SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

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

## Nineteenth Meeting

## June 28-29, 2017

Baltimore Marriott Inner Harbor
110 South Eutaw Street, Baltimore, MD 21201

John Paul Stenbit
Chair

James J. Miller
Executive Director

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

# 19th Meeting
# June 28-29, 2017

Baltimore Marriott Inner Harbor, Stadium Ballroom, 110 South Eutaw Street, Baltimore, MD 21201

## Agenda

**WEDNESDAY, JUNE 28, 2017**

10:00 - 10:05
**BOARD CONVENES**
*Call to Order & Announcements*
Mr. James J. Miller, *Executive Director, PNT Advisory Board, NASA*

10:05 - 10:30
19th Meeting Priorities – Focus for Aug. 17 PNT EXCOM
*(1) PNT Board letter on Adjacent Band Harmful Interference to GPS Users; (2) Administration Transition Package*
***VIEW PDF (1 MB)***
Mr. John Stenbit, *Chair;*
Dr. Bradford Parkinson, *1st Vice-Chair;*
Gov. Jim Geringer, *2nd Vice-Chair*

10:30 - 10:45
PNT EXCOM Priorities & Key Policy Initiatives
*National Coordination Office (NCO) Interagency Perspectives*
***VIEW PDF (656 KB)***
Mr. Harold "Stormy" Martin, *Director, National Coordination Office for Space-Based PNT*

10:45 - 11:25
U.S. Department of Transportation (DOT) Civil GPS/PNT Update
*GPS Adjacent Band Compatibility (ABC) Assessment*
***VIEW PDF (3 MB)***
Ms. Karen Van Dyke, *Director for PNT, DOT Office of the Secretary, Research & Technology*

11:25 - 12:05
National Advanced Spectrum and Communications Test Network (NASCTN) Briefing on Impact of LTE Signals on GPS Devices
***VIEW PDF (1 MB)***
Dr. William Young, *Group Leader, Shared Spectrum Metrology, National Institute of Standards and Technology (NIST)*

12:05 - 12:30
Iridium Briefing on Spectrum Landscape
*Impact of Proposed Adjacent Terrestrial Broadband Network on Satellite Operations*
***VIEW PDF (1 MB)***
Mr. Bryan Tramont, *Managing Partner, Wilkinson Barker Knauer LLP* & Ms. Maureen McLaughlin, *Vice President of Public Policy, Iridium*

12:30 - 1:00
Global Positioning System (GPS) Status & Modernization Milestones
*Emerging GPS III Capabilities & Services*
***VIEW PDF (3 MB)***
Col Gerard "Gerry" Gleckel, *Deputy Director, GPS Directorate, U.S. Air Force*

1:00 - 2:00
**LUNCH** — *(Ethics Briefing for Special Government Employees)*
Mr. Adam Greenstone, *General Counsel, NASA*

2:00 - 2:30
Update on GNSS Signal Performance Monitoring
*Current Operations and Emerging Capabilities*
***VIEW PDF (4 MB)***
Dr. Yoaz Bar-Sever, *Manager, Global Differential GPS System (GDGPS), Jet Propulsion Laboratory*

2:30 - 3:00
SCaN Next Generation Communications Capabilities
*A Beacon of Light into NASA's Future*
***VIEW PDF (6 MB)***
Mr. Phil Liebrecht, *Deputy, Space Communications and Navigation (SCaN) Program, NASA*

3:00 - 3:30
U.S. International Activities
*Bilateral & Multilateral Engagement & 12th International Committee on GNSS (ICG)*
***VIEW PDF (1 MB)***
Mr. Dave Turner, *Deputy Director, Office of Space and Advanced Technology, U.S. Department of State*

3:30 - 4:00
Cyber-Physical Security Aspects of Robust PNT
*Impacts from Loss of PNT Services to Transport Modes*
***VIEW PDF (7 MB)***
Prof. Rafal Zbikowski, *School of Aerospace, Transport & Manufacturing, Cranfield University*

4:00 - 4:15
**BREAK**

4:15 - 4:40
GNSS Threats, Attacks and Simulation
*Proactively Assessing and Mitigating Jamming & Spoofing*
***VIEW PDF (3 MB)***
Mr. Guy Buesnel, *PNT Security Technologist, Spirent Communications*

4:40 - 5:05
Automated Detection and Identification of GNSS Interference Events at the United Kingdom (UK) Border
***VIEW PDF (3 MB)***
Mr. Billy Marshall, *Research Systems Engineer, Chronos Technology*

5:05 - 5:30
Blended AGNSS & eLoran for Trusted Time & Location Services
***VIEW PDF 1 (541 KB)***
***VIEW PDF 2 (2 MB)***
Mr. Stephen Bartlett, *UrsaNav* & Dr. Eric Derbez, *iPosi, Inc.*

5:30 - 6:00
Assured PNT for the United States
***VIEW PDF (7 MB)***
Dr. Gene McCall, *Former Chief Scientist, U.S. Air Force Space Command*

6:00
**ADJOURNMENT**

## THURSDAY, JUNE 29, 2017

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

9:05 - 9:30
Announcements & Agenda – Intro to Administration Transition Package
*Concise Assessment & Member Feedback from June 28 Deliberations*
Mr. John Stenbit, *Chair;*
Dr. Bradford Parkinson, *1st Vice-Chair;*
Gov. Jim Geringer, *2nd Vice-Chair*

(9:30 - 10:50)
**Administration Transition Package**
**PNT Board Sector Working Group Position Papers**

9:30 - 9:40
Agriculture
Ms. Ciganer, Mr. Hatch

9:40 - 9:50
Aviation and Aerospace
Dr. Axelrad, Capt. Burns, Mr. Burgett, Dr. Enge, Mr. Murphy

9:50 - 10:00
Critical Infrastructure/Timing
Adm Allen, Dr. Betz, Mr. Faga, Mr. Goward, Mr. Shields

10:00 - 10:10
Military
Dr. Betz, Lt. Gen. James, Mr. McGurn

10:10 - 10:20
Policy/Multi-GNSS
Adm Allen, Mr. Faga, Mr. Goward, Mr. Marquez, Mr. McGurn

10:20 - 10:30
Scientific
***VIEW PDF (3 MB)***
Dr. Beutler, Mr. Dimmen, Mr. Higgins, Ms. Neilan

10:30 - 10:40
Spectrum issues
Mr. Brenner, Mr. Burgett, Dr. Camacho-Lara, Ms. Ciganer

10:40 - 10:50
Transportation (Non-Aviation)
Mr. Dimmen, Dr. Rashad, Mr. Shields

10:50 - 11:05
**BREAK**

11:05 - 12:00
Roundtable Discussion
*Recommendations & Presentation Preparation for Aug. 17 PNT Executive Committee – Key Priorities & Work Plan for 2017-2019*
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.

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# 19th PNT ADVISORY BOARD SESSION

**Executive Summary**

The 19th session of the National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board met on June 28-29, 2017, in Baltimore, Maryland. The principal goals of this session was to prepare the Advisory Board's submissions to the next session of the PNT Executive Committee (EXCOM), scheduled for August 2017.

**High-Level Action Items:**

- Mr. John Stenbit, Chair, in consultation with others, established a deadline of Friday, July 7, 2017, for Advisory Board members to submit final comments to Dr. Oria on the PNT EXCOM submissions; and a deadline of Friday, July 14, 2017 for preparation by Dr. Oria of the revised draft.
- Mr. Stenbit directed Mr. James J. Miller to circulate the revised July 14, 2017 draft to Advisory Committee members for final review.
- Thereafter, the revised draft is to be delivered by early August 2017 to Mr. Harold Martin, Ms. Karen Van Dyke and possibly others for final preparation prior to submission to the EXCOM.
- The Advisory Board approved the following motion: "The PNT Advisory Board takes note of the International Global Navigation Satellite System Service (IGS) White Paper on 'Satellite and Operation Information for Generation Precise Global Navigation Satellite Systems (GNSS) Orbit and Clock Products' and encourages the open sharing of technical information on GNSS systems important to the international geodetic community consistent with national security and intellectual property constraints."
- The Advisory Board approved the following motion: "The PNT Advisory Board notes with appreciation the work of the scientific and technical subcommittee of United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) and encourages ongoing efforts on this most important subject of interference and mitigation of GNSS signals."

**Other Action Items:**

- Mr. Bryan Tramont, Wilkinson Barker Knauer LLP, said he would supply a copy of a letter to which his firm had been a signatory on adjacent terrestrial broadband.
- Mr. Miller requested Dr. Sergio Camacho to provide a copy of his report on spectrum so that it could be posted on the GPS.gov website.
- Admiral Thad Allen stated the Advisory Board would benefit from a more detailed position on timing and urged the inclusion of this topic at its next session.
- Adm Allen suggested that, given that "policy" matters often fell outside the purview of the EXCOM, the Advisory Board should consider how to further resolve issues that fell between departments and agencies.

*[The Wednesday, June 28, 2017 session of the National PNT Advisory Board convened at 10:00 a.m.]*

**Board Convenes**

Call to Order & Announcements:

Mr. John Stenbit, Chair, welcomed those attending the 19th meeting of the National Space-Based Positioning, Navigation and Timing (PNT) Advisory Board meeting, in particular those who had traveled some distance.

