SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

NATIONAL SPACE-BASED POSITIONING, NAVIGATION, AND TIMING (PNT) ADVISORY BOARD

Eighteenth Meeting

December 7-8, 2016

Crowne Plaza Redondo Beach, Peninsula and Pacific Ballrooms
300 N. Harbor Drive, Redondo Beach, CA 90277

John Paul Stenbit
John Paul Stenbit
Chair

James J. Miller
James J. Miller
Executive Director

National Space-Based Positioning, Navigation, and Timing Advisory Board

18th Meeting
December 7-8, 2016

Crowne Plaza Redondo Beach, Peninsula and Pacific Ballrooms
300 N. Harbor Drive, Redondo Beach, CA 90277

Agenda

WEDNESDAY, DECEMBER 7, 2016

9:00 - 9:05
BOARD CONVENES
Call to Order & Announcements
Mr. James J. Miller, *Executive Director, PNT Advisory Board, NASA Headquarters*

9:05 - 9:30
18th Meeting Focus based on October 27 PNT EXCOM Priorities
Spectrum Repurposing & Existential Threats to GPS/GNSS Services
Mr. John Stenbit, *Chair;* Dr. Bradford Parkinson, *1st Vice-Chair;* Gov. Jim Geringer, *2nd Vice-Chair*

9:30 - 10:00
U.S. Department of Transportation (DOT) Civil GPS/PNT Update
GPS Adjacent Band Compatibility (ABC) Assessment
VIEW PDF (1 MB)
Ms. Karen Van Dyke, *Director for PNT, DOT Office of the Secretary, Research and Technology*

10:00 - 10:15
Policy Update and Recent PNT EXCOM Topics
National Coordination Office (NCO) Interagency Perspectives
VIEW PDF (420 KB)
Mr. Harold "Stormy" Martin, *Director, National Coordination Office for Space-Based PNT*

10:15 - 10:45
Global Positioning System (GPS) Status & Modernization Milestones
GPS III Satellite Vehicle and OCX Progress & Plans
VIEW PDF (3 MB)
Col Gerard "Gerry" Gleckel, *Deputy Director, GPS Directorate, Space & Missile Systems Center*

10:45 - 11:00
BREAK

11:00 - 11:30
U.S. International Activities Update: Multilateral and Bilateral Advances
11th Meeting of the International Committee on GNSS & Intl. Outreach
VIEW PDF (657 KB)
Mr. Ken Hodgkins, *Director, Office of Space and Advanced Technology, U.S. Department of State*

11:30 - 12:00
European Space Agency (ESA) Perspective on Galileo as an Emerging Utility
Economic Benefits and Serving Space Users for Societal Benefit
VIEW PDF (624 KB)
Dr. Werner Enderle, *Head, Navigation Support Office, European Space Agency*

12:00 - 1:00
LUNCH

1:00 - 1:25
Boeing GPS Overview
Building Global Capabilities
VIEW PDF (799 KB)
Mr. Douglas Skinner, *GPS Program, Networks & Space Systems, Space & Security, Boeing Defense*

1:25 - 1:50
Deep Space Atomic Clock (DSAC) & Optical Communications/Navigation
Emerging Capabilities for PNT Autonomy & Space Architectures
VIEW PDF (2 MB)
Dr. Don Cornwell, *Director, Advanced Comm and Nav Technology, Space Comm & Nav (SCaN), NASA*

1:50 - 2:15
GPS III – Poised for Tomorrow
Building Global Capabilities
VIEW PDF (573 KB)
Mr. John Voce, *Manager, Business Development, Lockheed Martin Navigation Systems*

2:15 - 2:40
GPS/GNSS Space Service Volume (SSV) Update Initiatives
U.S. and International Benefits — GOES-R in Action!
VIEW PDF (3 MB)
Mr. Joel Parker, *Aerospace Engineer, Nav & Mission Design Branch, Goddard Space Flight Center,*

NASA

2:40 - 3:05
Northrop Grumman PNT Overview
Building Global Capabilities
Dr. Dennis Hall, *Director of Emerging Communications, Northrop Grumman*

3:05 - 3:25
Real-Time GNSS for Earthquake and Tsunami Early Warning
Implementing GNSS as a Worldwide Public Safety Infrastructure
VIEW PDF (9 MB)
Dr. Gerald Bawden, *Program Scientist, Natural Hazards Research, NASA HQ*

BREAK

3:40 - 4:00
Update on Protecting United States Critical GPS Infrastructure
Department of Homeland Security Infrastructure Protection Initiatives
VIEW PDF (366 KB)
Mr. James (Jim) Platt, *Director, PNT Office, Department of Homeland Security*

4:00 - 4:20
Alliance for Telecommunications Industry Solutions (ATIS) GPS Vulnerability Report
VIEW PDF (520 KB)
Mr. Michael Calabro, *Contributing Engineer, Alliance for Telecommunications Industry Solutions*

4:20 - 4:40
Standardization of GNSS Threat Reporting and Receiver Testing through Intl. Knowledge Exchange, Experimentation & Exploitation [STRIKE3]
VIEW PDF (1 MB)
Dr. Mark Dumville, *General Manager, Nottingham Scientific Limited (NSL), United Kingdom*

4:40 - 5:00
Communicating Time Looks Like a Simple Problem, But If It's so Simple, Why Haven't We Solved It?
VIEW PDF (1 MB)
Mr. Harlan Stenn, *Founder and President, Network Time Foundation*

5:00: **ADJOURNMENT**

THURSDAY, DECEMBER 8, 2016

9:00 - 9:05

BOARD CONVENES
Call to Order
Mr. James J. Miller, *PNT Advisory Board Executive Director, NASA HQ*

9:05 - 9:30
Announcements & Agenda
Concise Assessment & Member Feedback from December 7 Deliberations
Mr. John Stenbit, *Chair;* Dr. Bradford Parkinson, *1st Vice-Chair;* Gov. Jim Geringer, *2nd Vice-Chair*

9:30 - 11:00
Representative & International Reports & Perspectives:

- RNSS Spectrum Vigilance — Status
  VIEW PDF (56 KB)

Ms. Ann Ciganer, *GPS Innovation Alliance (United States)*

- GNSS Science Advances
  VIEW PDF (2 MB)

Dr. Gerhard Beutler, *International Association of Geodesy (Switzerland)*

- Norway's Contribution to the Global Geodetic Reference Frame
  VIEW PDF (2 MB)

Mr. Arve Dimmen, *Norwegian Coastal Administration (Norway)*

- Protection of the GNSS Spectrum
  VIEW PDF (291 KB)

Dr. Sergio Camacho-Lara, *U.N. Center of Science and Space Technology (Mexico)*

- Prioritizing Dangers to the United States from Threats to GPS
  VIEW PDF (1 MB)

Mr. Dana A. Goward, *Resilient Navigation and Timing Foundation (United States)*

- Remarks on the International Activities Regarding GNSS Spectrum Protection — A Day Without Interference
  VIEW PDF (351 KB)

Dr. Refaat Rashad, *Arab Institute of Navigation (Egypt)*

11:00 - 11:15:
BREAK

11:15 - 12:00
PNT Board Member Roundtable Discussion
Priorities & Recommendations for new Administration PNT Executive Committee – Key Topics & Work Plan for 2017
All PNT Board Members

12:00 - 1:00
LUNCH - *Working*

1:00: **ADJOURNMENT**

Dates and times are as originally scheduled and do not reflect actual presentation times.

Table of Contents

Executive Summary 9

Wednesday, December 7

Board Convenes/Mr. James J. Miller 10

Introduction/Mr. John Stenbit, Chair; Dr. Bradford Parkinson, 1st Vice-Chair, Gov. Jim Geringer, 2nd Vice-Chair 10

U.S. Department of Transportation Civil GPS/PNT Update / Ms. Karen Van Dyke 11

Policy Update and Recent PNT EXCOM Topics / Mr. Harold Martin 12

Global Positioning System (GPS) Status & Modernization Milestones / Col Gerard Gleckel 13

U.S. International Activities Update: Multilateral and Bilateral Advances / Mr. Ken Hodgkins 14

European Space Agency Perspective on Galileo as an Emerging Utility /Dr. Werner Ederle 15

Boeing - GPS Overview / Mr. Douglas Skinner 16

Deep Space Atomic Clock (DSAC) & Optical Communications/Navigation / Dr. Don Cornwell 17

Lockheed Martin - GPS – Poised for Tomorrow/Mr. John Voce 18

Northrop Grumman - PNT Overview/Dr. Dennis Hall 18

GPS/GNSS Space Service Volume (SSV) Update Initiatives/Mr. Joel Parker 19

Real-Time GNSS for Earthquake and Tsunami Early Warning/Dr. Gerald Bawden 21

Update on Protecting U.S. Critical GPS Infrastructure/Mr. James Platt 22

Alliance for Telecommunications Industry Solutions GPS Vulnerability Report / Mr. Michael Calabro 23

Standardization of GNSS Threat Reporting and Receiver Testing Through International Knowledge Exchange, Experimentation & Exploitation/Dr. Mark Dumville 25

Communicating Time Looks like a Simple Problem, But if it's so Simple, Why Haven't We Solved It/Mr. Harlan Stenn 26

Advisory Board Discussion/All PNT members 26

Thursday, December 8

Board Convenes: James J. Miller 29

Representative & International Reports

Ms. Ann Ciganer 29

Dr. Gerald Beutler 30

Mr. Arve Dimmen 31

Dr. Sergio Camacho-Lara 31

Mr. Dana Goward 32

Dr. Refaat Rashad 33

Advisory Board Discussion: All PNT members 34

Appendix A: PNT Advisory Board Membership 37

Appendix B: Presentations 38

Appendix C. Sign-In List 39

Appendix D: Acronyms and Definitions 41

Summary - 18th National Space-Based PNT Advisory Board

EXECUTIVE SUMMARY:

The 18th session of the National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board met on December 7-8, 2016, at Redondo Beach, California. The principal goal of this session was to organize reports and other plans in support of Global Positioning System (GPS) and the Advisory Board for use in the transition to the new national administration.

HIGH-LEVEL ACTION ITEMS:

- Dr. Bradford Parkinson, 1st Vice-Chair, organized subcommittees on scientific, policy/multi-GNSS (Global Navigation Satellite System), aviation and aerospace, agriculture, transportation (non-aviation), critical infrastructure and timing, military, spectrum, and multi-GNSS issues. He charged each subcommittee with developing, by the end of January, a two-page statement, written in layman's language, on the value of GPS and the costs of any service interruption. The immediate audience for these reports is the Executive Committee (EXCOM).
- Dr. Parkinson noted that Mr. John Stenbit, Chair, and he would prepare the cover letter to the subcommittee reports.
- Mr. Stenbit urged members with any knowledge of pending appointments pertinent to GPS or to the board to communicate that information to Mr. James J. Miller. Such knowledge would help the board take the initiative in educating appointees to the new administration.

OTHER ACTION ITEMS:

- Mr. Harold Martin, National Coordination Office (NCO), urged members to read the recently released Department of Transportation (DOT) Federal Register Notice (FRN) on complementary PNT.
- Mr. James Platt, Department of Homeland Security (DHS), urged members to urge organizations known to them to participate in the DHS study of GPS and critical infrastructures.
- Mr. Dana Goward, Resilient PNT Foundation (RPNT), said he is seeking speakers for a March 17, 2017 conference on system backup.
- Mr. Kirk Lewis urged the board to make a formal declaration of the minimum number of U.S.-operated satellites needed.

Meeting Minutes – 18th National Space-Based PNT Advisory Board

Board Convenes

Call to Order & Announcements
Mr. James J. Miller, *Executive Director*
PNT Advisory Board, NASA Headquarters

Mr. James J. Miller welcomed everyone to the 18th meeting of the National Advisory Board for Space-Based PNT. Many Advisory Board members and presenters have traveled considerable distances to volunteer their time to the betterment of GPS. Mr. Miller extended a special welcome to Major General Kathy Chilton and Colonel Gerard Gleckel, Deputy to Colonel Steve Whitney, Director of the GPS Directorate (GPS-D), Space & Missile Systems Center (SMC). The PNT Advisory Board was established to provide independent advice and counsel at the Deputy Secretary level. The board is subject to the Federal Advisory Committee Act (FACA), therefore, formal minutes are taken and will be posted on the www.GPS.gov website within a week. PNT Advisory Board members have been nominated by one of the federal agencies represented at the PNT EXCOM and confirmed by the National Aeronautics and Space Administration (NASA) Administrator. The role of the board is to serve all GPS-using sectors. Any board member who believed they may face a conflict of interest on a particular discussion topic should recuse themselves from the discussion of those topics, and their recusal will be noted in the meeting minutes. The value of an independent body such as the Advisory Board is that its disparate membership brings a broader perspective than may emerge from federal bureaucracy. The central purpose of the 18th PNT Advisory Board meeting is to begin work on the transition plans for presentation to the incoming administration.

Introduction

Mr. John Stenbit, Chair; Dr. Bradford Parkinson, 1st Vice-Chair, and Gov. Jim Geringer, 2nd Vice-Chair

Mr. John Stenbit added his welcome and appreciation. He noted that the board's various committees met in working sessions on the previous day. At these sessions there was somewhat of a dissonance regarding the issue of Enhanced Loran (eLoran). Two technical studies were presented with the objective to allow the board to assess whether it should stand by its previous recommendations on eLoran, and in principle the judgment is that should. Further technical review of this subject is anticipated. Another important discussion was how to add into the general outlook new and longer-term uses for GPS that were not envisioned when the GPS program was launched. This issue surfaces regularly, and is a difficult subject due to its inherently speculative nature. Finally, another key on-going discussion is that of GNSS spectrum protection.

