to be placed in the position of acting as a procurement official.


Michael W. Wynne
Acting

APPENDIX B. TASK FORCE MEMBERSHIP

Co-Chairmen

Dr. Robert Hermann
Hon. James Schlesinger

Global Technology Partners, LLC
MITRE Corporation

Task Force Members

Mr. John Darrah
Mr. William Delaney
Mr. Arnold Donahue
Mr. Kirk Lewis
Gen James McCarthy, USAF (Ret)
Mr. Steve Moran
Ms. Ruth Neilan
Mr. Robert Nesbit
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APPENDIX C. BRIEFINGS RECEIVED BY THE TASK FORCE

Name	Topic
<i>Mr. Gil Klinger</i>	NSPD-X
<i>Mr. Jeff Shane</i>	Civil GPS Requirements
<i>Mr. Ralph Braibanti</i>	Draft GPS-Galileo Agreement
<i>Col Rick Reaser, USAF</i>	GPS/Galileo National Security Compatibility Criteria; Security Architecture
<i>Col Allan Ballenger, USAF</i>	GPS Program Update
<i>Col Norman Albert, USAF</i>	NAVWAR SAR Final Report
<i>Mr. Jay Rixse</i>	Project Atlas
<i>Mr. Milt Creighton</i>	Emerging Jamming Threats
<i>Maj Patrick Husted, USAF</i>	GPS Control Segment Modernization
<i>Mr. John Darrah/ Ms. Ruth Neilan</i>	Operationalizing GPS
<i>Lt Col John Anderson, USAF</i>	GPS III Space Segment & Launch Vehicle Compatibility; GPS UE NAVWAR Initiatives
<i>Ms. Ruth Neilan</i>	Monitoring Task Report
<i>Mr. Yoaz Bar-Sever</i>	NASA Global Differential GPS System
<i>Mr. Eddy Emile</i>	Advanced GPS User Equipment Architectures & Technology Roadmap U.S. Navy GPS Roadmap

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APPENDIX D. GPS CONSIDERATIONS FOR SMALL DIAMETER BOMB (SDB) AND THE F-22

Because of its light weight and compact configuration, the SDB promises greater mission effectiveness at lower sortie and logistic cost than was ever before achievable. The Task Force believes that, for optimum effectiveness, the employment objectives for the SDB should include all weather day-night delivery at an accuracy of 2 meters or better. Techniques to attain these levels of accuracy have been already been demonstrated for a variety of civil applications, including robotic farming, and precision machine operations to accuracies of better than 10 centimeters. The SDB objectives are achievable, but for successful implementation, at least four issues must be addressed:

1. The F-22 must have ensured, continuous availability of GPS. This implies that it should incorporate the latest in anti-jam GPS receiver and antenna technology. At least 90 dB of jam resistance is essential, and beam steering antennas will be required to counter distributed jammers.
2. The F-22 platform must be configured to directly hand off a complete GPS position, velocity and time solution to the SDB prior to release. This will ensure that the GPS receiver in the SDB can lock up immediately on release and clearance from the aircraft. This capability is essential to achieving jam resistance and sustaining accuracy.
3. The SDB program should pursue options to enhance GPS-inertial coupling to increase jam resistance beyond that provided by the baseline GPS-inertial package. All SDBs may not require this “silver bullet” capability; however, there should be at least one version of the SDB that is so configured.
4. To achieve the ultimate required operational effect, the issue of target location accuracy must be addressed, and will require higher precision than is now part of the “requirements”. To achieve 2 meter weapon-on-target accuracy, the allocation of Target Location Error should be less than 1 meter. The Task Force believes there are technologies and techniques to attain this

today, and the NGA should coordinate a system-of-systems effort to ensure this performance is realized.

APPENDIX E. SPATIAL INTEROPERABILITY

In the specific case of air-delivered weapon support to ground forces, the precision bombing benefits of the common-grid capability afforded by GPS cannot be assumed in advance. To ensure GPS common-grid is applied in air-delivered weapons support, a change in joint doctrine is necessary to require in-theater use of the grid reference alphanumeric position reporting system, Military Grid Reference System (MGRS), for all 2-D positioning, navigation and targeting purposes and as the 2-D component of 3-D operations. Universal use of the MGRS for all in-theater spatial operations will eliminate confusion regarding which coordinate system is being used in navigating and reporting positions and targets. It will also eliminate the practice of requiring that ground personnel electronically or manually convert positions and targets from MGRS to latitude and longitude for the purpose of obtaining support from aviation components.