Mr. James J. Miller, Executive Director, seconded the welcome. The Advisory Board, which first met in March 2007, has completed a decade of service. The U.S. Air Force has provided superior leadership to the Global Positioning System (GPS). Mr. Miller thanked Major General Catherine Chilton and Colonel Gerard Gleckel for attending the meeting. The board is governed by the Federal Advisory Committee Act (FACA). As such, written minutes are taken and will be posted, along with the presentations, on www.gps.gov. Should any member anticipate a conflict of interest, they should recuse themselves from the discussion and the recusal will be noted in writing in the meeting minutes. Board members have been nominated by one of the PNT Executive Committee (PNT EXCOM) member agencies, and the final appointments made by the National Aeronautics and Space Administration (NASA) Administrator. All members volunteer their work, thereby demonstrating their commitment to the success of GPS.

**Priorities for the 19th PNT Advisory Board Session**

Mr. Stenbit noted that he anticipated a busy agenda. The two major items, both discussed in the previous day's preparatory/fact-finding session, relate to the new U.S. administration and new PNT EXCOM appointed by the administration. The board's chief task is to provide both the administration and PNT EXCOM with a document that establishes the board's current status and, also, summarize its positions on various issues, including the importance of GPS and other Global Navigation Satellite Systems (GNSS) to the areas of responsibility of individual PNT EXCOM member agencies.

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**PNT EXCOM Priorities and Key Policy Initiatives**
*National Coordination Office (NCO) Interagency Perspectives*
Mr. Harold "Stormy" Martin, *Director*
*National Coordination Office for Space-Based PNT*

Mr. Martin noted his briefing would focus on PNT Resilience. While the administration is new, the U.S. National Space Policy remains unchanged. It continues to task GPS with providing international leadership in GNSS. The PNT EXCOM faces a variety of strategic issues. When "Y2K" arose, people did not throw away their computers. When Internet introduced the problem of computer viruses, that problem was not regarded as negating the value of computer connectivity. GPS faces a similar situation. Spectrum transmission is not safe. Most GPS receivers lack adequate cybersecurity. This is, in part, because receivers are designed more like radios than computers. The National Space Policy directs that system security be maintained. Early in 2017, a series of documents were been published establishing "best practices" for protecting GPS and the sixteen critical infrastructures that rely on GPS. There are a number of hazards to GPS, including jamming and spoofing. Spoofing can put inaccurate data into a system, thus creating more difficulties down the line.

Interference places critical systems at risk. At present, there are over 600 million GPS receivers in the U.S., and over two billion in the world. The goal is to create "competent" receivers that can review the legitimacy of incoming signals. On March 11, 2017 an Executive Order called for strengthening of cybersecurity. Cybersecurity risks are among the highest system threats currently faced by the government. The time to act is now.

Ms. Neilan asked Mr. Martin to define the term "digital data spoofing."

Mr. Martin said it is related to data outside the range of valid data that a receiver should acknowledge. Lists of such data are being compiled.

Ms. Neilan asked if anyone is receiving such data.

Mr. Goward said it already has occurred. Potentially, it can put bad information into a system. Thus, the board should regard it as a cyber problem.

Adm Allen noted that this is the first direct linkage he has seen between cybersecurity and GPS receivers. It is important both are part of the same conversation.

Mr. Brenner asked Mr. Martin to speak at greater length on how foreign GNSS can add to system resilience.

Mr. Martin noted that is part of U.S. National Space Policy. There is additional language in the FY'17 National Defense Authorization Act (NDAA) related to what systems may be used on the civil side. While there are recommendations on how receivers should be built, few formal requirements exist that receiver manufacturers are obliged to follow.

Ms. Neilan reported that the International Global Navigation Satellite System Service (IGS) has been working to have non-proprietary software built into receivers. In her view, this long-term effort has already achieved considerable success.

* * *

Mr. Stenbit noted that several talks on spectrum testing would follow. Dr. Parkinson would provide a summary overview prior to these presentations. Mr. Stenbit then recused himself from these discussions, turning the chair over to Dr. Parkinson. Other board members recusing themselves were Mr. Hatch, Mr. Burgett, Mr. Brenner, Dr. Enge, Mr. Burns, Mr. Murphy, and Dr. Faga.

*[Recusals: Mr. Stenbit, Mr. Hatch, Mr. Burgett, Mr. Brenner, Dr. Enge, Mr. Burns, Mr. Murphy, Dr. Faga.]*

Dr. Parkinson restated the board's view to date regarding its concerns that GPS is currently at risk from a proposal to allow terrestrial LTE transmissions, where signals are much stronger than GPS, in an adjacent frequency band intended for Mobile Satellite Services (MSS). The biggest risk is to high precision GPS receivers which happen to be the ones making the largest contribution to the economy. The original proposal called for implementing 40,000 broadband transmitters with a power range 5 billion times greater than GPS at a distance of one-quarter mile. Dr. Parkinson noted that his understanding is that use of the proposal's upper frequency band is no longer under consideration. The difficulty is in the relation between "S" (the signal power) and "N" (the ambient noise). The proposer can control the signal power, but not the ambient noise. Increasing channel capacity to accommodate the data streaming requirements, and other applications, can result in signal interference. Therefore, the board has developed six test criteria that would adequately assess the potential for interference. The main difficulty is that recent test sponsored by the proposer have not met any of these criteria. In the meantime, the federal government has undertaken a major effort to conduct testing that meets the six criteria. Such tests were conducted in 2011 and showed there was cause for concern, and again undertaken in 2016 where it was shown there was not significant improvement. The proposers have claimed that GPS receiver manufacturers are comfortable with the proposal, but such statement is very misleading. Moreover, GPS receiver manufacturers are only one constituency of the broader GPS user community. In the board's view aviation, agriculture, and surveying users have not been adequately consulted. Once again, it is necessary to stress the importance of high precision receivers where, for example, building surveying can now be accomplished in one-tenth the previous time at one-tenth the previous cost. In summary, the board believes all such applications should be explored in depth before any approvals are granted.

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**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 & Technology*

Dr. Parkinson opened this briefing by commending Ms. Karen Van Dyke for her leadership in the DOT – sponsored interagency assessment of GPS adjacent band compatibility.

Ms. Van Dyke explained the effort was instigated in 2012 by then Deputy Secretary of Transportation John Porcari to determine what tolerance exists in the GPS band. The effort was divided between certified aviation and all other civilian users. This briefing addresses the latter. It should be noted, however, that some news reports about the Federal Aviation Administration (FAA) and Ligado working on an agreement regarding certified aviation standards are not true.

Ms. Van Dyke welcomed the six criteria identified by the Advisory Board. The DOT Adjacent Band Compatibility (ABC) effort included open workshops where considerable feedback has been received. Such feedback largely mirrors what DOT has put forward. The most recent workshop was on March 30, 2017 workshop, and its summary is available at the www.gps.gov website (see: http://www.gps.gov/spectrum/ABC/#workshop6).

Major milestones for this effort included testing at the White Sands Missile Range (WSMS) as well as GPS receiver antenna characterization. Test results reflect the 1 dB interference tolerance mask recommended by the board. Eighty civil receivers of various types have been tested. Federal partners and private manufacturers were involved, with manufacturers being permitted to bring their own devices for testing. All Global Navigation Satellite System (GNSS) civil signals were tested, and multi-GNSS receivers also included. Unsurprisingly, high precision receivers are the receiver category that is most sensitive to interference from the adjacent band. The certified aviation field has used interference masks for some time and, thus, it was not necessary to include them in these tests. Test results show considerable variance in the response depending on the type of interference.

The tests focused on macro urban environments, but data does exist for other settings. The selection of use cases is of considerable importance; so it was discussed with both the Department of Homeland Security (DHS) and First Responders. For example, drones are now being used to support First Responder applications. High precision receivers are also used in applications such as tall building construction, precision agriculture, and machine control. This approach is in line with the stated priorities of the PNT EXCOM: namely, to focus on existing uses and vital needs for economic, public safety, scientific, and national security. Regarding macro urban transmitters, an important question is at what distance one needs to be from a transmitter to avoid degradation. This distance appears to be approximately 14 kilometers. Further, one can lose lock on a low elevation GPS satellite at approximately 3 kilometers.

Dr. Parkinson asked about the relationship between loss of lock and accuracy.

Ms. Van Dyke said degradation in accuracy is considerable when loss of lock occurs. Signal integrity in this circumstance is also of concern. Timing receivers are somewhat less sensitive, but can still be affected up to a distance of 1 kilometer.

Mr. Martin asked what power levels are used for the transmitters.

Ms. Van Dyke said the power level is based on International Telecommunications Union – Radiocommunication Sector Resolution 59 (ITU-R 59), which equates to 29 dBW and slightly lower than the 32 dBW of the proposer.