Dr. Bradford Parkinson, 1st Vice-Chair, noted that he represented the board at the recent International Committee on GNSS (ICG) meeting in Sochi, Russia, where the topic of a GNSS Space Service Volume (SSV) is high on the international agenda and both the full and regional GNSS systems are interested in scientific and other applications that derive from having an SSV. Since 2007 the Advisory Board has brought forth recommendations, many of them relating to new applications that were unforeseen when GPS was developed. The board has a responsibility to try to support such new applications. Existing applications already contribute approximately US$50 billion per year to the national economy. One such new application, which had never been originally imagined, involves using the SSV improve weather satellite positioning and, thus, greatly improve weather prediction. The board needs to take more effective steps to educate others on the importance of protecting such possibilities that were not originally foreseen. Another important topic for the board is the pressing threat to GPS posed by the repurposing of bandwidth adjacent to GPS frequencies, which include an upper and a lower band for broadband transmission. Difficulties may be created by: proximity in the frequency band, proximity in the location of the transmitter location, and in particular by the prospective strength of the transmissions within the repurposed band. In his view, it is clear that the proposed upper band for broadband transmissions cannot not be repurposed without grave impact on highly-valuable high precision GPS receivers. Also, contrary to previous belief, the proposed masking does not provide nearly the range of protection for general aviation. Dr. Parkinson identified the possible envelope of interference for high precision receivers. A central question is how powerful a broadband transmitter needs to be to emit a signal that exceeds the 1 dB (decibel) limit. This has, potentially, grave repercussions to GPS users. Finally, Dr. Parkinson noted that commercial GPS receivers already track signals from multiple GNSS systems. Thus, users needed to be reassured that this is not a violation of the law. This, however, is not currently the case. In his view these are some of the forward-looking issues where the board should play an advocacy role.

Mr. Stenbit noted that some of these matters were discussed at the last PNT EXCOM meeting.

Gov. Geringer, 2nd Vice-Chair, noted that he was present at the same meeting. There, he summarized the board's position that all GPS signals are affected at lower levels than previously understood. A key question is: how will interference from new systems be accommodated? At the PNT EXCOM there was some changes in the tenor of discussions, namely, while GPS is still being accorded greater importance, there remains some background sentiment that broadband may be more important.

* * *

U.S. Department of Transportation (DOT) Civil GPS/PNT Update
GPS Adjacent Band Compatibility (ABC) Assessment
Ms. Karen Van Dyke, *Director for PNT*
DOT Office of the Secretary, Research and Technology

(Note: The following board members recused themselves from this discussion: John Stenbit, Ann Ciganer, Ron Hatch, Per Enge, Joe Burns, and Scott Burgett. Dr. Parkinson took the chair in place of Mr. Stenbit)

Ms. Karen Van Dyke mentioned the 2012 letter from the then-EXCOM co-chairs expressing support for accepting broadband transmissions within repurposed spectrum provided this could be done "without affecting existing and evolving uses of space-based PNT services vital to economic, public safety, scientific, and national security needed." This has been a guideline for all work at the DOT and has been applied to all proposals regardless of the originator. The DOT-led effort has two components: first, certified aviation receivers; second, all non-aviation receivers. The DOT has taken to heart the six criteria for testing enunciated by Dr. Parkinson at the previous Advisory Board session. The entire process has proceeded with considerable engagement with civil partners. Five workshops have been held, Federal Register Notices have been posted and one-on-one discussions have been held with industry. Overall an open and transparent approach has been used, and the DOT strived to make sure no particular community would feel left out.

To date three milestones have been reached: (1) carrying out GPS/GNSS receiver testing at White Sands Missile Range (WSMR); (2) producing 1 dB Interference Tolerance Mask (ITM) results; and (3) provision of WSMR test plans and results on request to NTIA (National Telecommunications and Information Administration), NASA, and the U.S. Air Force. While testing was not done from a signal acquisition standpoint, re-acquisition testing was undertaken. Eighty receivers were tested. Ms. Van Dyke listed and thanked the twelve federal agencies and receiver manufacturers involved with the testing. Testing included a number of multi-GNSS receivers (10 different GNSS signals used in testing) and thirty-five high precision receivers. The objective was to determine what power levels can be tolerated, and, therefore, what interference protection is required. This effort was conservative in terms of criteria and definitions used. For example, degradation was only counted when the signal was not rapidly reacquired. Also, when a sustained drop over 1 dB occurred, the data was included in the proposed multi-GNSS mask. Ms. Van Dyke praised the professionalism of the WSMR staff.

Ms. Van Dyke presented a series of charts showing the test results. Key results are:

- ITMs have been produced as a function of interference center frequency for all emulated GNSS signals
- Results showed good consistency between repeated tests.
- The certified aviation receiver mask does not bound the masks of all six receiver categories tested by DOT.
- The satellite re-acquisition time degraded at interference level similar to Interference Power (IP) at 1 dB.
- Exceeding the 1 dB interference level can adversely affect receiver performance by slowing the reacquisition of satellite signals (after losing a signal such as, for example, due to building obstruction or driving under a highway overpass).

Relative to next steps, the goal is to develop representative use cases to better understand what power level could be tolerated by GPS receivers. The tolerable power level will be case-dependent, so a different approach must be used for each of the six cases – including, among other criteria, considerations such as the pertinent operating environment, number of satellites in-view, and applicable propagation logs. This will be a considerable effort and, thus, it is currently being worked aggressively. A public workshop will be held early in 2017 to obtain stakeholder feedback. Regarding certified aviation, a key criteria is the required standoff distance between a transmitter and the GPS receiver. A significant amount of work has been undertaken in this area with Ligado.

> Dr. Betz noted that high performance receivers commonly operate on different modes, some of which can be very sensitive to cycle slips. Has there been any testing of such receivers?
>
> Ms. Van Dyke responded that such testing has not happened yet. She agreed this is a priority concern.
>
> Dr. Parkinson noted the current great interest in UAVs (Unmanned Aerial Vehicles). Given their reliance on GPS, should a UAV receiver lose track on the GPS signal then vehicle control would be lost. Does the Federal Aviation Administration (FAA) agree that UAVs are critically dependent on GPS?
>
> Ms. Van Dyke said that while the FAA does not currently regard UAVs as its responsibility, the issue does concern them. The FAA and the Department of Defense (DoD) were currently engaged in developing a use-based scenario for this issue.

Dr. Parkinson asked if UAVs should fall under the aegis of the FAA or the DOT as a whole.

Ms. Van Dyke replied that it is a team effort, and the FAA has been a key part of this effort.

Major General Chilton agreed that a thorough testing is required. As such, the DoD appreciates that the DOT is undertaking such testing, which is essential to the nation, the economy and the government.

Ms. Van Dyke said she views the effort as a partnership that has received key support from the U.S. Air Force. It is important to include military-grade equipment in the testing.

Ms. Valerie Green (audience member, Executive Vice President and legal officer for Ligado) asked to speak.

Dr. Parkinson said that under the board's normal procedures while audience members might be called upon for comments if they have pertinent expertise, comments from the audience are in general not entertained by the board.

Ms. Green said she has information on Ligado that may be helpful to the experts, specifically about high precision GPS. In her view several manufacturers of high performance receivers have supported the reduced power levels that Ligado recently submitted to the Federal Communications Commission (FCC). She asked Ms. Van Dyke whether a single signal was used when creating the mask for the high precision sector. Could she explain this further? Also, were the receivers in the DOT test compatible with Ligado?

Ms. Van Dyke said that DOT's effort was not directed at assessing specific manufacturer's products but, rather, to determine the maximum tolerable interference. Specific manufacturers have not been disclosed because of non-disclosure agreements.

Dr. Parkinson noted to Ms. Green that she does not have standing as a questioner. His understanding is that the contractors cited by Ms. Green have not given a wholehearted endorsement of the Ligado position. Rather, they have said they accept the 1 dB criterion as proposed by the board.

Mr. Goward stated, as someone outside the review process, that it might be useful if the nature of those nondisclosure agreements were made public and how such agreements might affect the user community, writ large. Lack of visibility could reduce the level of confidence in the findings.

Dr. Parkinson said that, in his view, the problem is more profound. The Advisory Board has gone forward with six specific points in regards to Ligado, and that what Ligado has provided is essentially a legal response that does not address these specific technical issues. Dr. Parkinson added that at this point it's best to bring this discussion to a close by saying that he and Ms. Green simply disagree on this issue.

(Once this briefing, and discussion, concluded Mr. Stenbit resumed the chair)

* * *

Policy Update and Recent PNT EXCOM Topics
National Coordination Office (NCO) Interagency Perspectives
Mr. Harold 'Stormy' Martin, *Director*
National Coordination Office for Space-Based PNT

Mr. Harold 'Stormy' Martin noted that it is estimated that 3.6 billion GPS receivers now exist in the world. Half of these support multi-GNSS. Thus the "multi-GNSS world" has already arrived. By 2023 the number of GPS receivers should reach 9 billion, which is more than Earth's population. In fact, growth may occur even rapidly than expected because of UAVs, intelligent transportation systems, and logistical tracking devices. GPS is becoming so embedded that, in fact, there is somewhat a danger of becoming submerged. Thus, it is essential for the Advisory Board to act consistently in calling attention to the importance of GPS.

If we don't take care of GPS, it won't take care of us. This could be accomplished adhering to the basic tenets of U.S. policy: commitment to continuous, worldwide, free of direct user fees must be maintained. Because harm to one GNSS system (such as GPS) is harm to all, then we must continue working with other GNSS on everything from interoperability, compatibility and spectrum protection.

The PNT EXCOM is a proven mechanism for maintaining interagency coordination. The EXCOM, under the shared chairmanship of the Deputy Secretary for Defense and the Deputy Secretary for Transportation, has remained focused on issues

of high importance to the nation, including: GPS sustainment and modernization; international coordination; spectrum management; critical infrastructure; PNT resilience and complementary PNT, and outreach. Modernization required continued funding so that GPS remains the world leader in GNSS.

Protecting the GPS spectrum is critical. Three Presidential memos have been issued on broadband access. Each memo wisely chooses to protect current and planned GPS use at the federal, state, local, and tribal areas. The desired situation is one that offers more broadband and more GPS, not less of either. Spectrum sharing covers a multitude of government systems. Therefore, the greatest care is needed in addressing spectrum issues. The EXCOM continues to work, nationally and internationally, on spectrum protection. Decisions need to be data-driven. The adjacent band compatibility assessment is important to the PNT EXCOM, which is looking forward to its final findings. It should also be noted that in the DHS critical infrastructure report fourteen of the sixteen critical infrastructures depend on GPS for timing, and all infrastructures depend on GPS.

GPS resiliency is an important topic. It is good that both the Executive and Legislative branches of government consider this to be quite important. A key issue is what the critical infrastructure does should there be a GPS outage. Today (Dec 7, 2016) is a particularly appropriate time for this question, as it is the 75th anniversary of the bombing of Pearl Harbor. Vigilance must be maintained. This requires that we all work together to be prepared.

On the topic of complementary PNT, the EXCOM has established a way forward. Currently, time and other requirements are being identified. The timeline supports making investment decisions in 2018. The whole process is closely aligned to efforts on system protection and resilience, and involves work with the owner/providers of all 16 critical infrastructures. Such dialogue is important because most critical infrastructures are not operated by the federal government. Work began early in 2016, with the hope that a final requirements doctrine is in place by 2017. DOT has recently released a Federal Register Notice seeking comments. The document has been posted on GPS.gov, and people are urged to read it and provide comments. Also, several bills on related matters have been introduced in Congress.

In summary, both the Executive and Legislative branches of the government take these topics seriously.

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Global Positioning System (GPS) Status & Modernization Milestones
GPS III Satellite Vehicle and OCX Progress and Plans
Colonel Gerard Gleckel, *Deputy Director*
GPS Directorate, Space & Missile Systems Center

Col Gerard Gleckel noted that his superior, Col Steve Whitney, is otherwise committed and unable to attend. Col Gleckel observed that GPS is truly a "team sport" as he is in regular contact with Ms. Van Dyke, Mr. Martin, and others. Anecdotally, while most people do not know GPS is operated by the Air Force, his seatmate on a recent flight was a Nebraska farmer who described using GPS to support precision agriculture.

Col Gleckel presented a GPS overview slide that outlined civil cooperation, spectrum, and the baseline GPS constellation. It also listed the DoD agencies involved, maintenance and security activities, and international cooperation. The GPS Signal-in-Space (SIS) performance scorecard shows that it had its best ever performance (so far) during the week ending November 28, 2016 with an accuracy of 44.1 cm, eclipsing the previous best of 45.3 cm achieved the week of April 14, 2016. The GPS program office is proud of its transparency. The GPS-D is broadly accountable to the organizations represented in the PNT and to the general public. Performance standards are published on gps.gov. Data for 2014 and 2015 will be published in the near future.

Col Gleckel then reported on modernization efforts for the satellites, the ground system, and user equipment. Efforts to modernize must occur in parallel with efforts to maintain the current systems. Regarding the ground system, while the modernized operational control system (OCX) received considerable attention, US$83 million was spent between 2013 and 2018 to maintain the existing operational control system (OCS). Ten GPS III satellites are under contract. For GPS III SVs 11+ there have been overtures from industry that they have the capability to build the satellites. Teams have been sent to assess the capabilities of these candidates, including Boeing, Lockheed Martin, and Northrop Grumman. The draft Request for Proposals (RFP) could be issued in 2017.

OCX has been recertified through the Nunn-McCurdy process. The objective was to demonstrate that: cost is reasonable, priority is higher than other projects, adequate management is in place, and no less expensive alternative exists. OCX Block 1 will not be delivered until 2021. In consequence, the existing system is being modified to allow it to operate the three new GPS satellites that will be placed in orbit by 2021.

The Military GPS User Equipment (MGUE) program continues moving forward. Currently it is focusing on certifying GPS capability and security on 'equipment cards' so they can be built into weapons systems platforms. MGUE, he stressed, was no

longer a program that delivered millions of parts. Rather, it certified what was useable.

The GPS-D is committed to: (1) Maintain the "Gold Standard" status, which involves both modernizing the system and maintaining what exists; (2) Embrace the Space Enterprise Vision by continuing to enhance PNT resiliency, and (3) Embrace the need for alternative PNT sources and respond to the challenge of proposing and exploring solutions. While GPS will remain the cornerstone of PNT, it will not be the only piece; and (4) address the cost and schedule challenges of OCX.

A board member asked where the L5 signals fit in terms of Contingency Operations (COps) and OCX.

Col Gleckel responded that L5 will not be supported on COps.

Another board member asked what impact followed from the January 2016 GPS clock anomaly?

Col Gleckel deferred to Dr. Karl Kovach (Aerospace Corp), who was in the audience.

Mr. Stenbit invited Dr. Kovach to respond.

Dr. Kovach said there was a variety of impacts. Most military receivers sailed right through the anomaly. Some receivers, taking the view that GPS is never wrong, took the data, while other receivers rejected the information.

A board member added that, apparently, DHS received a number of fault reports. He asked whether the GPS-D determine how users in different industries or with different equipment were affected.

Mr. Kovach responded that his company has been closely tied to determining how the fault got through and affected users.