In any emergency situation, whether in a war zone or the domestic environment, spatial interoperability is as important as communications interoperability. Said another way, confusion in identifying an incident location can be as deadly as not being able to transmit that location to a potential responder. GPS can solve that problem, but only if it is employed smartly and with forethought. GPS enables common grid operations, but only if the participants agree in advance on which of the many available coordinate grids they will use to identify locations of importance to the operations. Coordinate grids are the languages of location, and using different grids in the same operation is analogous to trying to communicate in different languages.

MILITARY SPATIAL INTEROPERABILITY

In the military mission environment, spatial confusion in joint operations can result from different participants in an operation expressing locations using spherical geographic coordinates (latitude and longitude - lat/lon) and planar grid coordinates (Military Grid Reference System). There are good reasons for using each, primarily related to distances traveled, but from a spatial interoperability standpoint this is like discussing ground operations in

English and airborne operations in Chinese. When the two have to work together, translation is critical, but under stress, mistakes are all too common. The burden of conversion routinely falls on the ground troops, who are likely already over tasked in a stressful environment, many times under enemy fire. This is the reason for the recommended revision to joint operational doctrine expressed in the Weapons Delivery section above.

CIVIL/HOMELAND SECURITY SPATIAL OPERATIONS

In the civil environment, people today have great difficulty in finding map products (even those provided by digital sources) which contain grids that can be used with GPS equipment. Those map products that do include grids may use any of several grid systems to identify locations, a lack of standardization that can create time-consuming confusion in time of emergency. Many of the commercial proprietary grids do not permit precise locations to be determined, and virtually none work with GPS equipment. However, in a December 2001 action to address Homeland Security issues, the U.S. Federal Geographic Data Committee approved a new standard grid for such applications that can eliminate this spatial confusion. Called the U.S. National Grid (USNG), this standard will permit easy depiction of positions to 10 meters or less anywhere in the United States using an alphanumeric designator about the size of a telephone number. The USNG is based on the global standard grid called Universal Transverse Mercator, so it is non-proprietary and globally extendable. It is also designed to be identical to the MGRS grid coordinate system used by the Army and Marine Corps, so it can directly enable spatial uniformity in joint civil-military response operations.

Lack of a uniform method for describing incident locations has long been a major impediment to rapid and effective emergency response in diverse metropolitan and rural areas. Until the adoption of the USNG, there has been no standard that would enable uniform large-scale map products to be created that could be used directly with GPS equipment and be applicable across jurisdictional boundaries nationwide. The USNG corrects that glaring discrepancy, but, having now been officially adopted, it still must be used to be effective. A program of education and training, beginning at the middle school level, would be instrumental in facilitating its use by the public. More focused leadership by the Federal Government to promote such basic education as well as training in the uniform application of GPS at federal,

State and local levels by emergency responders would pay nationwide dividends for Homeland Security.

The immediate domestic impact of USNG will be to ensure that GPS is directly useable with properly gridded map products to quickly enable multi-agency and multi-jurisdictional emergency responders, and the public in general, to precisely identify geolocations in the real world. Linking current technologies of overhead imagery and Nationwide Differential GPS at one-meter accuracy, the USNG can facilitate direct creation of gridded, very precise, large-scale image maps that would be immediately useable with GPS receivers. These maps will be extremely useful to emergency responders as they will depict the emergency environment as it exists rather than as it previously appeared from potentially out-of-date legacy sources. GPS commercial receiver manufacturers are now beginning to include the USNG in their newest products. As awareness of its usefulness grows, prompted by education, the USNG will be a principal integrating mechanism to create spatial interoperability nationwide. It will be equally effective among multi-jurisdictional civil emergency response organizations and, when necessary, between those organizations and the military to support any and all domestic emergency response and disaster relief operations.

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APPENDIX F. USER EQUIPMENT UPGRADE COSTS (“SILVER BULLET” CAPABILITY)

A rough estimate of the cost of upgrading important military receivers with anti-jam fixes is given in the following table. These upgrades involve technologies such as adaptive antennas, advanced receiver processing architectures, and miniature precision clocks.