Other analyses are directed at inverse modeling, looking at both 29 dBW and 10 dBW power levels. It is now possible to evaluate the probable impact of any proposal put forward, provided the power level is known. Given the diversity of applications, it is difficult to determine a single answer for the physical range of the interference effects. Therefore, answers are application specific. Ms. Van Dyke presented a table on "Summary Inverse Modeling", which allows gauging the maximum allowable EIRP (Equivalent Isotopically Radiated Power) for both macro and micro urban deployments. The next steps in this study are to complete the GPS ABC Assessment Final Report and release for public review and comment. The target date is before the next PNT EXCOM meeting in August.

Dr. Parkinson called attention to the HPR (High Precision) and TIM (Timing) categories in the lower half of the "Summary Inverse Modeling" chart (slide #25, http://www.gps.gov/governance/advisory/meetings/2017-06/vandyke.pdf), where he noted the longer distance measure was 100 meters. His recollection is that the proposer talked in terms of 400 meters.

Ms. Van Dyke responded that an earlier Ligado presentation proposed a spacing of 433 meters.

Dr. Parkinson said that the chart suggested matters could be "orders of magnitude" away from anything the Advisory Board could consider an acceptable compromise.

Ms. Van Dyke noted that while the testing in 2011 showed there was an impact, the latest testing actually shows the magnitude of such impact.

Mr. Russell commented that the automotive field is moving toward connected vehicles and automated driving. Has Ms. Van Dyke considered the implications the test results in terms of client devices where distances are measured in centimeters?

Ms. Van Dyke noted that General Motors participated in the study. The greatest impact was in the downlink, and specific effects depend on the proximity to such devices.

Mr. Russell added that "smarter" vehicles have both GPS and cellular antennas. Traditionally, one meter was regarded as adequate, but such new technologies no longer fit in the category of "traditional cases."

Ms. Van Dyke agreed.

Dr. Parkinson said that cellphone manufacturers, because cellphones contain multiple antennas, have addressed similar problems for some time. In his view the issue cited by Mr. Russell should be solvable with sufficient frequency separation.

Mr. Russell noted that current cellphone frequencies have a large gap between 900 and 1.8 MHz. They don't face activity within only 50 MHz as they would in automotive uplink.

Maj Gen Chilton commented that the new Commander at Air Force Space Command (AFSPC), Gen Raymond, fully backs the 1 dB noise floor limit and she supported the DOT test efforts. She added that the Air Force was thankful for the work being done.

Mr. Miller announced that all the day's presentations are available for viewing at www.gps.gov. He noted it is necessary to include 'www.' (see: http://www.gps.gov/governance/advisory/meetings/2017-06/)

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**National Advanced Spectrum and Communications Test Network (NASCTN) Briefing on Impact of LTE Signals on GPS Devices**

Dr. William Young, *Group Leader*
*Shared Spectrum Metrology, National Institute of Standards and Technology (NIST)*

Dr. Parkinson opened the discussion by noting that Dr. Young had been asked to address the fourteen concerns regarding the NASCTN testing raised earlier this year by a few board members. Such concerns are in line with the Advisory Board's six criterion for testing.

Dr. Young noted that NASCTN was been established in 2015 by National Institute of Standards and Technology (NIST), National Telecommunications and Information Administration (NTIA), and the Department of Defense (DoD) to provide robust test processes and validate measurement data to develop, evaluate, and deploy spectrum-sharing technologies.

Dr. Young added that its tests on the impact of LTE signals on GPS devices are complete and the report is publicly available. The three-month effort involved 1,476 hours of testing, including 968 LTE exposure tests, and over 6,000 time-to-first-

reacquisition tests. For ease of interpretation, all tests were done in common format. The general objective was to develop a rigorous methodology for determining the impact of signals adjacent to the GPS L1 devices. Tests needed to be repeatable, calibrated, and well-documented. Further, testing needed to allow for retesting to analyze any anomalies that arise.

Dr. Young then addressed the fourteen concerns mentioned by Dr. Parkinson:

Comment #1: To justify replacing the 1 dB criterion for tolerable interference will require a very extensive justification looking at many worst cases GPS/GNSS operational situations

Dr. Young said NASCTN is not making a judgement on the 1 dB criterion. Testing beyond the nominal 1 dB degradation $C/N_0$ point allows the data to be used to estimate margins and support extrapolation to real-world conditions. Dr. Young provided samples of steady-state median plots.

Comment #2: The plan should include the goal of determining what level of LTE interference can be accepted by satnav receivers operating satisfactorily under all relevant conditions.

Dr. Young said a decision was made to bound the problem into something that is realizable and added value to the decision-making process. GPS L1 is the primary satnav signals used in the region of proposed LTE deployment.

Dr. Parkinson asked whether both L1C and L1 C/A signals are captured.

Dr. Young said they are.

Comment #3: The plan should address highly stressed conditions (the 'envelope' conditions).

Dr. Young described the test plan priorities, which include results from "stepped down" operation by only eight GPS satellites.

Mr. Goward asked whether the test plan adheres to Dr. Young's previous remarks on comment #2.

Dr. Young said he is reporting what was undertaken. In his view the fundamental point is to start at L1 and make sure it is capable.

Mr. Goward asked if Dr. Young's test plan adheres to the general principal articulated in comment #2.

Dr. Young said it adheres to the key point behind the principle.

Mr. Goward asked if the same is the case for comment #3.

Dr. Young said he believes those represent a limited condition that has not yet been studied.

Mr. Goward suggested there has not been adherence.

Dr. Young said the "envelope" conditions were not clearly defined in the charge. These have been estimated.

Dr. Parkinson asked if Dr. Young's principal concern was loss of lock, rather than loss of accuracy.

Dr. Young replied that loss of accuracy was determined. There is variability among receivers. Thus, it is not a linear process across the range of receiver types.

Dr. Parkinson said if these are Real-Time Kinematic (RTK) receivers.

Dr. Young said they are.

Mr. Goward requested that, in discussing each comment, Dr. Young state whether he feels the concern was addressed, or whether it was not relevant.

Dr. Young noted, regarding receiver in motion, he agrees it is important but, at the same time, he believes particularly rigorous testing would be required.

Comment #4: The plan should include all receiver classes, particularly those known to be the most sensitive to interference, e.g. acquisition (cold start) and reacquisition.

Dr. Young said the original proposal emphasized general aviation. Following the comment period, considerably greater emphasis was placed on high precision applications and timing devices. Antenna manufacturers were asked to provide the information they normally supplied to their customers. Twenty different device configurations were tested. The tests for time-to-first-fix and time-to-first-reacquisition were rigorous. Certified aviation, non-certified aviation, space-based, cellular, and military grade receivers were tested.

Dr. Parkinson asked where the Galileo GNSS fits.

Dr. Young said Galileo receivers were not tested.

Dr. Young added that precision receivers use very wide bandwidth for accuracy. The High Precision Positioning (HPP) devices tested were wide, narrow, and dual bandwidth antennas. Also, if tracking is the only issue, then the impact on measurement jitter is more critical. Finally, new design may reduce, but not eliminate, the susceptibility.

Comment #5: Plan should include moving receivers.

Dr. Young said testing has not addressed this. The testing criteria is sensitive to the use in question, particularly as far as repeatability is concerned.

Comment #6: The plan should include other sources of interference.

Dr. Young noted this is an open-ended criterion. More detail is needed. If, for example, the noise condition is changed during the test then it prevents adequate repeatability. Some devices are sensitive to noise change caused by temperature change. Testing was done at 300°K. Project engineers raised the question of how one can estimate performance changes due to changes in temperature. Testing of this is in progress. Research is underway into "live sky" noise conditions, for which Dr. Young presented some results.

Comment #7: Plan must include various received power levels and numbers of satellites.

Dr. Young noted that testing included a "limited" scenario that assumed only eight GPS satellites operating at various power levels.

Comment #8: Plan must include multiple receivers simultaneously, at least in some cases.

Dr. Young noted the RTK setup included multiple receivers using the "zero-baseline solution" method.

Dr. Axelrad asked why Dr. Young used data for median performance.

Dr. Young said data based on "average" is overly influenced by outliers.

Dr. Parkinson noted that for interference, "worst case" scenarios are of concern. The median is a 50/50 split in the data, but one may also want to know the 90/10 split.

Dr. Young said that is an excellent point. Such data exists, but was not been included in the presentation.

Mr. Russell said that, for safety of life issues, one does not want to drive a vehicle with 50 percent accuracy. One needs near 100 percent accuracy.

Dr. Young restated that the data exists and can be plotted as one wishes. In his view it is important not to give excessive influence to outliers.

Dr. Parkinson asked whether the basis for determining success or failure was been based on 50/50; 90/10, or 99.9/.1?

Dr. Young said NASCTN does not have authority to make policy recommendations or to supply "pass/fail" recommendations. Rather, the effort was to create rigorous data that could be supplied to decision-makers for their use.

Dr. Parkinson expressed concern that if data is presented at the median level, the report recipient might assume that is the appropriate standard.

Dr. Young said he understands the concern. He added that the median level approach was used in earlier reports.

Comment #9: Plan should include receivers for more satnav signals, including L1C and from other GNSS.