Maj General Chilton commented that from an operational point of view, a number of things have been learned. For example, Tactics, Techniques, and Procedures (TTPs) were quickly changed. Ideally this should be done even quicker, and that will be part of the new training at the Air Force on how to address such training. Maj General Chilton stressed she was speaking from the operational side, not the GPS side, but wished to provide a sense of comfort that matters are being addressed, including improved communications with users.

Dr. Parkinson said this is an excellent example of why GPS and its operational command remains the "Gold Standard." Responsibility was taken for the problem, information shared, a fix was identified, and assurance given on how the fix will ensure impacts to users do not happen again. In his view this should be the template every other GNSS should follow.

Maj General Chilton expressed thanks.

* * *

U.S. International Activities Update: Multilateral and Bilateral Advances
11th Meeting of the International Committee on GNSS (ICG) and International Outlook
Mr. Ken Hodgkins, *Director, Office of Space and Advanced Technology*
U.S. Department of State

Mr. Ken Hodgkins, in relation to the simultaneous efforts to maintain GPS as the "Gold Standard" while pursuing compatibility and interoperability with other GNSS, noted that 20 years ago he was in Moscow for the first exploratory meeting on GNSS compatibility and interoperability. That meeting was not productive, but it nevertheless marked the beginning. Ensuing international efforts over the past two decades are a testament to the U.S. government, particularly DoD, engaging the entire international community to develop GNSS and maximize U.S. taxpayers' investment. Outcomes include service continuity, stability, commonality, civil signal availability worldwide without charge, progress towards transparency, predictability, and the ability of manufacturers to obtain the technical data they needed to build receivers. Combined, these have made possible a level of innovation far beyond what could be foreseen back in 1996.

Key elements of U.S. National Space Policy are: (1) maintain U.S. leadership in GNSS; (2) civil services be provided continuously, worldwide, and without user charges; (3) encourage global compatibility and interoperability; (4) promote transparency; (4) enable market access; and (5) support international efforts to detect and to mitigate interference.

The 11th ICG meeting was hosted by Russia in Sochi, and involved 150 participants from 21 countries. The agenda included a meeting of the GNSS Providers' Forum, updates from system providers, an expert's session on applications, and meetings of all four ICG Working Groups. Key highlights include:

- The ICG recommends that the United Nations (UN) Committee on the Peaceful Uses of Outer Space (COPUOS) request annual member reports on activities to GNSS Interference Detection and Mitigation (IDM).
- Interoperability/Timing. An experts' level workshop in interoperability and timing is recommended for 2017.
- In early 2017 the Providers' Forum will publish an information booklet on Multi-GNSS SSV.
- The ICG recommends that GNSS Open Signal structure patents be discouraged and not used to collect royalties.

Other key topics discussed included the updates on the International Multi-GNSS Monitoring Activity led by Japan, GNSS-based Search and Rescue (SAR), and Space Weather, including ionospheric modeling.

While small progress has been made at each past ICG meeting, the cumulative effect is profound. Mr. Hodgkins then listed other recent activities and events at both the international and bilateral levels.

In summary, U.S. policy encourages worldwide civil GPS use in cooperation with other GNSS systems, supports the ICG, and regards international outreach as a priority. Issues such as IDM, space weather, and search and rescue, could not have been foreseen a few years ago. It is doubtful that any group other than the ICG could have undertaken the tasks. Thus, it is important not to take for granted efforts by the ICG.

Mr. Allen asked whether SAR at higher latitudes, particularly as they relate to Canada and Russia, were discussed.

Mr. Hodgkins responded that much of the SAR discussion was in regards to the Arctic Region, and the unique physical properties that limit what can be done above the Arctic Circle.

Ms. Neilan asked about status of the FCC waiver needed for use of Galileo signals within the U.S.

Mr. Hodgkins said it still under FCC review. The ICG has indicated it not see does a justifiable reason for not allowing all available GNSS signals use in the U.S.

Ms. Neilan added that ICG had been tracking GLONASS since 1998 and, in fact, most receivers in the market are multi-GNSS.

Mr. Stenbit said this matter will receive continued attention from the board.

* * *

European Space Agency (ESA) Perspective on Galileo as an Emerging Utility
Economic Benefits and Serving Space Users for Societal Benefit
Dr. Werner Enderle, *Head*
Navigation Support Office, European Space Agency

Dr. Enderle addressed the European Space Agency's (ESA) activities regarding a Multi-GNSS SSV activities. The key to a GNSS SSV is that when above the altitude of GNSS satellites it is possible to view spillover GNSS signals from satellites behind the limb of Earth. The history of GNSS signals use at Geosynchronous Orbit (GEO) altitude, and above, can be traced back to 1997, with Germany's EQUATOR-S mission. That was the first mission to track GPS signals above 61,000 km, which included both GPS signal main and side lobes. In 2002, the AMSAT amateur radio mission proved GPS was useable. To track such signals, key technical considerations include the design of the satellite antenna, satellite's orbital path and velocity, and in particular the GNSS equipment on-board a user spacecraft. ESA has always used multi-GNSS receivers. Also, analyses show that the improved L1 signal should have a positive impact to the SSV.

GNSS SSV tracking is an enabling technology to many new missions. User benefits include many technology aspects that enable new missions and satellite-servicing concepts. From a performance point of view the ability to track multiple GNSS systems in higher orbit improves signal availability to at least 4 GNSS signals at nearly all times, which allows for nearly continuous calculation of position, velocity and time. Finally, from an operational perspective it would help conduct operations in space with less interaction with ground.

ESA's activities regarding the development of an interoperable Multi-GNSS SSV include:

- Various studies related to the use of GNSS for support to Lunar Missions
    - AGGA4 (Advanced Galileo and GPS ASIC) – GPS/Galileo Miniaturised Space Receiver (GAMIR) space receiver development

- GNSS Space Service Volume Extension – Phase 1
- GNSS Space System Volume Extension – Phase 2
- On-Board Precise Orbit Determination (POD) – New POD Concepts
- New Generation of Space Receivers – AGGA5

The objective of the On-Board POD activity is to identify mission drivers and to understand the actual impact on the spacecraft itself as well as on ground-based tracking. The European Commission (EC) has also launched activities to look into the broader side of future mission requirements. These activities will be a major contribution to assess the requirements for the 2nd generation of Galileo satellites. In conclusion, ESA considers the GNSS SSV to be an enabler of many new missions, both scientific and commercial. Also, an interoperable GNSS SSV will drive developments elsewhere in spacecraft technology and navigation. Finally, an interoperable GNSS SSV will substantially impact spacecraft design and future operational concepts. Dr. Enderle added that his experience with ICG Working Group B had been different from that reported by Mr. Hodgkins. In his view considerable progress has occurred, including a first-ever commitment from Russia to participate in this activity.

In closing, Dr. Enderle noted that the views he's expressed do not, at this time, represent an official ESA position.

In response to a question from Mr. Stenbit on Galileo's requirements, Dr. Enderle noted that presently Galileo does not have a requirement to support space users. In 1999 the first specification for the Galileo transmission requirements did include such requirement, but was soon deleted. Now, sixteen years later, and with a better understanding, the matter is being reviewed.

Mr. Stenbit asked if all the work to-date has been focused on Galileo.

Dr. Enderle said at present there are no GNSS receiver in space that use Galileo signals.

Dr. Betz asked whether research is being done on existing receivers.

Dr. Enderle said at present his work is focused on developments at ESA.

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Boeing GPS Overview
Building Global Capabilities
Mr. Douglas Skinner, *GPS Program, Networks & Space Systems*
Space & Security, Boeing Defense

Mr. Douglas Skinner highlighted Boeing's forty-year history with GPS, starting with GPS Block I satellites. Boeing has been involved from the beginning in ground systems and is currently working with the government across a range of activities. Boeing is not only a GPS supplier, but is also a user. Along with other improvements, Boeing foresees GPS going digital and expects improvements to satellite and payload performance. Boeing is also interested in reducing mission costs, on-board electronics with lower size-weight and power (SWAP), faster and less expensive technologies, improved performance, and improving the ability to add greater capability to GPS. The latter is important towards ensuring flexibility in responding to evolving threats.

There are various focus areas for Boeing. First, as a system producer Boeing must help GPS retain its gold standard. Second, greater resiliency is needed both in GPS signals and assets. Third, as Boeing's experience with production capability increases it is expected there will be improved affordability. Fourth, Boeing strives to maintain flexibility both to new mission capabilities and mission threats.

In summary, Boeing is using product adaptations to ensure delivery of unique products. Also, digital payloads will enable valuable program and mission advantages. Finally, it is anticipated there will be significant progress towards low cost and low risk to improving GPS capabilities.

Mr. Stenbit asked what Boeing's two biggest ideas for future expansion of GPS may be.

Mr. Skinner said that, given that competitors are in the room, he cannot share such information.

Mr. Lewis asked how Mr. Skinner would compare the flexibility currently available on GPS IIF and GPS III SVs 1-10.

Mr. Skinner said GPS III SVs 1-10 provide considerably greater flexibility, but nothing like what is likely to happen in

follow on increment builds.

Mr. Lewis asked if Boeing is expecting to go 100% digital.

Mr. Skinner reiterated his reluctance to answer in the presence of competitors. In general terms, one wants as much flexibility as possible without doing anything detrimental to the existing missions.

Dr. Betz said flexibility is an enterprise-wide consideration. Flexibility matters not just at finite points, but also through the full undertaking. Dr. Betz noted it would be desirable in the future to have a presentation on enterprise-wide efforts.

Mr. Stenbit welcomed the suggestion.

* * *

Deep Space Atomic Clock (DSAC) & Optical Communications/Navigation
Emerging Capabilities for PNT Autonomy & Space Architectures
Dr. Don Cornwell, *Director*
Advanced Comm & Nav Technology
Space Comm & Nav (SCaN), NASA

Dr. Don Cornwell explained that SCaN is responsible for three NASA networks: Deep Space Network (DSN); Near Earth Network (NEN), and Space Network (also known as the Tracking and Data Relay Satellite System). SCaN works directly with mission using these networks and, therefore, it is very careful to incorporate their concerns regarding operations. Dr. Cornwell presented SCaN's Advanced Communication and Navigation High-Level Roadmap through 2025, where much of the technology involved is at TRL-6 (Technology Readiness Level 6) and, therefore, ready for operational use.

The DSAC project's objective is to demonstrate a small, low-mass prototype atomic clock with unprecedented stability for space navigation and science. It is a mercury-ion clock based on a titanium resonator. Because of budget limitations, the development is focused on new technologies such as the trap and optical systems. The clock's major advantage is long-term stability. The launch date for this clock has slipped to September 2017, and even the new date remains in question. The satellite will go into a Low Earth Orbit (LEO) orbit at 700 km, collect data for one year, and validate clock reliability in orbit. In 2015 the Aerospace Corporation released a paper supporting DSAC's work with the ion clock. The paper concluded that "Pragmatically, recognizing specific program funding limitations and the fact that a space-qualified Hg+ clock is already under construction, we recommend uninterrupted and adequate GPS support for development of the Jet Propulsion Laboratory's (JPL) space-qualified Hg+ clock." This statement is important as it is prescient in its benefits and caveat statements. Key information from this mission is to determine how the clock reacts to radiation and space-weather events. When comparing DSAC's performance to other space clocks there are a number of advantages, including: much lower accumulated range error, Allan Deviation outperforms all existing space atomic frequency standards, and both lower mass and low power requirements. This is important to because clocks with long-term stability are essential for long-duration space missions. Next steps in this project include extending clock lifetime, identifying SWAP reductions and manufacturing improvements, and integrating these into flight schedules and baseline costs. In the past NASA was a relatively rare user of deep space clocks, thus production never occurred in sufficient volume to fully refine manufacturing. This clock could have wider application and enable larger-scale production savings to occur.

Another important area for NASA are optical crosslinks to support satellite constellations. NASA's first laser communications mission was launched in 2013. The mission went perfectly and despite pre-launch concerns about tracking, every pass was instantaneously tracked over a three month period. As a result, the mission has been nominated for the Collier Trophy, which is generally awarded to an aircraft, and received the Nelson P. Jackson Award for 2015. Not all space applications require communications to bridge the distance between LEO and Near Earth Orbit (NEO). Therefore, smaller terminals for lower-rate crosslinks are being developed. Their design optimization depends, first, on prioritization of mass vs. power requirements and, second, on geometry simplification from platform selection and application. This includes, for example, a 0.5 kilogram unit that is capable to bridge 5,000 kilometers with 5 Mbps data rate. Finally, it is expected that the U.S. industry's commercialization of integrated photonics will allow many electro-optical components, even glass fibers, to be squeezed down. For NASA, this means that optical systems for communications and sensors could be reduced in size, mass, and cost by a factor of 100.

* * *

GPS – Poised for Tomorrow
Building Global Capabilities
Mr. John Voce, *Manager, Business Development*
Lockheed Martin Navigation Systems

Mr. John Voce began by addressing updated capabilities for the next GPS III increment build, which incorporates much of what has been learned from GPS III SVs 1-10. A capability assessment is in progress that will lead to a supplier competition. Baseline requirements include Regional Military Protection (RMP), SAR payload, and a laser retro-reflector array. The current GPS III payload is 75% digital, but it is foreseen that full digitalization will enable improved manufacturability and affordability. Digital waveform generators offer superior GPS signal performance. Another upgrade is the incorporation of high-efficiency high-power transmitters. RMP is ready to fulfill pending Capability Development Document (CDD), provides steerable M-code power, and employs an antenna designed for reduced complexity and affordability. In summary, GPS III SV11+ is in full development and will incorporate and benefit from pathfinders, simulators, and other techniques.

Mr. Stenbit asked Mr. Voce if there is anything he may want to urge be done on satellites to further improve GPS performance.

Mr. Voce said various aspects of satellite design and performance are still under discussion, and so are potential solutions that Lockheed would develop.

Mr. McGurn asked whether "Regional Military Protection" adds additional anti-jam protection.

Mr. Voce said it means there will be more power delivered to users on the surface.

* *` *

Northrop Grumman PNT Overview
Building Global Capabilities
Dr. Dennis Hall, *Director of Emerging Communications*
Northrop Grumman

Dr. Hall explained that Northrop Grumman has a 50-year history in space. In his view it is pleasing to see current emphasis on basics, high dependability, and long life, as these fall within his organization's area of expertise in satellite operations. Northrop Grumman's objective is to become a GPS supplier and satisfy the Advisory Board and others with its products. Also, by attending meetings such as this one Northrop Grumman is able to bring solutions to bear. Like Boeing, Northrop Grumman has a local factory. It is located in Redondo Beach and is capable of building satellites. He hopes Northrop Grumman will get the opportunity to do so.