The costs include both the individual anti-jam hardware and the cost of integration on the platform for the cases where a retrofit is assumed. Cases such as JDAM and artillery shells do not involve integration costs since the improvements would be installed in the initial production.

An AJ upgrade to a GPS munition-like JDAM might cost \$4K, an artillery shell \$1K, a strike aircraft \$50K, plus an additional \$50K for retrofit (“integration”) cost. Some platforms, like GPS-guided artillery shells and JDAMS, need only a portion of the inventory upgraded (the “silver-bullet” approach).

Platform	Total Number	Number Upgraded	Cost of AJ Upgrade	Total Cost
Strike Aircraft	2,000	2,000	\$50 K + \$50 K integration	\$.2 B
Various Cruise Missile Types	2,500	2,500	20 K + \$20 K integration	.1 B
JDAMS	230,000	50,000	4 K	.2 B
Artillery Shells	500,000	100,000	1 K	.1 B
Hand-held Receivers	100,000	100,000	1 K + \$1 K integration	.2 B
Other Platforms	5,000	5,000	20 K + \$20 K integration	.2 B
Total				\$1.0 B

APPENDIX G. ACRONYMS

2SOPS	2 nd Satellite Operations Squadron
AII	Accuracy Improvement Initiative
ASD(NII)	Assistant Secretary of Defense (Networks & Information Integration)
COMSEC	Communications Security
COTS	Commercial Off-the-Shelf
CSEL	Combat Survivor Evader Locator
DoD	Department of Defense
DSB	Defense Science Board
ECEF	Earth-Centered-Earth-Fixed
EELV	Evolved Expendable Launch Vehicle
EOD	Explosive Ordnance Disposal
EPLRS	Enhanced Position Location Reporting System
ERGM	Extended Range Guided Munitions
EU	European Union
FAA	Federal Aviation Administration
GDGPS	Global Differential GPS service
GEO	Geosynchronous Earth Orbit
GLONASS	Global Orbiting Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPS III	Global Positioning System III

IA	Information Assurance
IGS	International GPS Service
ISR	Intelligence, Surveillance/Reconnaissance
ITRF	International Terrestrial Reference Frame
JCS	Joint Chiefs of Staff
JDAMs	Joint Direct Attack Munitions
JPL	Jet Propulsion Laboratory
JPO	Joint Program Office
JRIDS	Joint Tactical Information Distribution System
JROC	Joint Requirements Oversight Council
JTRS	Joint Tactical Radio System
L2C	Civil GPS Signal at L2 Frequency
LAAS	Local Area Augmentation System
LPI/LPD	Low Probability of Intercept/Low Probability of Detection
M-code	Military Code
MCS	Master Control Station
MEO	Medium Earth Orbit
MGRS	Military Grid Reference System
NASA	National Aeronautics & Space Administration
NATO	North Atlantic Treaty Organization
NAVWAR	Navigation Warfare
NDGPS	Nationwide Differential GPS
NDS	NUDET Detection System
NGA	National Geospatial Intelligence Agency
NIST	National Institute of Standards and Technology
NPCO	National Space-based PNT Coordination Office
NPEC	National Space-based PNT Executive Committee
NUDET	Nuclear Detonation
OCS	Operational Control Segment
OMB	Office of Management and Budget
OSD	Office of Secretary of Defense

PNT	Positioning, Navigation and Timing
PPS	Precise Positioning Service
PPS-SM/AOC	PPS Security Module/Auxiliary Output Chip
PRONAV	Protection of Navigation
QZSS	Quazi-Zenith Satellite System
R&D	Research & Development
SAASM	Selective Availability Anti-Spoofing Module
SDB	Small Diameter Bomb
SSPS	Signal Specification/Performance Standard
SPS	Standard Positioning Service
STRATCOM	U.S. Strategic Command
TLE	Target Location Error
UHF	Ultra High Frequency
USD(AT&L)	Office of Undersecretary of Defense (Acquisition Technology & Logistics)
USNG	U.S. National Grid
USNO	U.S. Naval Observatory
UTC	Universal Coordinated Time
WAAS	Wide-Area Augmentation System
WGS-84	World Geodetic System 1984
YMCA	Y-code, M-code, CA- coarse acquisition code