Dr. Young said a key question is how interference is attributed to the receiver or to the link in question. In his view it is simpler if units are broken apart. A decision was made to put an RTK "rover" under interference condition and the "base" outside where it could be controlled. This allows targeting of what is being affected. The stakeholder consensus was that the rover is the biggest consideration. The objective was to make sure nothing in the test regimen itself add to the interference. The GPS L2, GPS L5, Galileo and GLONASS signals were outside the scope of the project. In his view the inclusion of additional signals would add uncertainty to the test results.

Comment #10: Plan should focus on absolute power levels, not signal to interference ratio.

Dr. Young said absolute power levels were used. Future testing of resilient receivers is highly important and, he believes, this work would be of value.

Comment #11: Plan should address how test data will be extrapolated to operational conditions.

Dr. Young noted that the key thing here is the ability to include antennas, which in turn allows to determine the filtering that occurs at the antenna level. For example, the path loss model can be used to extrapolate the results to different separate distances between the LTE source and the GPS device. Different path loss models could be used. Also, thermal conditions had an influence that is now being tested.

Comment #12: At a minimum, the test plan and test results should clearly and prominently highlight limitations of the testing, and the resulting restrictions on drawing conclusions from the tests.

Dr. Young said no claims have been made on what the tests did or did not do. Rather, data was provided so others could use the information. As mentioned earlier, NASCTN is not authorized to make policy recommendations.

Comment #13: To have credibility within the PNT community, it is clear real PNT expertise must be added to the test team. If the plan is to answer the real question, the satnav community can provide assistance.

Dr. Young noted that testing reflected 150 comments on the original test plan.

Comment #14: The test plan review process should be open and formal.

Dr. Young responded that all plans were public. Further, plans were sent to significant stakeholders. All comments have been posted on the NASCTN website.

Mr. Russell said that, as a technical person, he understands that projects are often done based on someone else's willingness to finance them. Nonetheless, he is surprised that a document, developed with rather biased rules in its charter, would be issued by any technical person with a commitment to ethics.

Dr. Young said he has no doubts about his own ethics and stands by the information presented in the report. Beyond that, he has no comment.

Mr. McGurn said he likes "median" as a statistic. However, would it be possible to get a sense of what the distribution looks like?

Dr. Young said the information is available, but cannot provide it off-hand.

Dr. Parkinson asked if someone has taken the nominal spacing and reached some rough conclusions for what the allowable power for the most sensitive receivers would be.

Dr. Young said that has not been part of their charge, which was to supply data.

Dr. Parkinson regarded that question as the "bottom line" to the undertaking. He asked if Dr. Young is aware of anyone else pursuing this question.

Dr. Young said he has not seen any results.

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**Iridium Briefing on Spectrum Landscape**
*Impact of Proposed Adjacent Terrestrial Broadband Network on Satellite Operations*
Mr. Bryan Tramont, *Managing Partner, Wilkinson Barker Knauer LLP*
Ms. Maureen McLaughlin*, Vice President of Public Policy, Iridium*

*[Recusals: Except for Mr. Stenbit, all Advisory Board members who earlier recused themselves rejoined the discussion.]*

Mr. Tramont opened the discussion and noted that 1627.5 to 1637.5 MHz is the frequency band of interest to Iridium.

Ms. McLaughlin then described the system. Iridium system has high redundancy and low latency. It has backward compatibility with existing networks and devices. Iridium also provides full coverage over the Polar Regions. The next generation of 66 satellites is fully-funded at $3 billion, which is a rather heavy investment for just 9 MHz of bandwidth.

*[Recusals: Mr. Stenbit, interjected that individuals who previously recused themselves must remain recused for the balance of this presentation.]*

The first launch of ten satellites, accomplished by SpaceX, have gone smoothly. Launches will continue into 2018. Iridium has four major vertical markets: land/mobile; mobile-to-mobile (M2M); maritime, and aviation. M2M is experiencing rapid subscriber growth. Iridium's polar capabilities are also becoming more important with the increased ship traffic in that region. Finally, the company has 57,000 general aviation subscribers. While 90% of the current client base is commercial, Iridium has a strong relationship with the U.S. government.

Mr. Tramont then reviewed the regulatory and business evolution of the Mobile Satellite Service (MSS) frequency band that is adjacent to GPS. This designation was made by the Federal Communications Commission (FCC) in 1994. In 1998, Iridium launched its first constellation. Mr. Tramont explained that as a university professor he stressed to his students the importance of locating like services within the same frequency band. Iridium, is one such case. In 2001, the FCC began work on the Ancillary Terrestrial Components (ATC) within the band, which was followed an order that ATC operations must protect satellite operations. However, in 2004 LightSquared received FCC authority to operate near the GNSS band. Such operation was broadly seen as a threat to GNSS reception and thus, the authority was withdrawn in 2012 and LightSquared then filed for bankruptcy. Iridium is not, in general, opposed to ATC. The issue is when the ATC expands grows and undermines the fundamental purpose of the MSS band. In 2015 Ligado (formerly LightSquared) filed a new series of applications seeking flexibility for its terrestrial operations. Iridium's concern is that such operation, if approved, would create interference to Iridium's receivers. Iridium has submitted two technical studies to the FCC and would be pleased to present a report to the Advisory Board's at its November 2017 meeting. Finally, it should be noted that Iridium is just one of 22 signatories to a letter calling attention to these concerns.

The letter stresses that decisions on bandwidth allocation should not be based on what is best for a specific application but, rather, for the operation of all systems within that band.

Dr. Parkinson said he is aware the Ligado proposal would affect some GPS users as well as users in the weather sector.

Mr. Goward asked if the referred letter is available.

Mr. Tramont said he will be pleased to supply a copy.

Dr. Parkinson said the letter will be circulated among board members.

Mr. Shields noted that ITU, in its radio regulations, specifies what different bands are for. These have related support from the ITU-R regarding the potential interference. Have these matters been brought into the discussion?

Mr. Tramont said this is very important. A point that has repeatedly been made by various bodies is the importance of maintaining the integrity of GNSS applications.

Dr. Parkinson asked about Mr. Tramont's view of the FCC's receptiveness to the arguments Iridium is advancing.

Mr. Tramont said he preferred not to comment on this. However, he believes the FCC is keeping an open mind.

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*[Recusals: Mr. Stenbit resumed his duties as Chair and all previously recused board members rejoined the discussion]*

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**Global Positioning System (GPS) Status & Modernization Milestones**
*Emerging GPS III Capacities & Services*
Colonel Gerard Gleckel, *Deputy Director*
*GPS Directorate, U. S. Air Force*

Col Gleckel noted that the number of civil and commercial users of GPS globally continues to rapidly increase. While the board is fully aware of the civil uses of GPS – ranging from timing, to agriculture, to safety of life, and others – often military audiences - are not fully aware of the entire range of uses. Therefore, the GPS Directorate (GPS-D) has become an advocate for both civil and military users.

Dr. Parkinson noted that the GPS-D is doing an excellent job of management. It is very important to keep reminding people that GPS is not a military system that was extended to civil use but, rather, it has always been the intention that it be both.

Col Gleckel then addressed threats and mitigation. The U.S. is no longer alone and unafraid in space. Military satellites have become targets for potential adversaries. In his view the major threats are cybersecurity, jamming and spoofing, and kinetic (physical destruction of the satellite). The kinetic risk is lowered by the large and redundant number of GPS satellites. Also, resilience is facilitated by the system's robust and diverse user equipment inventory, the encrypted military signals, and cybersecurity improvements in the existing control segment. The modernized operational control center (OCX), and Military GPS User Equipment (MGUE) are all designed and implemented with these threats in mind. GPS III SV01 is currently in storage, awaiting for launch in 2018.

Dr. Parkinson asked why the satellite has not yet been launched.

Col Gleckel said the launch date will be determined by the availability of a launch vehicle.

Col Gleckel then provided status on the first ten GPS III satellite vehicles (SV 01-10). GPS III SV 11-32, also referred to as GPS Follow-On, is currently in competition. The intention is to identify, through a competed approach, a single contractor to build all 22 satellites, as any switching from one manufacturer to another would incur billions in startup costs. The follow-on contract will have "tech insertion points" where the selected contractor could add improvements or threat protections.

Dr. Parkinson noted that the SV 11-32 satellites could end up having a radically different design. When would the final satellite be launched?

Col Gleckel said it would probably be in FY 2033.

Ms. Neilan asked which GPS III satellites would carry NUDET (Nuclear Detonation Detection System).

Col Gleckel said SV-9 and SV-10 will not; SV 11 and those subsequent will.

Regarding OCX, it has been publicized that problems have occurred, but since then, OCX has gone through the Nunn-McCurdy process and recertified, with tighter management in place. OCX Block 0, the launch and checkout for GPS, will be delivered in the fall. Also, existing Operational Control Segment (OCS) has been assigned $130 million for cyber upgrades between 2011 and 2021.

Ms. Neilan asked if, for OCX, attention is being paid to other international systems.

Col Gleckel said OCX is aimed at GPS.

In March 2017 MGUE Inc 1 was demonstrated on guided test flight and, in early June, the first fight test were held with the M-code receiver on the B-2 bomber. Four additional flight tests with the B-2 are planned, leading to actual bomb release testing. A number of M-Code Capability Advances are being brought to the warfighter.