Referencing a comment made by Col Gleckel, Dr. Hall said Northrop Grumman is a Phase I participant for the next GPS III increment build. His organization is learning a great deal about how satellites are purchased as well as the necessary responsiveness to requirements. Northrop Grumman is already an L-band amplifier contractor. An emphasis has been placed on solid state amplifiers to push for higher efficiency, thereby reducing the impact on the spacecraft and lowering the cost. Like Boeing, is a contractor for a Beyond Orbit Reprogrammable Waveform Generator, and is working from the definition of re-programmability that the U.S. Air Force has put forward. Northrop Grumman's upper management is committed to GPS. In his view Northrop Grumman's general approach is superior to those of its competitors in ways that, at this time, he cannot publicly disclose. Dr. Hall thanked Col Gleckel and his team for their willingness to dig into and understand Northrop Grumman's somewhat different approach as well as being forthcoming about any concerns they may have had.

* * *

GPS/GNSS Space Service Volume (SSV) Update Initiatives
U.S. and International Benefits – GOES-R in Action!
Mr. Joel Parker, *Aerospace Engineers*
Navigation and Mission Design Branch
NASA Goddard Space Flight Center

Mr. Joel Parker noted that the briefing would cover two separate efforts, one to update the GPS SSV and another one to develop an interoperable Multi-GNSS SSV. In relation to the GPS SSV, NASA's Magnetospheric Multi-Scale (MMS) has been awarded the Guinness World Record for the highest-altitude GPS fix ever recorded – 70,135 km – and it is expected that this record be raised to 160,000 km by February 2017 when MMS is scheduled to raise its apogee.

When tracking GNSS signals in High Earth Orbit (HEO) one is, in essence, "squinting" over the edge of the Earth to "see" the signals broadcast by satellites on the other side of Earth. The greater the diversity of signal angles that are tracked the more accurate the navigation solution. SSV is defined as the volume of space between the altitudes of 3,000 and 36,000 km. The three criteria used to define the characteristics of GNSS signals within the SSV are: signal availability, minimum received power, and pseudorange accuracy. Work on developing the GPS SSV has been ongoing since 2000, and the current GPS SSV specifications were formalized in 2006 for what used to be GPS III 'Block A' and has now become GPS III SVs 1-10. Since then our understanding of GPS performance within the SSV has improved and a large number of missions have come to rely on this capability. There are concerns that if the 2006 GPS SSV specifications are not updated to capture some of these capabilities, then missions relying on them could be at risk. Thus, NASA is currently proceeding on requesting an update of GPS III SSV specifications to include some of the capabilities GPS is already delivering.

A key civil stakeholder, and case study for efforts to update the GPS SSV specifications, is the Geostationary Operational Environmental Satellite-R (GOES-R). It is a series of four satellites that provide the principal sources of weather information. The most recent satellite was launched on November 19, 2016, and is currently moving into its final orbital position. The newest satellite will be subject to tight control, tight jitter requirements, and stringent navigation stability requirements, in order to deliver the highest quality of weather data to users. Compared to older GOES satellites, GOES-R provides three times as many channels, four times better resolution, and five times faster scans. The older system in essence took intermittent photographs of the Earth, whereas GOES-R will take a continuous visual record. Thus, to meet these mission requirements, NASA has developed a new set of proposed GPS SSV requirements to meet GOES-R mission requirements with as little impact as possible to GPS.

> Mr. Stenbit asked when the new GOES-R capabilities will become available.
>
> Mr. Parker said GOES-R will become operational during the next few months and remain in operation until the 2030s.
>
> Mr. Lewis asked whether if GPS does not meet those SSV requirements by 2030 it also means that GOES-R will never meet its mission requirements.
>
> Mr. Parker replied that one could only simulate what it knows. Initially GOES-R as a single spacecraft will be fine because current GPS satellites already deliver well in excess the performance to meet the mission requirements. The risk occurs when, over time, GPS III SV 11+ satellites replace older ones and become the majority of the constellation sometime in the 2030s. In March 2016 the proposal was submitted to the GPS Interagency Forum for Operational Requirements (IFOR), but since then discussion within the IFOR has stalled.

Mr. Parker presented conclusions and next steps for GPS SSV:

- NASA has proposed updated GPS SSV requirements to protect high-altitude space users from risk of reduced future GPS capability.
- Available data suggested that these updated requirements can be easily met.
- NASA seeks USAF engagement in implementing a minimal-impact requirement.
- NASA believes the proposed requirements are critical to support future SSV.
- The proposed requirements are an innovative, whole-of-government approach.
- NASA encouraged input from the SSV Independent Review Team.

NASA has also supported activities to develop a Multi-GNSS SSV within the ICG. The ICG has four working groups, and all GNSS providers are members of WG-B, which is where Joint SSV Analysis discussions occur. In 2009, NASA documented the GPS SSV capabilities and recommended that other GNSS providers supply similar data. As of 2016 all GNSS providers (including regional systems) have publicly announced their capabilities to provide support within the SSV. At the ICG-11 session in Sochi, Russia, all providers confirmed that they are working together to provide a basis to provide technical outreach to

space agencies. The objective of the ICG WG-B Joint SSV analysis effort is to demonstrate the advantages of having an interoperable Multi-GNSS SSV, including GNSS constellations such as BeiDou, Galileo, GLONASS, and GPS as well as regional systems such as Navic and QZSS.

In summary, the GPS SSV, first defined for GPS Block IIF in 2000, continues to evolve in fantastic ways. GPS has also led the way in developing formal specifications for GPS III. Work continues today on parallel tracks to ensure that the GPS SSV, and future Multi-GNSS SSV, keep pace with user demand. It is essential to follow both approaches in parallel to: (1) ensuring robust GPS capabilities to enable and enhance new missions; and (2) develop an interoperable GNSS SSV to ensure redundancy. Discussion of these and other points will continue at the "Workshop on Emerging Technologies for Autonomous Navigation," to be hosted by NASA at its HQ in Washington, on February 15, 2017.

Mr. Lewis expressed some uncertainty regarding GOES-R. Requirements aside, what is the performance currently being provided by the U.S. needed to meet what GOES-R needs to get its job done?

Mr. Parker noted that the performance required to meet the minimum mission requirements has been presented in the briefing slides.

Mr. Lewis said his concern is with current performance rather than the requirement. Historically, U.S. Air Force performance tends to exceed requirements. Is it the requirement or the actual performance that is more important?

Mr. Parker responded that capability and specification are different things. Science applications can eke out as much of the GPS capability as they can to do highly interesting science. However, if an application is critical to weather forecasting, one might be less tolerant of risk design based on performance rather than based on requirements.

Mr. Lewis asked whether, assuming ICG recommendations are adopted, there are restrictions on other than military users.

Mr. Parker said he cannot answer for other GNSS systems. NASA undertakes science.

Ms. Neilan asked whether the planned workshop might have crossover with applications such as, for example, self-driving cars.

Mr. Parker said that in principle no, but there will be some technology overlap.

Mr. Miller noted that NASA is a science agency, but once science is proven it typically evolves into an operational capability. For the GPS SSV, capabilities needed to meet the GOES-R mission are already out there and being exploited by other space missions. NASA took action over a decade ago because there were variations in the antenna patterns for the different GPS satellite blocks and, thus, there was a need to 'stabilize' the antenna patterns over subsequent blocks not only on the basis of what currently exists but, also, what we might want in the future. NASA does not want to be an "unauthorized user," as is currently happening with GOES-R.

Mr. Lewis said, taking the long view, it is somewhat concerning to say one won't need more flexibility in thirty years than what it has now.

Mr. Stenbit noted that a similar conversation occurred at a previous meeting. In summary, NASA has discovered operational utility of increasing dominance and importance not because specifications were raised, but because performance has improved. There is pressure to bring specifications up to some of the performance being delivered, and there is considerable pushback from the Air Force on what the cost is. Mr. Stenbit added he would like to leave that observation where it stands and asked whether any existing body is making an independent assessment of the matter.

Mr. Parker said he is not aware of any such body.

Mr. Stenbit said he is sympathetic that the Air Force does not wish to spend billions of dollars to make requirements congruent with performance.

Maj General Chilton said the Air Force is sympathetic. An independent group should be reporting to the IFOR in February 2017.

Mr. Stenbit said the government is sometimes slow in convening substantive discussions when there is real money on the table. It appeared that a new statement is being made; namely that, with conditions, NASA is willing to assist on such costs. This is a good sign.

Maj General Chilton said the pertinent team had been very busy on OCX, but the team is now back on task. A bureaucratic process exists and needs to be followed.

Mr. Stenbit said that he thought it better to proceed as a matter of expectations management rather than formal requirement.

Dr. Parkinson said three things were floating around. First, when one discusses the main beam one is not discussing the side lobes, which from NASA's standpoint represent a significant performance improvement. Second, "specifications vs. requirements" is a phrase that can easily become a sledge hammer. NASA and the Air Force have greatly different views of what that means. Third, NASA just wishes to painlessly use the side lobes and is willing to let others use them at their own risk.

Mr. Stenbit said this topic would be on the agenda for discussion at the next Advisory Board meeting.

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Real-Time GNSS for Earthquake and Tsunami Early Warning
Implementing GNSS as a Worldwide Public Safety Infrastructure
Dr. Gerald Bawden, *Program Scientist*
Natural Hazards Research, NASA HQ

Dr. Gerald Bawden noted that, along the lines of Dr. Parkinson's earlier comment that in the early days of GPS a great many uses for the system had not been foreseen, one such use is to use GPS signals to assess disturbances in the ionosphere and save lives from tsunamis, earthquakes, and other natural disasters. A number of major tsunamis have occurred over the past 15 years, most notably the 2004 Indian Ocean Tsunami that claimed over 250,000 lives in Banda Aceh, Indonesia, even though the tsunami did not reach the coastline until two hours after the earthquake that caused it.

A case can be made for using GNSS to mitigate such catastrophes. Mitigating the effects of a tsunami requires answering the following questions when an earthquake occurs: where did it happen, how large is it, is it capable of generating a tsunami, has a tsunami already been generated, how long until it makes landfall, and how deep will the water be at landfall? These are the questions that can be answered, to a greater or lesser extent, thanks to GNSS. It can assist in identifying the location and magnitude of an earthquake and its capability of producing a tsunami. During 2011 Japan Tsunami the high density of GPS monitoring stations in Japan enabled collecting a large amount of data. Over the past five years, US$10 million have been invested for a multi-agency study led by NASA. Data of the physical displacement of the monitoring stations in Japan due to the earthquake shows that the undersea land shift was as much 50 meters; by the time it reached Japan the maximum horizontal displacement on land was 5.3 meters, and the maximum vertical subsistence was 1.2 meters. Clearly, if one lives near the coast and the land is going to drop 1.2 meters, one needs to move inland immediately.

Dr. Bawden presented two case studies, one depicting a model for determining fault location, and another one reflecting the real-time displacement on a fixed fault surface. The purpose of these examples is to show how GNSS could address the questions posed earlier. The first case study is for the 2011 Japan Earthquake, where the GPS data collected and modeled by NASA would have predicted an earthquake of 8.8 on the Richter scale within 140 seconds of initial landslip. This is very close the actual 9.0 magnitude as measured by seismometers, thus showing that GPS data can be used to determine the likelihood of the tsunami. The second case study uses data taken along the Cascadia subduction zone in the Pacific Northwest, the San Francisco Bay Area, and the southern San Andreas Fault. NASA and the National Oceanic and Atmospheric Association (NOAA) were involved in this study, which shows that while traditional seismic measurements techniques took two hours to determine the effect of the resulting tsunami, the GNSS-based approach would have taken only 157 seconds (under 3 minutes) to assess the effects. This shows that in 2004, had this new technique been available, people at the beach in Banda Aceh would have been able to begin evacuation within 5 minutes of the earthquake rather than being surprised at the beach when the tsunami reached them two hours after the earthquake, which is about the same time traditional seismic measurements would have taken to assess the potential impact of the tsunami.

It is important to remember that not all earthquakes produce tsunamis and, thus, detecting an earthquake does not automatically imply that a tsunami will occur. At present Deep-ocean Assessment and Reporting of Tsunami (DART) buoys are the only way to determine ocean level disturbance caused by tsunamis. Depending on their location, it takes 30 minutes before the DART buoys note a disturbance in the sea level. However, because such disturbances are transmitted 'upwards' and case pressure onto the atmosphere that within 25 minutes reaches the ionosphere. In turn, the ionospheric perturbation can be determined by tracking its effect on GNSS signals as they travel from space to the surface. An analysis of the data collected during the 2011 Japan Earthquake has shown it could have been used to track the movement of the tsunami. Also, in the future as the number of GNSS satellites increases so will the number of tracking stations measuring GNSS signals on the ground, thus enabling a better assessment of sea level disturbances and the ability to issue a tsunami warning.

Dr. Enge noted that the ionosphere can be unpredictable and, potentially, cause false alarms.

Dr. Bawden said false alarms are always a concern. NOAA has reported difficulties with rogue waves; that is, waves that appear in the data even though they had not been predicted. The last such incident occurred on July 13, 2015, when a wave of 1.5 meters was predicted to hit the East Coast. GNSS data for that date did show the wave. Another advantage of GPS data is that it enables understanding the nature of the earthquake. The 2004 India Ocean Earthquake was, in fact, a 'scissors-like ripping' of the ocean floor. This results in a completely different tsunami than what would follow a point-source earthquake.

Dr. Bawden identified three requirements of a GNSS-based earthquake and tsunami warning system: (1) higher density network of tracking stations with real-time sharing of GNSS data in seismically active regions; (2) partnership between regional and national early warning centers; and (3) partnership between the international GNSS community and the earth observation community. Currently there are 14,667 known and publicly accessible GNSS sites, of which 2,287 are real-time sites. Chile, for example, has recently added 150 GNSS sites, one for every 40 km along its coast. Data streaming from these sites to NASA is pending at this time. In addition, NASA is funding a conference in Japan to broaden cooperation within the scientific community.

Mr. Allen noted he has been involved in efforts to predict river rise. Could a similar technology be applied to predict river rises and floods?

Dr. Bawden said not directly, but a GPS receiver near the water could be used to report changes in water levels.

* * *

Update on Protecting United States Critical GPS Infrastructure
Department of Homeland Security Infrastructure Protection Initiatives
Mr. James Platt, *Director, PNT Office*
Department of Homeland Security

Mr. James Platt noted that he is new to the position as Director of the DHS PNT office. Recent DHS actions relative to PNT include: (1) forming the DHS PNT program office; and (2) the signing in Oct. 2016 of the DHS Positioning, Navigation & Timing executive steering committee charter, which involves members from across DHS to enable the agency having a unified position. Other activities at DHS include receiver testing, validating requirements for the timing sector, and a Request for Information (RFI) for an Analysis of Alternatives.

Receiver testing is being conducted to raise DHS awareness of system vulnerability. DHS is taking a layered approach to risk management. The long-term objective is to increase resilience through equipment diversity, improved equipment, improved awareness, and better assessment of vulnerabilities and their impact on infrastructure. If appropriate protection cannot be achieved, then this will be used as a basis to lobby Congress to fund a backup to GPS. In July 2016 testing was conducted at WSMR with participation from over 200 individuals from 61 agencies. Twenty-one types of jammers, and fifty in all, were used. One of the objectives was to show the user community how their receivers react to jamming. Many users were not aware of the effects of jamming. Further, many do not understand how the larger system, of which PNT is a part, would be affected. Testing will continue in April 2017, and will involve GPS receiver manufacturers in an Open Air Test Bed in Indiana. Follow-up testing incorporating critical infrastructure owners and operators will occur in July 2017 at the Idaho Test Labs. It is hoped this approach will create a supply and demand situation, where users will want to acquire improved receivers and, in turn, manufacturers will have a market for those receivers. Further, this testing should help users decide which receivers provide the highest security.

Mr. Lord asked will the testing tell someone what it is they need? Is a list of receivers going to be recommended?

Mr. Platt responded that testing is not aimed at convincing people but, rather, to raise awareness of how their systems would react if fed bad data.

DHS is also working on establishing Complementary PNT (CPNT) validation. This has been an issue for years and, to-date, there is still no certainty on how timing requirements should be protected. DHS had decided to tackle this task by means of a cross-sector assessment that provides information to support decisions regarding sector-specific studies. Work began in October 2016 for the energy/electric sub-sector. Requirements validation should be completed by September 2017. DHS is focusing on areas with stringent timing requirements. The validation of timing requirements for critical infrastructures is not an easy process. Some critical timing users have been reluctant to integrate GPS into their system because they question whether GPS will always be available. Participation by industry experts is essential. DHS is also working with many voluntary associations. DHS is working hard to develop the requirements for a backup system. The current absence of defined requirements is a major

stumbling block towards the creation of such a backup system.

Mr. Burgett noted that interference is a rather broad topic. Is Mr. Platt talking specifically about in-band jammers or other types of interference?

Mr. Platt said jamming needs to be examined broadly and, at present the focus is on intentional interference.

Mr. Powell, in reference to the July 2017 testing procedure in Iowa, asked if the DHS testing will be an open air test.

Mr. Platt said that is what is being planned.

Mr. Goward asked how DHS responded to the GPS disruption in January 2013.

Mr. Platt said the event occurred prior to assuming his present position. For all practical purposes, January 2013 amounted to a spoof of the entire system. A variety of actions were undertaken, but there was very little consistency on how receivers reacted. This underscored the view that receiver manufacturers and users need to better understand how receivers react to disruption.

Mr. Stenbit said he is very pleased to hear Mr. Platt's views, as he thinks they will improve the Advisory Board's relationship with DHS.

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Alliance for Telecommunications Industry Solutions (ATIS) GPS Vulnerability Report
Mr. Michael Calabro, *Contributing Engineer*
Alliance for Telecommunications Industry Solutions

Mr. Calabro presented a GPS Vulnerability Report prepared by ATIS. ATIS is a standards body consisting of various North American stakeholders in telecommunications. The objective of this briefing is to put ATIS "on record" regarding GPS testing and vulnerability, particularly the telecommunications sector's critical reliance on GPS. Telecommunications are critically dependent on GPS for precision timing functions. GPS synchronizes national and international network operation and scalability. Without such synchronization, network functionality would begin to break down. GPS is the only system that can meet the increasingly stringent timing requirements. Current timing requirements range from 100 milliseconds for applications such as billing and alarms, to 30 nanoseconds for enhanced primary reference time clocks. At this time only GPS can meet the latter.

The ATIS report identifies five key vulnerabilities to GPS, the occurrence, and potential mitigation:

- Spoofing (occurrence: rare; mitigation: Maximize Out-of-Band Transmission)
- Adjacent Band Transmitters (occurrence: under study; mitigation: Antenna Technical Tracking)
- GPS Segment Errors (occurrence: rare; mitigation: Alternate Timing Sources)
- Environmental (occurrence: common; mitigation: Enhanced GPS Signal)
- Jamming (occurrence: common; mitigation: Robust GPS Receiver Technology)

There is no "silver bullet" to solve all these problems. Each needs a different response. ATIS is exploring alternative timing sources that could operate down to 30 nanoseconds.

ATIS recommends the following:

- Responsible federal agencies should consider adding signal-side security measures, such as Navigation Message Authentication (NMA), to the L2C and L5 modernized civil signals as a protection against spoofing.
- The Sector Coordinating Council representing the civil signal user community should poll users of civil signals for their level of interest in having NMA on the modernized civil signals.
- Regarding licensed adjacent band transmitters, ATIS considers it crucial to consider how signals in adjacent bands may impact the sector.
- Regarding COAST SYNC, ATIS recommends the development and implementation of an eLoran system, or its equivalent.
- Use of global systems for timing and telecommunications.

ATIS hopes to be the general touchpoint for the telecommunications industry, and develop interactive means to communicate with relevant bodies. Regarding testing, ATIS wishes to encourage transparency and openness in all GPS-related testing. For example, it is important to understand the differences a timing receiver vs. a navigation receiver, where timing testing requires stability of the delay through the antenna. In summary,

First, the ATIS COAST SYNC committee represents the timing issues of North American telecom networks.

Second, such networks are critically dependent on GPS-derived timing using stationary antennas. Future requirements are likely to be more stringent.

Third, all alternatives to GPS timing have significant limitations.

Fourth, any proposed adjacent band signal must be tested to ensure it does not degrade network functions.

Gov. Geringer called attention to a reference "particularly for new and newly-developed requirements." Those requirements are set by whom?

Mr. Calabro said telecommunications is a very standards-based industry. Such standards are developed internationally. Specific requirements, such as the 30 nanosecond requirement for high precision timing clocks, will flow down to other users.

Gov. Geringer noted that if this is a requirement of the telecommunications industry, how does this feed back into the receiver manufacturers or the program office? Do responsibilities flow in that direction?

Mr. Calabro responded that they do not. Receiver manufacturers either supply devices capable of meeting a standard, or they do not. Their actions are commercially driven.

Gov. Geringer added that if ATIS is relying on GPS for its timing function, then adjacent band interference could have very serious repercussions for the telecommunications industry.

Mr. Calabro agreed. That is why ATIS is very concerned with testing in this sector.

Gov. Geringer asked if the FCC is aware of ATIS' concerns.

Mr. Calabro said that, at present, ATIS has no formal relationship with the FCC.

Ms. Neilan asked Mr. Calabro to explain how his organization works with international bodies.

Dr. Marc Weiss (audience member) noted that he also participates in the International Telecommunication Union (ITU) group that focuses on timing and synchronization. There are mechanisms where bodies such as ATIS can submit documents to the ITU, where a number of requirements are developed. This is an area of increased activity in recent years.

Mr. McGurn noted that toughening receivers does not help if the GPS signal fails. What is needed is use of another system. Had ATIS made the FCC aware of its interest in this area?

Mr. Calabro said some ATIS members participate in FCC working groups, where they have advocated for a GNSS backup.

Mr. Stenbit noted that the Advisory Board has published a list of criteria. He called Mr. Calabro's attention to the statement that all types of receivers need to be assessed, including issues associated with timing and the urging that some government R&D be directed to this question. He welcomes any ideas ATIS might have on the subject.

Mr. Calabro said ATIS would be happy to share what it knows.

Mr. Lewis said it is his understanding that many communication towers with rubidium clocks can swing through a short interruption. Is this still the case?

Mr. Calabro said that depends on the nature of the interruption.

Mr. Lewis said he did not see this addressed in the ATIS presentation.

Mr. Weiss noted that requirements are moving towards more localized operations, where rubidium clocks would not be employed due to their cost. The requirements for telecommunications had gone from frequency, where holdover is much harder, and the requirements re getting tighter. Also, fifth generation (5G) requirements have not been mentioned because they have not yet been specified. Some models are seeking a 30 nanosecond standard, but the holding time at that level is quite short.

Mr. Stenbit said he believes it important to get the issues out so that discussion will ensue.

Dr. Parkinson said that in discussions with ATIS he has presented the six points the Advisory Board has adopted, along with fourteen additional points. In his view ASTI has not been particularly responsive, though understand that ATIS is resource-limited and may not be able to respond to questions regarding GPS signal acquisition and reacquisition. Still, ATIS should find it useful to review the fourteen points.

* * *

Standardization of GNSS Threat Reporting and Receiver Testing Through International Knowledge Exchange (STRIKE), Experimentation & Exploitation
STRIKE3 Initiative
Dr. Mark Dumville, *General Manager*
Nottingham Scientific Limited (NSL), United Kingdom

Dr. Mark Dumville explained that STRIKE3 is a new European initiative of monitoring stations to assess the number of threats in the GNSS bandwidth. The three-year effort began in February 2016. During the first year the network of monitoring stations is used to create a threat database. In the 2nd year of this effort GNSS receivers will be tested against this database of actual threats. Finally, in the third year receivers that pass the test will be deployed.

Six percent of European Gross National Product (GNP) – about 800 billion Euro – is dependent on GNSS. GNSS is, however, increasingly vulnerable and subject to threats and degradation. The purpose of STRIKE3 is to monitor, detect, characterize, mitigate, and protect from such threats. In short, STRIKE3 is compiling a virus catalog to be used to create an anti-virus catalog. At present there are 25 monitoring sites, a number that will hopefully be raised to 40. Also, discussions are in progress to locating sites outside Europe.

The system enables, for example, that should 20 jamming incidents be reported along a highway, then it is possible to determine whether this is due to 20 separate jamming devices or one device being driven back and forth. This information then point to an appropriate response. Both intentional and unintentional interference can be detected. A unique "fingerprint" can be made for each occurrence and, thus, individual jammers can be uniquely identified, assessed as to intent, and tracked down. To date the STRIKE3 database has 58,000 jamming events, including events such as interference at a power substation, a major airport, a GNSS tolled motorway, and the downtown in a major city. For example, one major episode lasted for 3,167 seconds, resulting in a loss of GNSS and a positioning error of 70 meters. The STRIKE3 effort enables advising individual organizations where to focus their augmenting or toughening resources.

Mr. Stenbit expressed surprise that a jamming episode lasted for 50 minutes. What was the cause?

Dr. Dumville said he is not certain.

Mr. Goward reported that an East Coast container port was partially shut down for seven hours. Apparently, a truck driver arrived to collect a container; the container was not ready, and the driver left a jamming device on while waiting for the container to be ready. In view of this, it would be desirable for the U.S. to have an equivalent to STRIKE3 gathering such information.

Dr. Parkinson asked if the STRIKE3 system can be purchased for use in the U.S.

Dr. Dumville said the system can be implemented at modest cost.

Mr. Neilan noted that the waveforms for this event suggest 300 different types of jammers. Have the waveforms revealed what sort of jammer was used?

Dr. Dumville noted that at a conference the previous year individual jammers were tracked.

* * *

Communicating Time Looks Like a Simple Problem, But if it's so Simple, Why Haven't We Solved It?
Mr. Harlan Stenn, *Founder and President*
Network Time Foundation

Mr. Harlan Stenn explained that the Network Time Foundation (NTF) is the current home of the former Network Time Project (NTP). NTP was started by David Mills in the early 1980s and is now the longest running undertaking of this kind. Initially, no legal entity was established. NTF has been created as a 501c3, and supports the following projects: NTP, Ntimed, PTPd, LinuxPTP, RADclock, and the General Timestamp API. It is expected that NTF will be implemented this year and will focus on enabling reliable communications and time dissemination / time transfer.

The U.S. Naval Observatory (USNO) and the National Institute of Standards and Technology (NIST) exchange time with national laboratories and others and, from this collaboration, produce time. This time is published by GPS and others. NTF works on protocols to help distribute that time to users, with approximately 16 billion requests for time each day. It is important that end users obtain time from multiple sources as any single time source could be incorrect. However, users typically don't do this and, in consequence, they cannot validate whether the time stamp they are using is accurate.

Over time clocks have become more accurate, but issues persist. First, timestamps are only useful locally, due to such factors as daylight savings time, leap seconds, or unforeseen events such as the Northeast blackout of 2003. Second, many clocks are not properly synchronized. For example, in one case, hospital records showed a patient having been defibrillated at 2:15 p.m. However, the clock on the defibrillator, which was not synchronized, showed the procedure taking place at 2:26 p.m. As a result, the patient's attorney claimed the hospital had delayed urgent treatment. This is why it is important to have multiple sources for time. Timestamps usually lack sufficient contextual information, which is needed so they can be reliably used.

NTF's General Timestamp API would address the need for monotonic time and databases. Pertinent questions that need to be addressed are: What systems are undergoing correction? What error bounds exist? What timescale is being used? When two timescales are in use, is there an event influencing their comparison? One needs to know the degree of specificity a clock requires. For example, in January 2016, GPS synchronization was off by 13 microseconds over a period of five hours which, in turn, could translate into a positioning error of over two miles.

A timestamp structure must include: system time, amount of pending correction, leap second correction, expected/maximum error, timescale, clock discontinuity counter, host and clock ID, and a provable signature. For this timestamp to work it must be supported in the kernel and have both library and application support. This cannot be achieved with NPTv4, as its core characteristics cannot be changed. Current systems also assume that all other participants play by the same rules which, increasingly, is not the case. With the General Timestamp API, however, one would know the timescale the other system is using. Multiple time sources are needed. Two sources are not sufficient because, in the event there is a difference, one cannot know which one is right. The same problem occurs with three sources should one of them go down. Therefore, to ensure some level of redundancy it is recommended that four sources become the common standard. However, it should be noted that even with four sources, problems could arise if leap seconds are treated differently in each source.

In summary, inadequate time stamping can potentially have expensive consequences should something go wrong. Thus, adequate certification and compliance are needed to ensure rigorous records are kept.