Summarizing, GPS III increases anti-jamming capabilities through increased signal power. Further, MGUE is improving anti-jamming and spoofing capabilities with advanced algorithms and M-Code. OCX will offer improved network cyber security and other expanded capabilities.

Mr. Goward noted that on June 16, 2017, the Air Force issued a press release regarding the GPS system's "near-perfect performance" for civil GPS service in 2014 and 2015. In his view this was somewhat misleading as it did not mention the problems in January 2016. The public thinks of GPS not just as the satellites themselves, but as the entire system. Thus, a headline could might mislead persons that make no distinction between satellites and receivers. They might conclude that "near-perfect performance" means they need not worry about their receiver's capability. Therefore, it is important that individuals charged with writing press releases exercise a degree of caution.

Col Gleckel said he understands the concern. While GPS has a strong backbone, backups and other support are required.

Mr. Goward asked how the performance criteria used in the press release compares to those developed by the DOT.

Col Gleckel said he would need to investigate that further.

Mr. Faga, regarding OCX, asked whether at some point the people funding the enterprise might simply said: "Enough." What alternatives exist?

Col Gleckel responded that the "enough" point was passed when OCX went through the Nunn-McCurdy process. Nevertheless, the current system, OCS, is working well and being updated.

Ms. Van Dyke said, relative to the press release, DOT received inquiries that suggested people believed the system had been perfected. That message should not be conveyed.

Col Gleckel said he understands there is a fine line between making fair claims for one's achievement and overstating things.

Dr. Parkinson noted that while GPS remains the "Gold Standard," what struck him regarding OCX was Mr. Martin's comments on cyber-security. Adding the updates to OCS has been a painful experience and, more importantly, OCX itself is a substantial update.

Mr. Stenbit asked how many satellites currently carry M-Code.

Col. Gleckel said: 24.

Mr. Stenbit noted that very complex programs are being operated. Problems exist and, understandably, they did not lend themselves to quick fixes. As such he appreciates the contributions of the GPS D and is very happy with its stewardship.

Ms. Neilan asked if OCX has "hooks" for the other international satellites.

Mr. Stenbit said other nations will not want us controlling their satellites. However, mechanisms are needed to bridge the performance of the various systems.

Col Gleckel said that OCX is not where multi-GNSS is coming together. That will come together at the receiver level.

Mr. McGurn said it is good M-Code testing has started. How long will it be until M-Code use is qualified by warfighters?

Col Gleckel said his task is to make the capability available. Warfighters will receive equipment based on when those responsible for ordering do so. For example, aircraft carriers only came in for upgrades once every year or two.

Ms. Van Dyke added that she wished to clarify a statement for Ms. Neilan. Other GNSS service providers are looking at multi-GNSS monitoring. However, questions exist on whether the U.S. will do likewise. Mr. Turner of the State Department will speak to this in his presentation.

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Mr. Miller noted this concluded the end of the morning sessions, and the Special Government Employees would have their annual ethics briefing during the lunch hour.

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**Update on GNSS Signal Performance Monitoring**
*Current Operations and Emerging Capabilities*
Dr. Yoaz Bar-Sever, *Manager*
*Global Differential GPS System (GDGPS), Jet Propulsion Laboratory (JPL)*

Dr. Bar-Sever said the briefing would review the GDGPS monitoring system, its current capabilities, and services offered. GDGPS is a tool to provide GPS performance monitoring for the Air Force that dates back to 2002, when it began following a frequency jump by a satellite-borne Rubidium clock. GPS satellites are observed by many monitoring stations that provide a 20-fold redundancy. Recent activities include the addition of CNAV-tracking capabilities on L2 and L5. The January 2016 integrity failure could have been greatly reduced if CNAV had been tracked.

Dr. Parkinson asked under what circumstances is a station's data eliminated.

Dr. Bar-Sever responded that an automatic editing capability eliminates data that falls outside established ranges. There are also other quality control measures in place.

Mr. Goward asked if monitoring is limited to the L1 frequency.

Dr. Bar-Sever said all signals are monitored.

Dr. Parkinson asked if the value produced by this tracking scheme has ever experienced a "walk".

Dr. Bar-Sever said the signals never walk. However, on some occasions, for reasons yet not understood, the signal has experienced a "jump."

Dr. Bar-Sever said the monitoring capability is based on over eighty global tracking sites. Some are operated by JPL, with decades of stability. In addition, GDGPS provides support to single frequency users by leveraging JPL's ionospheric expertise and a dense global network

Ms. Neilan asked why the International GNSS Service (IGS) and its monitoring stations have not been mentioned.

Dr. Bar-Sever said IGS stations do participate, and the system benefits from their contribution.

GDGPS already monitors all the key navigation metrics of the GPS civil signals. Further, JPL currently had the data needed to verify 90% of the Civil Monitoring Performance Specifications (CMPS). JPL has proposed to raise this to 98% within a year, at a capital cost of $3 million and annual operating costs of $3 million. This would leverage the considerable investment already made in the system.

Mr. Goward said it appears to him that civil system monitoring is already occurring.

Dr. Bar-Sever said it is occurring in part. A total of 193 requirements exist and not all are being performed. The system is now getting 90% of the key navigation metrics. An expenditure of $3 million would be needed to raise this to 98%.

Mr. Goward asked what hazard exists from not monitoring the additional eight to ten percent of requirements.

Dr. Bar-Sever clarified that currently only about ten percent of the requirements are being reported. While the information exists to monitor many more requirements, available funds do not allow for their reporting.

Mr. Goward asked if this means information is being withheld from the U.S. government.

Dr. Bar-Sever said the information is fully available.

Ms. Van Dyke said she believes Dr. Bar-Sever is referring to what is available in real-time. The question remains on whether it has already been integrated into a real-time capability.

Dr. Bar-Sever said he believes it has already been integrated, but does not know to what extent it is done automatically.

Ms. Van Dyke said one of the drivers for OCX is to allow real-time monitoring to aviation users.

Gen James added that while a great deal of data is collected, not all of it is immediately sent out to meet the CMPS requirements. Considerable sums are required to turn data into usable information.

Mr. Goward said it appears a considerable amount of departmental political and policy history are at issue.

Dr. Bar- Sever acknowledged that is the case.

Mr. Stenbit said that while the data exists, only a small portion is readily available.

Dr. Enge note we are in an era of multi-constellations. Not only are there three frequencies, but there are four sources for these frequencies and the information must be combined to support Advanced RAIM (ARAIM) in aviation. The expectation is that each major system will do its own monitoring. The core constellation is GPS and normal/ customary monitoring is for GPS L1 C/A. Then, on top of that, is the Wide Area Augmentation System (WAAS). Dr. Enge encouraged Dr. Bar-Sever to sharpen this section of the presentation.

Dr. Bar-Sever said he is not directly engaged with WAAS but, rather, is doing performance monitoring for the Air Force.

Dr. Enge said he nonetheless considers the matter important.

Dr. Bar-Sever added that GDGPS operates in real-time, but operators cannot respond to "one second" data. The data could potentially be translated to real-time if operators had a system that does it.

Dr. Parkinson noted that this operation began on a shoestring and is doing excellent work at low cost. It was a marvelous asset for GPS.

Dr. Bar-Sever said the system has served as a prototype and testbed for OCX.

Ms. Van Dyke noted that DOT is looking to update the CMPS.

Dr. Bar-Sever said that all other constellations are being monitored. An assessment has been made of the advantage of having GLONASS on top of GPS. This assessment suggested a 20% improvement occurs. Also, the system has very recently added the capability to monitor tsunamis by measuring propagation across the ionosphere.

Mr. Higgins noted that the only Australian stations in use are near its east coast.

Mr. Bar-Sever said that there are 1,000 sites available worldwide, but it is not feasible to use them all.

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**SCaN Next Generation Communications Capabilities**
*A Beacon of Light into NASA's Future*
Mr. Phil Liebrecht
*Space Communications and Navigation (SCaN) Program, NASA*

SCaN connects space vehicles across the solar system, providing an integrated navigational capability as well as communications. This briefing addresses both. To provide a sense of scale, communicating from planet Pluto is 20 orders of magnitude more difficult than communicating from an iPhone to a cellphone tower. In the future, SCaN will employ optical communications. Use of higher frequency lasers will overcome the occasional blockages caused when the Sun is positioned between the Earth and a planet. Projections are that laser communications in space can produce forty times the current data rates. Laser-based systems have less mass and consume less power. They are also more secure because laser beams are narrower. Further, newly-emerging technology will allow use of off-the-shelf components. The current RF network will continue to exist as it provides some capabilities otherwise not available. The new laser communication capability will first be demonstrated on a Near Earth DTE (Direct to Earth) basis. This will complemented by a Near Earth Relay to support applications that lack critical latency capability. Eventually a Deep Space DTE will be demonstrated. There are many challenges that need to be addressed, including the effect of weather on laser communications.

The Near Earth DTE capability should be available by 2019, and the Near Earth Relay sometime between 2019 and 2023. It is anticipated that the second generation will produce 100 GB of data per second. Deep Space DTE should be available by 2023 and provide 200 million bits-per-second from Mars, a huge improvement over current capability.

In terms of operational capabilities, the minimum expectation is that by the mid-2020s some ground-based capability to receive this information will exist. Following several years of demonstrations and testing, the LCRD (Laser Communication Relay Demonstration) relay will be available. Some testing may occur on the International Space Station (ISS). A key objective is to create a very robust communications arrangement with Mars years before any likely date for human exploration.

Navigation capabilities will be supported with the Deep Space Atomic Clock (DSAC) and, also, the Next Generation Broadcast Services (NGBS). NGBS will complement GPS and, also, provide science data of use to navigation. SCaN, as it moves into the future, will continue to integrate its navigation capabilities into its activities. As such, Mr. Liebrecht noted he appreciates the assistance received from the U.S. Air Force and GPS.

Mr. Faga asked, relative to the technology slide, whether NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) mission is still in progress.

Mr. Liebrecht said LADEE was designed as a three-month mission and then, as planned, was crashed into the Moon.

A question was raised regarding the effect of cloud cover on laser communications operations.

Mr. Liebrecht noted that cloud cover can be a problem if the clouds are not thin. The most common way to mitigate this is to have reporting done by multiple ground stations, in the expectation that not all will be simultaneously experiencing cloud cover.

A question was raised on how important is pointing to system operation.

Mr. Liebrecht responded that past issues, such as pointing acquisition and tracking, are now under control. Demonstrations have been done in Europe and Japan, and commercial interests have also been working to address the issue.

Mr. Miller added that years ago he discussed with Air Force colleagues the possibility, following GPS III SV11+, of hosting the DSAC mercury-ion clock on board the GPS satellites, to allow comparisons to be made with Rubidium clocks. This point is being made to plant the seed for future discussion at the Board.

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**U.S. International Activities**
*Bilateral and Multilateral Engagement & 12th International Committee on GNSS (ICG)*
Mr. David Turner, *Deputy*
*Office of Space and Advanced Technology, U.S. Department of State*

Mr. Turner began by presenting a statement defining U.S. PNT policy. Mr. Turner noted he always presented this chart because if policy objectives are not being met then the necessary tasks are not being accomplished. The policy objectives are to ensure compatibility, achieve interoperability, and promote fair global competition.

In terms of bilateral dialogues with Europe, the most recent meeting in April 2017 included discussions on the status of the FCC Part 25 waiver request for Galileo. Also, active negotiations are progress with the European Union (EU) for U.S. access to the Galileo Publicly Regulated Service (PRS), an encrypted signal akin to GPS M-Code.

A sub-group on compatibility and interoperability met with Chinese representatives during the Institute of Navigation (ION) Conference last September in Portland, Oregon.

On May 15-16, a dialogue with Japan was held on GPS and Quasi-Zenith Satellite System (QZSS) compatibility and interoperability, and the last dialogue with India was a civil space joint working group meeting in September 2015 in Bangalore.

Mr. Turner then turned to the FCC Part 25 Rule that requires that receivers tracking non-U.S. GNSS signals to be licensed by FCC. In 2011 the Executive branch proposed a waiver process for use of foreign GNSS signals in the U.S. To date, no granting of waivers has occurred, though "a waiver of sorts" has been issued allowing use of Space-Based Augmentation Systems (SBAS).

Dr. Parkinson asked which PNT member agencies have been engaged in this.

Mr. Turner said all nine agencies agreed to the 2011 waiver policy. Likewise, in 2013 all nine agencies supported forwarding to the FCC the EU waiver request that had been submitted to the U.S. State Department in 2013. In January 2017 the FCC filed formal notice, followed by a comment period that ended in March 2017. Since then, no further action has occurred in the public domain.

Mr. Miller asked if, other than the issue of meeting minutes of its discussions, the FCC has ever declared the source of the authority to require waivers.

Mr. Turner said, if the question is: "Is there anything in writing from the FCC that justifies this?" then the answer is: "Sort of." In his view, the issue is one most properly addressed in a Part 25 proceeding, but no such discussion has occurred since 2006.

Mr. Brenner said the FCC has the authority to waive its own rules. By the FCC's definition, a mobile phone constitutes an "earth station" and, therefore, needs a waiver. However, Rule 25 does not indicate who is responsible for seeking such waiver. His recollection is that in 2011 the NTIA filed a letter that referred to this process.

Mr. Turner said Mr. Brenner is correct. It took the Executive branch five years to determine what would go into that letter. It is interesting that the docket contains similar comments, e.g. who, other than a GNSS provider, is responsible for seeking such a waiver?

Mr. McGurn noted that, given the widespread use of multi-GNSS receivers, "the horse is out of the barn." Does this concern anyone at the FCC?

Dr. Parkinson note that the board believes that, for safety reasons, commercial aircraft in U.S. airspace should make use of all available GNSS signals. Does this in any way influence the FCC?

Mr. Turner noted that, while Dr. Parkinson is correct, the FCC rules do not apply to the federal government. Therefore, no waiver is needed relative to FAA requirements.

Mr. Turner then described additional bilateral dialogues with such non-GNSS providers such as Canada, the Republic of Korea, Australia, Vietnam, the United Arab Emirates (UAE), and Ukraine. Scheduled meetings with the United Kingdom have been postponed due to that nation's election. All these nations have considerable interest in GNSS, and Canada merits commendation for its excellent laws pertaining to jamming.

Ms. Neilan sought details about the UAE's involvement.

Mr. Turner said the new UAE space agency is acting as an umbrella body while it organizes its internal processes.

Mr. Turner then turned to the topic of multilateral discussions. The ICG-10 meeting was held in Boulder, Colorado in November 2015; ICG-11 was been held in Sochi, Russia, in November 2016; and ICG-12 will be in Kyoto, Japan in December 2017. The PNT Advisory Board participated at the meeting in Sochi, where Dr. Parkinson made a plenary presentation on adjacent band interference issues and Dr. Rashad participated as a representative of the Arab Institute of Navigation (AIN). The State Department's approach is to promote the idea that system protection is not solely the responsibility of nations that are GNSS providers, but also of nations whose citizens used the services. A process has been established by which countries will report annually on actions taken to safeguard GNSS.

Ms. Neilan noted that no timing experts were present at those meetings. In her view, this is also an important activity.

Mr. McGurn noted that GLONASS has established two websites that provide considerable information. Are any efforts being made to encourage other GNSS providers to do the same?

Mr. Turner said there are two separate issues. The first one is the information from GNSS providers that is posted on the ICG website, including a "report card" on a system's performance. The second is whether this information should assessed independently. Both are important. The U.S. itself is not yet fully compliant with the information sought by the ICG, but it is moving in that direction.

Dr. Camacho-Lara noted that a proposal has been drafted for the ICG Secretariat. Is there any reference to which countries would need to pay attention to interference issues?

Mr. Turner said all countries should pay attention.

Dr. Camacho-Lara said the current wording suggests that certain countries have been identified as needing to act.

Mr. Turner said no country has been identified for failing to act in this area. However, seminars are being held for non-GNSS provider countries on the importance of spectrum protection. The U.S. clearly does not want to make any accusations. Mr. Turner invited Dr. Camacho-Lara to meet with him to review and identify any potential issues with the wording.

Ms. Neilan said that Dr. Camacho-Lara has contributed significantly to this effort. Ms. Neilan asked if Ms**.** Ciganer has commented on the subject.

Mr. Turner said she has not.

Mr. Turner then described other outcomes of the ICG-11 meeting. These include: (1) agreement that open service agreements should remain patent free; (2) additional discussions on a multi-GNSS Space Service Volume (SSV); (3) reports on the implementation of Search and Rescue (SAR) capabilities on GNSS; and (4) discussion of space weather and its impact on GNSS.

Mr. Turner presented a chart showing that status of GNSS Interface Control Documents (ICDs) and Open Service Performance and Standards.

Ms. Neilan noted the chart has valuable information. However, it does not list the representatives from other GNSS.

Mr. Turner said the representatives should be present at the next ICG session.

Mr. Turner then presented the GPS Performance Report Cards for 2014 and 2015, showing a "green" (favorable) marking in all categories.

Mr. Stenbit asked if the report cards include the January 2016 anomaly. If not, how many "greens" would be a different color?

Mr. Turner said he believes, though as a non-expert, the criteria being shown would still remain "green."

Mr. Stenbit noted it is important to encourage transparency regarding any problems that may arise.

Mr. Turner noted that the U.S. has always been transparent in communicating to international bodies when a problem occurs; why it occurred, and what is being done to remedy it. The report for 2016 should be posted within several months.

Summarizing, Mr. Turner stressed the continued importance of compatibility, interoperability, and transparency, matters pursued through bilateral and multilateral meetings. The ICG, with strong U.S. participation, continues to pursue a GNSS "System-of-Systems," that will benefit GNSS users worldwide.

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**Cyber-Physical Security Aspects of Robust PNT**
*Impacts from Loss of PNT Services to Transport Mode*
Dr. Rafal Zbikowski, *School of Aerospace, Transportation & Manufacturing*
*Cranfield University*

Dr. Zbikowski noted that Cranfield University is a former Royal Air Force (RAF) airbase and has its own aircraft supporting aeronautics R&D. Drones and driverless automobiles can be regarded as cyber-physical systems. An important question is: How can a particular vehicle perceive its environment to create situational awareness? This is not a simple task because it is a physical problem rather than just a number residing in a computer. A further element is the physical control of actuation dynamics. These are interactive, and include wireless network dynamics, sensing dynamics, actuator dynamics, and motion dynamics. The combination of these is what makes a cyber-physical system.