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Advisory Board Discussion:

Mr. Stenbit noted that, because on the following day he would have to leave earlier, the board would now have its member discussion. The remaining presentations would be given on the following day. Also, board members should focus more on the future issues rather than only addressing short-term problems. Mr. Stenbit requested member comments.

Mr. Powell: Pass.

Dr. Rashad: Pass

Dr. Camacho-Lara said that the question of authorization to use multi-GNSS signals in the U.S. requires attention because, among other things, it is important issue when trying to increase the involvement in spectrum protection from the international community.

Dr. Axelrad seconded Dr. Camacho-Lara's comments.

Mr. McGurn said he believes the FCC wants the authorization to receive multi-GNSS to happen.

Mr. Goward said, first, the Advisory Board needs to know more about current proposals in Europe to auction spectrum adjacent to the GNSS band. Also, the President's Commission on Cybersecurity has made a recommendation related to PNT that is more robust than previous statements. Finally, there may be potential cost savings in dispensing with hard-copy presentations.

Mr. Allen said that a discussion is needed to anticipate what the incoming administration might want to do about resilient infrastructure. Further, the board should align itself more closely with on-going efforts in the cybersecurity area.

Mr. Burns urged board members to keep in mind that considerable time is needed to deploy new equipment through commercial aircraft fleets. For example, while the adoption of the Automatic Dependent Surveillance-Broadcast (ADS-B) is mandatory, work to implement it has been in progress for seven years.

Ms. Ciganer noted that the issue of spectrum protection will be addressed the following day. Today's briefings on GPS innovation were interesting, and it is refreshing that robust innovation continues to occur.

Ms. Van Dyke thanked the board for its support on the issue of Adjacent Band Compatibility testing. Also, she commended DHS for its work and partnership in this area.

Mr. Martin echoed these comments and said he looks forward to the advice that would be forthcoming from the next PNT EXCOM meeting.

Mr. Miller said Mr. Goward's suggestion that hard copy presentations be dispensed with is worth considering.

Dr. Parkinson noted that the board has a responsibility in educating members of the incoming administration. Rather than waiting, the board must act quickly to learn who these people are and then contact them. The PNT EXCOM is likely to consist of who, while highly intelligent, are largely uneducated on the issue of PNT. As we've seen in the past, as soon as a person became knowledgeable, their terms of office end, so we're back at the starting point. The board needs to accept this fact and act accordingly.

Mr. Stenbit suggested that anyone with knowledge of pending appointments should relay the information to Mr. Miller.

Gov. Geringer said the board should explore what additional taskings it may receive from the new PNT EXCOM. The board should not wait until it is asked to educate but, rather, should prepare a list of what it would like others to learn. The board needs to identify its message and how to deliver it.

Mr. Miller noted that transition teams are just now being formed. Relative to PNT issues, departments and agencies should synchronize the message they want to deliver. Education should also focus on the large number of new people below the PNT EXCOM level. Also, it is important to keep in mind how on-going work on space-qualified atomic clocks has wide-reaching implications to many space-based applications.

Maj Gen Chilton expressed thanks for the invitation to attend today's meeting. The DoD intends to continue supporting the efforts of the Advisory Board and, also, appreciates the efforts of the DOT.

Col Gleckel stated his appreciation for the work done by the Advisory Board, both on GPS and in other areas.

Mr. Lewis noted there may be some risks ahead with the desire to reduce overall costs. For example, as the total number of GNSS satellites reaches ninety, someone at the Office of Management and Budget (OMB) might conclude, erroneously, that the U.S. could perhaps reduce its own system to only eighteen-plus-three satellites which, at one time, was the number declared as minimally acceptable. The board needs to make a formal declaration of the currently minimal required number of U.S.-operated satellites needed to address issues such as operational sovereignty.

Dr. Betz said the board needs to take a long-term view of the spectrum and spectrum protection. For example, are decisions being made today a good match for the likely spectrum needs of 2025 and 2035? How may such spectrum needs evolve over that time?

Dr. Enge noted there is a distinction between work that is interesting and work that is important. For example, the board could, with some confidence, make the statement that reasonable redundancy for timing exists at the 1 microsecond level. The work conducted in the UK, and briefed to the board, has sharpened our understanding.

The central problem relative to resilience is that no one approach is likely to be effective for all circumstances or applications. Today's briefing from Ms. Van Dyke's presentation is probably one of the most important ones we've

heard, and it is important we give it careful attention.

Mr. Stenbit said the board could serve the country by establishing specific testing regimes that could be widely employed.

Mr. Burgett said the presentations on science and applications are very impressive.

Ms. Neilan said she, too, is very impressed with those presentations and, thus, will carry them to the ICG meeting. The ICG would hold its annual workshop in July 2017. Also, she has already invited various board members to attend as it is an excellent opportunity to meet others working one these issues.

Dr. Beutler said he will hold his major remarks for the following day. In general, there is a need for a new paradigm for scientific requirements of multi-GNSS. Further, science presentations could be made more coherent by perhaps create a small group to focus on them.

Mr. Stenbit said he will encourage that.

Mr. Hatch said the NASA atomic clock presentation is particularly impressive. This pointed to two major downstream improvements: first, it would make combined tracking possible and, second, would allow the integration of inertial systems.

Mr. Dimmen noted the board has an on-going concern with affordability. ESA has recently launched four satellites on a single rocket. As others have commented, a multi-GNSS world is not something for the future, but rather something that has arrived. This underscores the importance of international cooperation.

Mr. Shields said he hopes real pressure is exerted on the FCC to "make legal" devices that are already being implemented on smartphones, vehicles, etc. The U.S. is at risk of looking silly to its international partners. Also, sharp focus is needed when explaining the value of GPS to the new administration.

Mr. Stenbit said that demonstrating the value of GPS does not require global statements of economic worth but, rather, specific examples that can also readily persuade an average person.

Dr. Parkinson said the agriculture sector needs to be highlighted. The value of precision agriculture is staggering, but the "voice" of agriculture is rarely heard.

Mr. Shields said we should also pay attention to whom the farm states have just voted. Senators and representatives from those states should be made keenly aware of the value of GPS to agriculture. This should be done in a straightforward way, showing the "before GPS" and "after GPS." The "after GPS" part could, for example, include pictures of tractors driving at night. While pictures need to be supported with numbers, those pictures are what is likely to be remembered by those senators and representatives. This should be done in other pertinent areas, e.g. pictures of GPS equipment in the New York Stock Exchange, etc.

Mr. Stenbit adjourned the session of Wednesday, December 7, 2016 at 5:12 p.m.

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Mr. James J. Miller called the Thursday, December 8, 2016 session to order at 9:02 a.m.

Opening Remarks

Mr. John Stenbit, Chair, reported that Dr. Beutler and Ms. Ciganer have devised a statement on the pressures related to future scientific uses of GNSS. He asked the board in what other areas could we also issue a statement?

Dr. Parkinson suggested scientific, aviation, transportation (non-aviation), agriculture, and precision timing as possibilities.

Mr. Stenbit noted that as he needs to leave early, the Advisory Board would first address the agenda items originally scheduled for 9:30 a.m. to 11:00 a.m. Thereafter, the Advisory Board will resume its roundtable discussion from the previous day.

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Representative and International Reports & Perspectives

1) Ms. Ann Ciganer (U.S.), ***GPS Innovation Alliance (GPSIA)***

Ms. Ann Ciganer noted the Electronics Communication Committee (ECC) recommendation 1108, which allows the introduction of commercial pseudolites into the RNSS bandwidth (1559-1610 megahertz), is circulating among the forty-eight relevant telecommunications agencies for approval. Thus far, fourteen agencies are implementing it.

Also, a new and concerning development is that ECAT (European Common Application Table) now shows an application within the RNSS band for terrestrial transmitters. This is a force multiplier for the issue of RNSS spectrum protection because equipment manufacturers typically reference ECAT when designing equipment. The fact that such an application could be approved means further such proposed applications should be anticipated.

The proposed regulation clearly states that an operator is required to get a license from the telecom administration which, in turn, requires certification from the GNSS operators. Recommendation 1108 should be withdrawn because it is misleading as written and, if enacted, the international GNSS community would need to maintain constant vigilance against bandwidth incursion.

We have shown that it is possible to withdraw this recommendation. One country has changed its "yes" to "no." A GPSIA representative met with the country's telecom administration and informed them the ECC report has acknowledged that pseudolites create harmful interference, are subject to misuse as jammers and spoofers, and could be very harmful to aviation. As a result of this meeting the telecom administrator said their country would reverse its position.

The 2004 agreement between the U.S. and the European Union (EU) provides the framework to discuss such matters, but it appears that the telecom administrations are either not aware, or do not understand it.

Ms. Ciganer said she hopes that ECC 1108 gets tabled for a year.

Dr. Parkinson asked why the Europeans are not strongly opposing this recommendation.

Ms. Ciganer said GPSIA has written to the PNT EXCOM and to the European Commission (EC).

Dr. Parkinson asked if the EC is actively engaged in opposing the recommendation.

Ms. Ciganer noted that GPSIA is actively working with the Europeans on two other issues and will continue to work with them.

Dr. Parkinson asked if Galileo is involved.

Ms. Ciganer noted that one European university wanted to commercialize pseudolites, but following discussions, it decided to take a different direction once it understood the personal responsibility in taking such step.

Ms. Ciganer asked Mr. Dimmen if he could provide a European perspective.

Mr. Dimmen said Europe has many jurisdictions and it is not easy to have a good overview of the status. His understanding is that a coordination process is in motion and he had personally raised this topic with the

Norwegian "FCC" who are now considering how to proceed.

Ms. Ciganer stated that the point that is not understood is that the national operators are not going to provide confirmation. It is inconsistent for a national telecom administration to allow harmful interference. When this point is raised with national agencies it is apparent that they do not understand this. The statement that "Government users are also concerned that uncontrolled use of these devices might negate the trust placed in GNSS and thereby undermine the trust placed in any location-based application" is on the U.S. website describing the 2004 U.S.-EU agreement. Thus, assistance is needed to communicate this to various bodies in Europe.

Ms. Ciganer added that a U.S. satellite has been given permission to operate in the L2 frequency, and this could potentially cause interference. Thus, she is attempting to create a coordinated process that would prevent this from happening.

Dr. Betz noted, relative to the spectrum landscape, GPS and QZSS are the only systems with signals centered in 1227 MHz (L2). There were other systems at 1207 MHz, Galileo at 1278 MHz, and BeiDou at 1268 MHz. The spectrum team at the GPS-D has been working this matter very carefully from the perspective of interference effects. Perhaps meetings with the appropriate persons could be held.

Ms. Ciganer said she is not suggesting there is a regulatory gap. The whole U.S.-European team keeps hearing of more systems coming in and, thus, more attention is required. Existing regulations make it impossible to use pseudolites, so the issue becomes implementing what is already in place.

Mr. Stenbit said the Advisory Board needs to understand the subject better before deciding what action is needed.

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2) Dr. Gerhard Beutler (Switzerland), *International Association of Geodesy (IAG)*

Dr. Gerhard Beutler said he would address multi-GNSS from the users' perspective at three levels: the level of the IAG; the level of the IAG analysis center, and the level of the user of the analysis center.

Not all GNSS are in Medium Earth Orbit (MEO). The QZSS satellite is in an inclined geosynchronous orbit, and the BeiDou constellation includes both, MEO and GEO satellites. In addition, the precise type of MEO orbits varies considerably from one GNSS to another. This is why GNSS orbit monitoring is important, e.g., in the frame of the IGS Multi-GNSS Experiment and Pilot Project (MGEX), which tracks all GNSS signals from 170 sites worldwide. MGEX data is not just collected, but also analyzed by some of the IAG analysis centers. These analysis centers routinely produce information on orbits, clocks, coordinates of ground tracking network, earth rotation parameters, and intersystem biases. MGEX analysis of GNSS orbits shows that GPS is the most consistently accurate constellation. The current orbit quality per coordinate is: GPS, 1-4 cm; GLONASS, 4-12 cm, and Galileo, 4-14 cm. With full deployment coming up, it is expected that non-GPS systems will improve markedly over the next few years. It is important to validate the GNSS orbits by independent techniques, and the only practical way to accomplish this is through Satellite Laser Ranging (SLR). At this time all GNSS systems, except GPS, are equipped with Laser Retro-reflector Arrays (LRA).

The IGS analysis centers provide ultra-rapid solutions four times a day with a three-hour latency. Rapid solutions are available once a day with a half-day latency. Final solutions are available once per week with a latency of one week. The IGS MGEX solutions are currently available weekly, with a latency of one week. The ultimate goal is to switch the MGEX solutions to the official IGS solutions, but this capability has not yet been reached. Everything MGEX does is publicly available.

Users outside the International GNSS Service (IGS) can also analyze their data using MGEX. If one combines GPS data with GLONASS data one receives an improvement of about 35% percent for real-time kinematic applications based on the so-called precise point positioning (PPP). The addition of Galileo raises the improvement to about 40% percent, and adding BeiDou raises it to about 46%. The gain for a position at a particular epoch is, roughly, equal to the square root of the number of satellites supplying data at that epoch. Surprisingly, when comparing the new and old processing schemes applied to post-processing it has been noted that the new scheme often does not improve results as expected from the statistics perspective. This is an area governed by systematic and not random errors that requires further study.

In summary, the key message is that there is a multi-GNSS world in the IGS. Dr. Beutler called attention to a forthcoming article by Montenbruck et al, "The MGEX of the IGS: Achievements, Prospects, Challenges," to be published in *Advances in Space Research*.

Mr. Stenbit commented that when individual data is not correct, the error gets compounded when the data was aggregated. This is a classic system problem that demonstrates the need for adequate interface mechanisms.

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3) Mr. Arve Dimmen (Norway), Norwegian Coastal Administration

Mr. Arve Dimmen said he would address two topics the Ny-Alesund facility and the Norwegian Forum for Autonomous Vessels.

The Ny-Alesund facility is Norway's contribution to the global geodetic reference frame. This facility is now very much a reality. The antennas have been installed and will be tested next year. It combines four measurements techniques, one of which is SLR. It is the northernmost SLR tracking station. Cooperation with NASA has been very good. The station remains a priority and necessary funds are in place for its completion. Mr. Dimmen also showed several photographs, taken three years apart, of a nearby glacier that in this time has retreated several hundred meters.

The Norwegian Forum for Autonomous Vessels was established October 4, 2016. The Norwegian Coastal Administration is responsible both for delivering services to ensure safety of transport and is the regulatory body for maritime traffic in Norwegian waters. Therefore is it important to work actively with other stakeholders regarding Autonomous Vessels to understand how this development influences Maritime safety and what opportunities it gives for maritime transportation.

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4) Dr. Sergio Camacho-Lara (Mexico), *U.N. Center of Science and Space Technology*

Dr. Camacho said he would first present a brief overview of activities at the UN-affiliated Regional Center for Space Science and Technology Education for Latin America and Caribbean (CRECTEALC), and then he would make two proposals, one on promoting the use of multi-GNSS and another on protecting GNSS spectrum.

CRECTEALC is a small center hosted by INAOE (National Institute of Astrophysics, Optics and Electronics). Historically, INAOE has offered M.Sc. and Ph.D. programs in astrophysics, optics, electronics and computer science Since 2014, INAOE/CRECTEALC offer an M.Sc. program in Space Science and Technology, with students choosing to specialize in Remote Sensing and Geographic Information Systems; Satellite Communications; Space Environment (particularly Near-Earth Objects), and GNSS. UN regional centers, such as CRECTEALC, also serve as information centers for the ICG and the GNSS Providers' Forum. Greater advantage could be taken of these centers to build capacity and disseminate information beyond the developed world. For example, in May 2016 a space policy and space law workshop, held in Nicaragua and in a September 2016 workshop held at the UN Regional Centre for Space Science and Technology Education for Asia and the Pacific in China (RCSSTEAP-China). RCSSTEAP-China and CRECTEALC stressed the importance of protecting the GNSS spectrum. CRECTEALC has also signed a Memorandum of Understanding with the Samara State Aerospace University in Russia, and will be signing a similar agreement with RCSSTEAP-China for technical and policy capacity building in GNSS.

Because all GNSS systems will, hopefully, soon be interoperable, we should promote the use of multi-GNSS in the U.S. as a complement to GPS, including in case of any outages that may occur. This does not negate the development of eLoran, or other backup system, to address issues relating to broader RF interference with GNSS signals. Spectrum protection efforts are being conducted at the ICG and elsewhere. The ICG has made an updated recommendation that ICG member administrations encourage protection of the RNSS spectrum from unwanted emissions. Further, ICG recommended that efforts should be made to encourage reporting on domestic RNSS spectrum protection through the Scientific and Technical Subcommittee (STSC) of the UN COPUOS. In fact, a follow-on UN STSC statement paragraphs 145, 2016 report to COPUOS; A/AC.105/1109), in line with the relevant ICG recommendation, urges efforts to raise general member awareness of the importance of interference, detection, and mitigation. Clearly, spectrum must be protected globally given that applications are used nationally and globally by most nations. This issue has drawn high attention from the eighty-two members of COPUOS. Whatever is supported by the STSC is supported by COPUOS and, subsequently, is adopted by the UN membership as a whole.

Separately, UN COPUOS is preparing guidelines, space-related and space- and ground-related, for the long-term

sustainability of outer space activities. The goal is to encourage UN member states and international intergovernmental organizations to ensure that their space- and ground-based activities are conducted in such a manner as not to cause harmful interference with the reception and transmission of radio signals and are in accordance with the ITU Radio Regulations and the ITU Radio Communication Sector (ITU-R) Recommendations. Ultimately, it is expected that UN member states and intergovernmental organizations will be invited to report annually on a voluntary basis on their efforts related to IDM of the radio spectrum. Pursuant to this, Dr. Camacho-Lara urged the Advisory Board to make technical presentations at the forthcoming STSC conference in Vienna on the nature of IDM issues, the importance of GNSS to all countries, and what would be required to achieve effective IDM.

Mr. Stenbit asked whether Dr. Camacho believes the Advisory Board should take a direct role in this.

Dr. Camacho said he believes the Advisory Board should be represented as part of the UN delegation. Non-GNSS operating nations need a clearer understanding of the importance of GNSS to them, in particular the general economic importance to these nations.

Dr. Parkinson asked whether Mr. K. Hodgkins, Department of State, may be an appropriate person for this task.

Dr. Camacho said Mr. Hodgkins could give the political points, while perhaps someone from the Advisory Board could make a technical presentation.

Dr. Parkinson said Mr. David Turner at the Department of State may be capable to do this.

Dr. Camacho agreed.

Mr. Turner said that we are in the very early stages of introducing IDM to the broader community. The UN space applications program holds regular regional workshops, and will be sponsoring one in February 2017. Mr. Turner is not sure whether a technical presentation is needed at this time. The workshop will be the first occasion upon where UN member states are being asked to make a statement of their efforts on IDM. The process is focused on the importance of the subject and what the U.S. is doing.

Ms. Ciganer said she believes Dr. Camacho is raising a new aspect. While he has noted the importance of IDM, Dr. Camacho had also called attention to the need to raise the protection of the spectrum in the first place. In 2004 NASA did an excellent study of the noise floor. The premise is that spectrum protection works. That report might help make the case for why an effort to protect the spectrum should be made.

Dr. Parkinson said that if the Advisory Board Provides Mr. Hodgkins with material that strongly supports on the protection of the spectrum, it could reflect what Dr. Camacho is urging, that government representatives understand the importance of the issues. Dr. Parkinson asked Dr. Camacho if would be satisfied with this action.

Dr. Camacho said he is. The important point is to make each nation's representatives aware of why this issue is important to their own country.

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5) Mr. Dana A. Goward (U.S.), ***Resilient Navigation & Timing Foundation***

Mr. Goward commented that risk to PNT come from a wide range of sources; on one end it could be a naturally-occurring event, and on the other end it may be a maliciously-intended even. Thus, it is necessary to conduct a risk assessment for each threat; the vulnerability to each threat; and the damage that could result. For example, let's look into a hypothetical blizzard striking South Florida and use a scoring system from 0 to 100. As Florida is ill-equipped to handle blizzards, the vulnerability level is 100. For similar reasons, the consequences of damage could be, say, 85. However, the likelihood of the blizzard in South Florida is, for practical purposes, 0. Therefore, the overall threat – vulnerability times consequence times likelihood – is also 0. An example of a malicious threat could be, say, a Martian invasion. The level of maliciousness for such invasion rank as 100 and consequences also as 100. However, as Martians lack the ability to travel through space their capability to carry through the attack is 0 and, once again, the overall threat is 0.

Mr. Goward listed twenty-two possible natural, accidental, or malicious threats to GPS. For natural threats, he presented an assessment criteria for vulnerability, consequence, and threat level. Similarly, he presented an assessment for malicious acts and the threat level for intent and capability.

Mr. Goward also presented two tables:

Table 1: Total Risk to GPS Services & U.S. National and Economic Security. It gives category and total scores for each of the twenty-two threats cited.

Table 2: Vectors by Risk Score. The three highest are, first, a one-year total of criminal and privacy violations; second, terrorist jamming; and third, military-style jamming.

Dr. Parkinson asked about potential risks or hazards are not included in these tables, and noted that board members should remain mindful of them.

Mr. Goward added that he is seeking speakers for a March 17, 2017 conference on GNSS backups where threat assessment is an important part.

Mr. Goward presented a list of nine possible mitigation actions, each of which increase protection, toughen the system, or provide augmentation. This list is based on a literature review and, thus, may not be comprehensive. Finally, two steps that would most reduce risk: (1) toughen by requiring critical infrastructure owners to be able to operate without space-based PNT for thirty days; and (2) augment the system, by providing an alternative PNT signal, such as eLoran. This model and analysis is not the final word on the subject, but it is a good starting point for discussion, and urged all interested to consider this matter.

In closing, Mr. Goward noted he will chair a panel on "Is it time for backup?" at the March 17, 2017 conference on GNSS backups. At this time he is seeking speakers for both sides of the question. One argument against developing immediately a backup is, for example, that it is more important to complementary systems (such as other GNSS).

Dr. Betz said that if the dominant threat is jamming, how pertinent is the target of 30 days of GPS-free operation?

Mr. Goward said this is a good question. In cases of jamming it is highly unlikely that 30 days of GPS-outage would occur. The 30-day figure was initially selected across the board because that is the time period generally viewed as a normal business cycle.

Dr. Betz said that, in his view, it is less a question of resilience to a jamming threat than one of how long it would take to recover from a threat.

Mr. Goward agreed but, in his view, the board needs a threat model to address threats in general. This presentation is one such approach.

Dr. Parkinson agreed as to the need and the value of the presentation.

* * *

6) Dr. Refaat Rashad (Egypt), *Arab Institute of Navigation*

Dr. Refaat Rashad said he would address the topics of IDM and GNSS backup.

Dr. Rashad said that six months ago he participated in a program that included the topic of "A Day without GPS." In his view, it would be better to address the topic of "A Day without Interference." The GNSS community is aware of the danger in system outages. Many conferences have been held on IDM, and included participation of Advisory Board members and briefers such as Dr. Parkinson, Dr. Betz, Dr. Enge, Mr. Miller, Ms. Neilan, Mr. Martin, Mr. Hodge, and Mr. Goward. The RPNT Foundation has also been engaged in a number of educational activities on this topic. However, European and other representatives have been less active than U.S. representatives, and many international organizations have responded somewhat weakly to the IDM issues.

Regarding taking measures against interference, Dr. Rashad called attention to the 1992 resolution (4.5) that stipulates "the frequency assigned to the station of a given service shall be separated from the limits of the band allocated to this service in such a way that, taking account of the frequency band assigned to a station, no harmful interference is caused to services to which frequency bands immediately adjoining are allocated." Also, the 1992 resolution (4.10) stipulates that: "In the assignment and use of frequencies, it is necessary to take into account the fact that safety services require special services to ensure their freedom from harmful interference."

Finally, eLoran is good candidate as system backup However, few countries are doing much in this area. Studies are in progress in the United Kingdom and South Korea, but most nations have merely made promises. The international effort to create a GNSS backup system is limited. Also, there is a concern that while efforts are directed against external interference, on the other hand, friendly interference may be tolerated. If friendly interference is permitted, then the domino theory suggests this will make external interference more likely. In short, the GNSS world is still a long way from having a "Day without Interference."

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Advisory Board Discussion & Action Items

Dr. Parkinson asked Mr. Miller to distribute the draft chart that shows how the Advisory Board might divide itself into working subcommittees.

Mr. Miller noted that it is customary for a new administration to decide which advisory boards it wants to sustain and, also, declare which issues are a priority. The selection of advisory boards is influenced by the Annual Report made by the General Services Administration (GSA) on the cost and effectiveness of each board. However, because PNT Advisory Board members contribute their time, the board has their full expertise for less than the cost of a single FTE (Full-Time Equivalent) and the board's annual dollar-cost has remained relatively steady at US$180,000.

Dr. Parkinson added that performance measures are also vital, and questions that need to be answered are: What recommendations has the board made and what actions have been taken by the Federal government's actions in response? What savings have been enabled? What efficiencies have been gained? What productivity enhancements have been realized? Dr. Parkinson noted that, in his view, revenue savings and enhancements of tens of millions of dollars may be quite easily traced back to the board's influence on the PNT EXCOM. Thus, the board should be well prepared to address these questions in any presentations to the incoming Administration.

Dr. Parkinson thanked NASA for being a highly-supportive sponsor, and directed the board members' attention to organizing subcommittees. He has discussed this with Mr. Stenbit, and the first order of business is to proceed on the setting up the structure of the subcommittee. Dr. Parkinson asked whether the initial list – agriculture, aviation, timing, finance, policy, scientific, spectrum issues, and transportation (non-aviation) – is reasonable.

Dr. Betz suggested merging 'timing' and 'finance,' as the latter is principally about the former.

Mr. Shields said that while Dr. Betz is correct from a technical standpoint, from a government and business standpoint there are two separate and distinct audiences. For example, it is doubtful the U.S. Treasury is too concerned with cellphone timing issues. In general, presentations should not be rooted on how board members view things 'as engineers' but, rather, how the respective audiences may view things.

Dr. Parkinson endorsed Mr. Shield's view, and added that each should, by the end of January, have a two-page report completed that is accessible in layman's terms, makes appropriate use of pictures, and uses dollar values that are demonstrable and defensible. The expectation is that someone entering the new administration could be given a simple document that covers the necessary high points in a clear and persuasive manner, and complete with the relevant implications. In regards to precision agriculture, such a document may already exist.

A question was raised whether a separate report is needed on consumer devices such as cellphones.

Mr. Shields noted that some applications, such as smartphone-based navigation, could be placed under transportation. He also offered to lead the effort in the finance subcommittee.

Dr. Parkinson said he believes automotive – which at the very least should include turn-by-turn navigation – should be placed under 'transportation.'

Dr. Parkinson said Mr. Stenbit places particular emphasis on precise timing as it relates to the finance sector. This, in turn, opens the subject to other sectors, such as power grids, it becomes a separate topic. Thus it is important we resist the urge to be so comprehensive that it ends up undermining the purpose of informing a new administration. In his view five or so reports is the optimal number.

Mr. McGurn added that the reference on the previous day to a 30 nanosecond timing requirement really struck him. This could be discussed within the communications subcommittee. Enhanced Loran could, perhaps, address the issue of backup to timing.

Dr. Parkinson suggested adding this to the list.

Mr. McGurn commented on whether the issue of broader multi-GNSS use falls under the policy subcommittee.

Dr. Parkinson noted that spectrum and policy issues needed to be coordinated.

Dr. Beutler said that given the importance of multi-GNSS use in the science subcommittee, it is not clear why it should be discussed in a different topic area.

Dr. Parkinson responded that, in general, overlap is preferable to underlap. Perhaps the cover letter could emphasize the broader topic of multi-GNSS use, spectrum protection, and backups.

Mr. Miller suggested that 'aviation' be expanded to 'aviation/aerospace', given the range of space applications supported by GPS. He suggested that by spring 2017 one package of essential information be compiled for use by all agencies represented in the EXCOM in their briefing team meetings to the new administration. This would enable establishing a consistent common front on these issues.

Dr. Parkinson suggested that Mr. Martin serve on the policy subcommittee.

Mr. Martin accepted.

Dr. Parkinson then asked members to consider their particular area of participation.

A suggestion was brought up to broaden the 'GPS Backup' subcommittee beyond just backing up GPS. Diverse backup technologies may be preferable for different areas.

Dr. Parkinson agreed.

Dr. Parkinson invited participation from the board's international members.

Mr. Dimmen said he could contribute to maritime transportation.

Dr. Parkinson offered an anecdote from the Soviet-era Five-Year-Plans; factories were given quotas to produce nails. However, if quotas were numeric then the result was tiny nails, but if quotas were established by weight the result was factories producing railway ties. The bottom line is that subcommittees are being assigned a quota of two pages, with reasonable font-size and avoiding overcrowded pages. It is preferable having good pictures than detailed technical explanations.