Another important aspect are PNT-based safety messages such as, a vehicle that is braking. If the braking vehicle ahead on the road, and perhaps obscured by a truck, the use of PNT is to warn all following vehicles of a sudden slowdown of the traffic thus limiting the risk of longitudinal collision. If, however, the braking vehicle is approaching an intersection, the use of PNT is to avoid a much more dangerous side collision. Thus, the requirements for robust PNT, and transmission of this information, are stricter.

Cyber-physical security is, for example, a 'classic' physical attack such as "Stuxnet," used to disrupt operation of Iranian centrifuges operated as part of that nation's nuclear program. In this instance a cyber-physical attack needed to penetrate an IT layer, an industrial control system layer, and a physical layer. The challenge in managing driverless vehicles is that there will soon be ten times as many pilotless craft as piloted ones, and their operation through existing traffic controller capabilities will not be possible. Unmanned craft, therefore, must substantially self-organize themselves. This requires robust PNT. For example, autonomous cargo delivery is likely to be an early and important user of unmanned vehicles. A potential scenario is one where a driverless truck carrying Budweiser beer drives to an airport where its contents are picked up by a robot, placed on an aircraft, and flown to another country. This operation requires "digital trust." How can one assure that robust PNT is available each step along the way? In this situation there are three pertinent wireless networks: MANET (Mobile ad hoc network), FANET (Flying ad hoc network) and VANET (Vehicle ad hoc network). The key role played by PNT is that network cohesion requires precise timing information. For example, potential cyber-physical threats to MANET including eavesdropping, impersonation, spoofing, and interruption. Robust PNT is essential to countering such threats.

In summarizing, connected autonomous vehicles - on the ground or in the air - are emerging in large numbers. Operation of such vehicles requires wireless networking of all moving vehicles. MANETs, which is necessary to this, requires robust PNT for motion planning. These vehicles are networked and function in real time, which makes them Cyber-Physical Systems (CPS). Another key challenge to CPS is wireless clock synchronization.

Ms. Neilan expressed her appreciation for the presentation.

Mr. Burns noted that at least six companies have signed up with the FAA in hopes of gaining contracts for traffic control of unmanned craft. Is Dr. Zbikowski's university working with these companies?

Dr. Zbikowski said they are. Cranfield University is engaged in building something of a UK national center of excellence devoted entirely to this subject, and it is being undertaken with strong support from industry. Nonetheless, the main issue at this time are the various uses of smaller Unmanned Aerial Vehicles (UAVs). One British airline used drones in hangers to do inspection of aircraft. It would be impossible to monitor the operation of such drones by the existing air traffic controller system.

Mr. Burns asked if Dr. Zbikowski has any thoughts for PNT backup in such instances.

Dr. Zbikowski said that if one is flying, then there is an ambience of inertial sensors. A way would be needed to determine what is and is not acceptable to safe operation. Thus, while in the U.S. 32,000 annual vehicular fatalities may be considered acceptable," it is doubtful such sentiment would exist for a similar number of aviation-related deaths.

Dr. Parkinson noted that he prefers the term Positioning, Velocity and Timing (PVT) to PNT. Velocity has become an almost a forgotten measurement. However, velocity could be a more sensitive measure of spoofing than positioning. Dr. Parkinson commended Dr. Zbikowski for any work he may be doing along these lines.

Dr. Zbikowski said that because his own background is in guided weapons systems, he agrees that velocity modeling is of key importance.

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**GNSS Threats, Attacks and Simulation**
*Proactively Assessing and Mitigating Jamming & Spoofing*
Mr. Guy Buesnel and Mr. Mark Holbrow, *PNT Security Technologist*
*Spirent Communications*

Mr. Guy Buesnel noted the briefing would focus on interference and spoofing. Spirent's products simulate satellite constellations and signals with the objective to provide analysts a context for checking GNSS robustness. Spirent also provides simulators for users less versed in PNT technologies and requirements. The vulnerabilities of GNSS are well known, so this briefing instead focuses on some lesser known cyber vulnerabilities that are not specific to GPS, but to PNT systems generally.

Much of the information on jamming is underreported and anecdotal. There a number of readily-available jammers. There is much disinformation on the effects of these jammers. For example, one user claimed his jammer produced a power level so low that it did not radiate outside of his automobile. Although the user didn't say how he knew this, we know this is a physical impossibility.

Interference can be in-band or out-of-band, where the latter is just as hazardous. In China, there are online offers for 100-watt jammers, and specifically for installation on drones. In Australia, a jammer caused a drone to lose control and land on a roadway; though luckily no one was injured. Keeping track of the proliferation of jammers is difficult. Spirent has been tracking interference events to, in addition to determining its location, to play back the data into equipment that creates scenarios for users to test system robustness. This, in turn, helps users determine what is reasonable to spend on mitigation.

To date, spoofing has been mostly considered as the "poor relative of jamming." Spoofing used to be difficult to accomplish, but that is no longer the case. For instance, two Chinese researchers, for less than $1,000, built a radio-based spoofer that directs a drone to fly into a restricted area, or make a parked car appear to be submerged. These researchers presented their work at a public seminar attended by over 800 persons. In December 2016, drivers in St. Petersburg and Moscow were re-routed as much as 30 miles. Also, just last week, a Russian company reported it was selling systems to allow drones to fly into restricted areas by mis-reporting the drone's location. Some receivers are easy to spoof. Sometimes, when spoofing degrades receiver's timer it does not recover even after spoofing is halted. These developments merit careful attention.

Ms. Neilan asked how a receiver can be monitored against spoofing.

Mr. Buesnel said often something in the receiver software is not functioning properly. Sometimes fake signals can be warned against, but in one instance the receiver, having reported that the data as faulty, accepted it anyway.

Ms. Neilan asked what the targets of the spoofing was.

Mr. Buesnel said it was a cellphone.

The next topic is how to evaluate resilience. Information technology attacks on telephones began in the 1970s, and RF threats came in later. It is important not to wait until after some disastrous occurrence. Also, many persons have an unfortunate" blind trust" in GPS. Such "over trust" of GPS has, for example, caused two ships to collide even though the data they were using said the ships were still 500 meters apart.

Mr. Burns noted that, when testing drone systems, GPS is intentionally turned off. The absence of agreed upon performance standards is a problem and, thus, it is difficult to tell if a fault is with the GPS component or with another aircraft system. How could this be addressed?

Mr. Buesnel responded that detection is 9/10ths of the law. Standards bodies are not necessarily the way to go, because they're not always sufficiently sensitive in responding to rapidly-changing circumstances.

Mr. Goward noted that the Society of Automotive Engineers (SAE) is working to develop standards for autonomous vehicles.

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**Automated Detection and Identification of GNSS Interference**
Events at the United Kingdom Border
Mr. Billy Marshall, *Research Systems Engineer*
*Chronos Technology*

Mr. Marshall explained that Chronos Technology was founded in 1986 with the objective to specialize in PNT systems. In the past decade, it has particularly worked in conjunction with Bath University on techniques for detecting and locating sources of interference in the GNSS bands. Today's briefing focuses on recent efforts at a large British port to identify sources of interference.

There are a number intentional GNSS jamming sources including, most commonly, efforts to thwart employee-tracking systems. Jammers can also be used to cloak illegal activities, such as vehicle hijacking and car theft. Jamming is most common on highways near airports. Mr. Marshall presented multi-year information on the monitoring of jamming. He identified two test locations: one on a motorway near an airport, and the other in a city. While approximately five events per day were identified at each location, in the city the mean duration of the events were four times greater, likely because the vehicles carrying the jammers are moving more slowly in heavy traffic.

A current project is "JammerCam," which can detect a jammer in a passing vehicle, thereby triggering a camera to record the license plate and send the data to a server. The image capture allows the creation of a database of vehicles engaged in jamming. Most of the system's components are off-the-shelf. The detection algorithms of this system are continuously being improved.

Ms. Neilan asked in how many places is this system operating.

Mr. Marshall said at present they are being used for trial near entry and exit points of a major port. A follow-up trial will begin in a few months.

Dr. Parkinson asked if consideration has been given to marrying this technology with to one that identifies the license plate number of the vehicle engaged in jamming.

Mr. Marshall said this will be done the project's next phase.

During the seven month proof-of-concept at a port, approximately 2,000 vehicles were monitored each day, with one detection for every 350 vehicles. The highest daily total of detections was 22. There were several serial offenders, such as a driver using different trucks each day. It is possible this was a case of non-intentional jamming due to a faulty antenna. The driver was asked to have his antenna fixed. Fewer detections occur on weekends, when traffic volume is lower. The most frequent detections are between 10 a.m. and 4 p.m. The port has a two-lane entrance. If vehicles enter simultaneously then it is not possible to tell which one of them is jamming. Currently it is not possible to distinguish between nearby "low power" disruption and a further distant "high power" disruption. Detection is possible only if the vehicle in question is moving past the sensor. A central question is how best to use the information that is captured.