Mr. McGurn said he wishes to work on the military subcommittee as well as on international policy.

Dr. Parkinson said each subcommittee should designate a leader or co-leaders. The overarching purpose is to make a brief, clear, straightforward argument for the importance of the PNT Advisory Board and, in general, of GNSS.

Dr. Axelrad asked for clarification on the organization and purpose.

Dr. Parkinson said the individual two-pagers will to technology user groups, while the cover letter will emphasize: (1) the overall importance of GPS to the federal government; and (2) that the PNT Advisory Board is the only body that spans the broader range of concerns.

Dr. Axelrad asked whether all drafts should go through a single editor for consistency.

Dr. Parkinson said someone needs to act in the role of lead provider. He asked Mr. Shields to circulate a two-page template. Also, the final reports would be reviewed by Mr. Miller.

Mr. Goward said he believes the critical infrastructure group should include finance, and offered to lead this group.

Dr. Betz said he would join that effort. Dr. Betz also suggested common themes: How is GPS used in this area? What are the benefits? What are the implications if GPS was lost?

Mr. Lewis said that, having been through previous administrative changeovers, it is important to identify the issues the incoming administration would face in the next four years. Further, the Advisory Board should be ready to offer advice on the issues it is identifying.

Mr. Shields said he would prepare and circulate a draft structure the following week.

Mr. Lewis asked who the principal audience is, and what is the deadline?

Dr. Parkinson said the primary audience is the PNT EXCOM, and the deadline is late January.

Dr. Parkinson suggested expanding the 'policy group' to include multi-GNSS. No objections were raised.

The final subcommittee structure and writing assignments are as follows:

- Cover Letter – Mr. Stenbit, Dr. Parkinson, Gov. Geringer
- Agriculture: Ms. Ciganer, Mr. Hatch
- Aviation and Aerospace: Dr. Axelrad, Mr. Burgett, Dr. Enge, Capt Murphy
- Critical Infrastructure/Timing: Adm Allen, Dr. Betz, Mr. Faga, Mr. Goward, Mr. Shields,
- Military: Dr. Betz, Gen James, Mr. McGurn,
- Policy/Multi-GNSS: Adm Allen, Mr. Faga, Mr. Goward, Mr. P. Marquez, Mr. McGurn
- Scientific: Dr. Beutler, Mr. Dimmen, Mr. Higgins, Ms. Neilan
- Spectrum issues: Mr. Brenner, Mr. Burgett, Dr. Camacho-Lara, Ms. Ciganer
- Transportation (Non-Aviation): Mr. Dimmen, Dr. Rashad, Mr. Shields

In closing, Mr. Miller expressed deep-seated thanks to Maj General Chilton for her participation in the PNT Advisory Board. He also proposed that the next board meeting be held in June 2017 after the new administration has had the opportunity to settle in.

The Thursday, December 8 session of the eighteenth meeting of the PNT Advisory Board adjourned at 12 p.m.

* * *

Appendix A: PNT Advisory Board Membership

Special Government Employees

SGE's are experts from industry or academia who temporarily receive federal employee status during Advisory Board meetings.

- **John Stenbit** (Chair), MITRE
- **Bradford Parkinson** (Vice Chair), Stanford University
- **James E. Geringer** (Second Vice Chair), ESRI
- **Thad Allen**, Booz Allen Hamilton
- **Penina Axelrad**, University of Colorado
- **John Betz**, MITRE
- **Dean Brenner**, Qualcomm
- **Scott Burgett**, Garmin International
- **Joseph D. Burns**, Sensurion Aerospace
- **Per K. Enge**, Stanford University
- **Martin C. Faga**, MITRE
- **Ronald R. Hatch**, consultant to John Deere
- **Larry James**, Jet Propulsion Laboratory
- **Peter Marquez**, Planetary Resources
- **Terence J. McGurn**, private consultant (retired CIA)
- **Timothy A. Murphy**, The Boeing Company
- **Ruth Neilan**, Jet Propulsion Laboratory
- **T. Russell Shields**, Ygomi

Representatives

Representatives are individuals designated to speak on behalf of particular interest groups.

- **Gerhard Beutler**, International Association of Geodesy (Switzerland)
- **Sergio Camacho-Lara**, United Nations Regional Education Center of Science and Space Technology - Latin America and Caribbean (Mexico)
- **Ann Ciganer**, GPS Innovation Alliance
- **Arve Dimmen**, Norwegian Coastal Administration (Norway)
- **Dana Goward**, Resilient Navigation and Timing Foundation
- **Matt Higgins**, International GNSS Society (Australia)
- **Refaat M. Rashad**, Arab Institute of Navigation (Egypt)

Executive Director

The membership of the Advisory Board is administered by a designated federal officer appointed by the NASA Administrator:

- **James J. Miller**, Executive Director

Special Counselors

- **Mr. Kirk Lewis**, Institute for Defense Analyses (IDA)
- **Dr. Scott Pace**, The George Washington University (GWU)
- **Dr. Tom Powell**, Aerospace

Appendix B: Presentations

(All briefings are available at: www.gps.gov)

GPS Adjacent Band Compatibility Assessment/Ms. Karen Van Dyke

U.S. Space-Based Positioning, Navigation and Timing (PNT) Policy Update/Mr. Harold W. Martin III

GPS Status & Modernization Progress: Service, Satellites, Control Segment, and Military GPS User Equipment/ Col Gerry Gleckel

U.S. International Activities Update: Multilateral and Bilateral Advances/Mr. Ken Hodgkins

ESA Activities related to GNSS Space Service Volume/Dr. Werner Enderle

GPS Overview/Mr. Doug Skinner

NASA's Deep Space Atomic Clock and Optical Communications Program for PNT Applications/Dr. Don Cornwell

GPS III: Poised for Tomorrow/Mr. John Voce

GPS/GNSS Space Service Volume (SSV) Update Initiatives/Mr. Joel Parker

Development of a GNSS-Enhanced Tsunami Early Warning System/Dr. Gerald Bawden

Update on Protecting United States Critical GPS Infrastructure/Mr. Jim Platt

GPS Vulnerability Report/Mr. Michael Calabro

Standardization of GNSS Threat reporting and Receiver testing through International Knowledge, Experimentation and Exploitation [STRIKE 3]/Dr. Mark Dumville

Communicating Time Looks Simple. So Why Haven't We Solved it Yet?/Mr. Harlan Stenn

Representatives & International Members Reports & Perspectives:

RNSS Spectrum Protection – Status/Ms. Ann Ciganer

Multi-GNSS: Users' Perspective/Dr. Gerhard Beutler

Norway's Contribution to the Global Geodetic Reference Frame/Mr. Arve Dimmen

Protection of the GNSS Spectrum/Dr. Sergio Camacho

Prioritizing Dangers to the United States from Threats to GPS/Mr. Dana A. Goward

Remarks on the International Activities Regarding GNSS Spectrum Protection/Dr. Refaat Rashad

Appendix C: Sign-In List

Wednesday, December 7, 2016

PNT Board Members:
- John Stenbit, PNTAB Chair
- Penina Axelrad
- John Betz
- Gerhard Beutler, AIUB
- Scott Burgett
- Sergio Camacho, Mexico
- Ann Ciganer, GPSIA
- Arve Dimmen, Norwegian Coastal Administration
- Jim Geringer,
- Ruth Neilan, PNTAB
- Tom Powell, Aerospace
- Refaat Rashad, Arab Institute of Navigation
- Russ Shields

Other NASA Personnel:
- Frank H. Bauer, FB-ACS
- Larry James, NASA Jet Propulsion Laboratory
- Don Cornwell, NASA
- Allison Craddock, NASA Jet Propulsion Laboratory
- Paul Kim/NASA
- Bill Notley, NASA
- A. J. Oria, NASA Headquarters
- Joel Parker, NASA
- Robert Tjoelker, NASA Jet Propulsion Laboratory

Other Attendees:
- Phil Bruner, NGC
- Jim Burton, National Coordination Office
- Guy Buesnel, Spirent
- John Caldorini, Aerospace
- Cathy Chilton, United States Air Force
- Frank Clark, United States Air Force
- Lee Cosart, Microcosm Corporation
- Larry Davidoff, Boeing
- Brad Davis, Hellen Systems
- Jim Dougherty, IDA
- Mark Dumville, NSL
- Werner Enderle, European Space Administration
- John Fabis, Northrop
- Gerald Gleckel/ SMC/GP
- Valerie Green, Ligado
- Steve Grupenhagen, SAF/AQS
- Ranwa Haddad, Aerospace Corporation
- Dennis Hall, Northrop Grumman
- Ken Hodgkins, United States Department of State
- Karl Kovach, Aerospace Corporation
- John LeBrecque, Overlook
- Eileen Leonhardy, Rockwell Collins
- Bridge Littleton
- Max Mai, United States Air Force
- Doug Meyer, NGC
- Eric Nelson, United States Air Force
- Bill Nichols, Booz Allen
- James Platt, DHS

Edward Powers, United States Navy
Joe Rolli, Harris
Steve Wilson, John Deere
Doug Skinner, Boeing
Doug Smith, Ligado
Harlan Stone, Network Time Foundation
Steve Sullivan, Network Time Foundation
Al Trivison, United States Air Force
Karen Van Dyke, Department of Transportation
John Voce, Lockheed Martin
Marc Weiss, NIST
Paul Williams
[One illegible]

Thursday, December 8:

PNT Board Members:
Gerhard Beutler, AIUB
Scott Burgett, PNTAB
Ruth Neilan, NASA Jet Propulsion Laboratory
Brad Parkinson
Tom Powell, Aerospace

Other NASA Personnel:
Frank Bayer
Paul Kim
Jim Miller
William Notley
A.J. Oria

Other Attendees:
Gary Buesnel, Spirent
Jim Burton, National Coordination Office
John Caldorini, Aerospace
Jim Doherty, IDA
Mark Dumville, NSL
Gerry Gleckel, United States
Steve Grupenhagen, SAF/AQS
Ken Hodgkins, Department of State
Eileen Leonhardy, Rockwell Collins
James Platt, Department of Homeland Security
Harlan Stenn, Network Time Foundation
Paul Williams, GLA

Appendix D: Acronym & Definitions

5G	Fifth Generation Mobile Communications
ABC	Adjacent Band Compatibility
AFSPC	Air Force Space Command
ATIS	Alliance for Telecommunications Industry Solutions
BeiDou	China's GNSS
CDD	Capabilities Development Document
cm	Centimeter
COps	Contingency Operations
COPUOS	UN Committee on the Peaceful Uses of Outer Space
CPNT	Complementary PNT
CRECTEALC	Center for Space Science and Technology Education for Latin America and Caribbean
DART	Deep-ocean Assessment and Reporting of Tsunami
dB	decibel
DHS	Department of Homeland Security
DoD	Department of Defense
DOT	Department of Transportation
DSAC	NASA Deep Space Atomic Clock
DSN	NASA Deep Space Network
EC	European Commission
ECAT	European Common Application Table
ECC	Electronics Communication Committee
eLoran	Enhanced Loran
ESA	European Space Agency
EU	European Union
EXCOM	Executive Committee
FAA	Federal Aviation Administration
FACA	Federal Advisory Committee Act
FCC	Federal Communications Commission
FRN	Federal Register Notice
FTE	Full-Time Equivalent
Galileo	European GNSS
GAMIR	GPS/Galileo Miniaturised Space Receiver
GEO	Geosynchronous Orbit
GLONASS	Russian GNSS
GNP	Gross Domestic Product
GNSS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellite
GOES-R	GOES Series R
GPS	Global Positioning System
GPS-D	GPS Directorate
GPS-III	GPS Block III
GPSIA	GPS Innovation Alliance
GSA	General Services Administration
HEO	High Earth Orbit
Hg	Mercury
Hz	Hertz
IAG	International Association of Geodesy
ICG	International Committee on GNSS
IGS	International GNSS Service
IDM	Interference, Detection, and Mitigation
IFOR	GPS Interagency Forum for Operational Requirements
IGS	International GNSS Service
INAOE	National Institute of Astrophysics, Optics and Electronics
IP	Interference Power
ITM	Interference Tolerance Mask
ITU	International Telecommunication Union
ITU-R	ITU Radio Communications Sector
JPL	NASA Jet Propulsion Laboratory
km	kilometer

L2C	2nd GPS Civil Signal (commercial)
L5	3rd GPS Civil Signal (safety-of-life / aviation)
LEO	Low Earth Orbit
LRA	Laser Retro-reflector Array
MEO	Medium Earth Orbit
MGEX	Multi-GNSS Experiment and Pilot Project
MGUE	Military User Equipment
MMS	NASA Magnetospheric Multi-Scale 4mission
NASA	National Aeronautics and Space Administration
Navic	India's regional navigation system, formerly known as the Indian Regional Navigation Satellite System (IRNSS)
NEN	NASA Near Earth Network
NEO	Near Earth Orbit
NIST	National Institute of Standards and Technology
NMA	Navigation Message Authentication
NOAA	National Oceanic and Atmospheric Association
NTF	National Time Foundation
NTIA	National Telecommunications and Information Administration
NTP	Network Time Project
OCS	GPS Operational Control System
OCX	GPS Modernized Operational Control System
OMB	Office of Management and Budget
QZSS	Quasi-Zenith Satellite System, Japan's regional navigation satellite system
PNT	Positioning, Navigation, and Timing
POD	Precise Orbit Determination
PPP	Precise Point Positioning
R&D	Research and Development
RCSSTEAP	UN Regional Centre for Space Science and Technology Education for Asia and the Pacific
RMP	Regional Military Protection
RFP	Request for Proposals
RNSS	Radio Navigation Satellite System
RPNT	Resilient PNT
SAR	Search and Rescue
SIS	Signal-in-Space
SLR	Satellite Laser Ranging
SMC	AFSPC Space & Missile Systems Center
SSV	Space Service Volume
STRIKE3	Standardization of GNSS Threat Reporting and Receiver Testing through Intl. Knowledge Exchange, Experimentation & Exploitation
STSC	Scientific and Technical Subcommittee
SV	GPS satellite vehicle
SWAP	Size, weight, and power
TRL	Technology Readiness Level
TTP	Tactics, Techniques, and Procedures
U.S.	United States
UAV	Unmanned Aerial Vehicle
UN	United Nations
USAF	U.S. Air Force
USNO	U.S. Naval Observatory
WSMR	White Sands Missile Range