Mr. Stenbit said the technology does not seem scalable: ranges are short and motion is required. The issue of scalability has been raised before at similar briefings to the Advisory Board.

Mr. Marshall said the system works well in such setting. In terms of scaling, monitoring can still be done at every entrance to the port.

Mr. Higgins asked if any study has been done as to how much of the jamming problem can be attributed to mischief.

Mr. Marshall said he has not.

Mr. Higgins said more information would useful as current reporting is heavily anecdotal.

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**Blended AGNSS & Enhanced Loran (eLoran) for Trusted Time & Location Services**
Mr. Stephen Bartlett, *UrsaNav &* Dr. Eric Derbez, *iPosi, Inc.*

Mr. Bartlett noted the recent issuance of a report by the UK government on how a GPS interruption would affect that nation, particularly on transportation and supply chains. Losses are estimated at one billion Pounds Sterling (GBP) per day of a nationwide disruption of service over a five-day period. In Mr. Bartlett's view, this demonstrates the need for a variety of backup arrangements to GPS (and GNSS). The specific arrangement depends on the circumstance/application where GPS is used. Enhanced Loran (eLoran) has an important role to play as a backup for many users.

Dr. Derbez said he would discuss a proposal to anchor all the critical infrastructures that make use GPS. His company is a venture-backed start-up based in Boulder, Colorado, that designs and integrates very sensitive GPS receivers. One of these receivers was placed in a two-story concrete building in Boulder and demonstrated it could recover a position fix even at 11 feet below grade. Critical infrastructures that require precise, secure, and trusted timing, include power distribution grids, telecommunications, and the financial sectors. In regards to the power grid, in 2003 there was a major power failure in 2003 on the U.S. Eastern Seaboard that took years for engineers to figure out what happened. In 2007, following the deployment of synchophasers, the cause of a blackout in Florida was determined within two days. The telecommunication sector's long-term wish is to be able to withstand a permanent GPS outage. There have been a number of conversations about using eLoran as a backup, which is the best and least expensive means to create a suitable response, but this would still take some time to deploy. Four eLoran would be sufficient to cover the continental United States. Incorporating a new system with a 'closed' Loran side signal would help because, by definition, one cannot spoof a system that cannot be replicated. In essence, this combination would do for the civilian infrastructure what the GPS P(Y) code does for the military. At present, this approach can only be used in stationary receivers. However, because eLoran experiences much less signal loss in basement settings, users could recover inside a building with a loss in the order of, approximately, 10 dB. In summary, the objective of this proposal is to combine two great technologies that would require only four Loran installations which already exist. Industry-specific trials are expected to be held late in 2017.

Mr. Stenbit noted the board frequently discusses eLoran.

Adm Allen asked if the proposed four Loran sites are legacy Loran-C sites.

Dr. Derbez said they are.

Ms. Neilan asked what the user equipment requirements are.

Dr. Derbez said one can literally run it on a Windows-based platform. The costs include a tuner, a good oscillator, and the antennas.

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**Assured PNT for the United States**
Dr. Gene McCall, *Former Chief Scientist*
*U.S. Air Force Space Command*

Dr. McCall said he would discuss a number of unconventional approaches to resolve a range of issues. What is important is maintaining PNT rather than only preserving GPS service. It would take the simultaneous failure of eight to ten satellites to halt GPS, the probability of which is infinitesimal. A widely proposed backup is eLoran. Thus, it would be useful to determine how GPS (and GNSS) and eLoran work together rather than just using one to back up the other. While GPS and eLoran are adequate to the present, they may not be adequate to the future when more precise timing requirements and better accuracy is needed for cyber-defense and high-precision applications such as driverless automobiles. System performance has always exceeded its requirements and, thus, people typically use a particular system not to the limit of its specifications/requirements but, rather, to the limit of its capabilities.

Thus, performance must be achieved and a system should enable a pathway for future technological improvements. Dr. McCall noted that his own definition of an "unjammable" system is one that can resist a 1 kW jammer at distance of 1 km. This requires, approximately, 100 dB of protection. In his view this can be achieved. Jammers commonly used by truck drivers can be ordered from the website 'jammerfromchina.com' for $200-300. This issue has been raised with DHS, which declared this was an FCC problem. In turn, the FCC said that while it had the authority to takedown websites, such authority does not extend to non-US sites. The FCC noted that that if jammers are being imported, then it becomes a DHS problem. Dr. McCall then presented a photograph of what has been reported to be Russian workers installing GPS jammers, to be used in the event of a U.S. cruise missile attack on Russia.

Ms. Neilan asked if the Russian jammers also affect GLONASS.

Dr. McCall said they would jam all GNSS signals.

Dr. McCall noted that North Korea has carried out concerted jamming attack on South Korea. As of yet, concerns about jamming in Europe are limited. Jamming is a growth industry where stronger jammers are increasingly being produced at lower costs.

Regarding WAAS, if such system were disrupted, then 1,815 airports would lack precision approach capability. The National Transportation Safety Board (NTSB) considers non-precision approaches to be hazardous; further, the United Parcel Service (UPS) prohibits its pilots from flying such approaches.

A protected GNSS system should incorporate the following features:

- For increased anti-jamming: coherent detection of all satellites in view, high chipping rate (10 MHz for P, L5 codes), and an external source of the navigation message to allow extended correlation time.
- For improved accuracy: short ephemeris and clock update times.

For coherent detection the system locks on to all satellites in view simultaneously. The initial position fix typically has errors as large as 200 m. Thus, the system starts with an eLoran position to reduce the initial error. This approach provides protection against jamming. Also, eLoran signaling provides a 9th pulse modulation to transmit the GPS navigation message and precision ephemeris and time. An integrated system would improve accuracy, reduce position errors, provide a 15-minute ephemeris that reduces errors below 1 meter and the time error to less than 1 nanosecond.

Ultratight coupling of GPS and an Inertial Navigation System (INS) provide jamming resistance as high as 65 dB. Incorporating an eLoran carrier phase measurement would allow to form a "Resilience Triad" to raise jamming resistance to 90-100 dB. Furthermore, spoofing would be eliminated as a threat as only the ephemeris transmitted by eLoran would be considered valid. The GNSS and eLoran solutions must agree; otherwise, false signals are ignored or treated as jamming. Jamming resistance would also raise the effective satellite power and enable indoor navigation.

A way ahead for such a system includes the U.S. Coast Guard as the logical manager. The Coast Guard has done an outstanding job regarding eLoran and, at its academy, has the necessary technical capability. Dr. McCall noted that, it is unclear to him who has final authority. Sometimes the high-level committees, such as the PNT EXCOM, tend to disperse responsibility in ways that may not be productive.

Dr. Parkinson noted that Dr. McCall's straightforward comments reflect years of close engagement with the issues and with the U.S. Air Force.

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*[The Wednesday, June 28, 2017 session of the PNT Advisory Board adjourned at 5:05 p.m.]*

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*[The Thursday, June 29, 2017 session of the PNT Advisory Board convened at 9:00 a.m.]*

**Board Reconvenes**

Mr. Stenbit noted that the morning's discussion would focus on the board's input to the meeting of the PNT EXCOM. Two issues need to be discussed at the PNT EXCOM:

(1) Making the new PNT EXCOM members aware of the issues they're inheriting, specifically: interference to the GPS, and eLoran.
(2) Matters associated with transition into a new administration. At the last PNTAB meeting it was agreed to develop an information package that could be included in administration briefings, and working groups (WGs) were established to develop briefings to cover specific areas (agriculture, aviation & aerospace, etc.).

On the information package, it is important to include concrete recommendations rather than only subject matter briefings on how GPS is being used. Therefore, the intent this morning was to have each WG discuss specific revisions to the current draft.

Mr. Stenbit asked if any other board member has another topic they wish to address in the morning session.

Mr. James J. Miller, Executive Secretary, noted that Dr. Camacho-Lara has expressed an interest to make a presentation on current discussions at the UN regarding spectrum interference. Also, Dr. Gerhard Beutler expressed an interest to discuss an IGS White Paper and endorsement by the board.

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**PNT Advisory Board Information Package for Transition Briefings**

1. Agriculture WG: Mr. Ron Hatch

Mr. Hatch said his WG believes the biggest threat faced is encroachment on the GPS/GNSS L1 signal, either directly below or within the designated spectrum. Agriculture, as a high precision function, needs the entire bandwidth. Precision agriculture provides enormous benefits: $30+ billion annually in the U.S. alone. Use of precision agriculture is ubiquitous. Any limits placed on that use could be catastrophic.

Mr. Stenbit asked if any figures exist on the productivity improvements created by one-inch precision level.

Mr. Hatch said he has no figures for this.

Dr. Parkinson reported that in California, precision agriculture is credited with reducing by 10% the $200 million spent yearly on fertilizers.

Mr. Hatch added that precision agriculture makes possible to work in fog or at night.

Mr. Higgins noted that spraying at night reduces waste.

Mr. Hatch noted additional benefits from such capabilities include, for example, land contouring.

Dr. Parkinson said a farmer investing $40,000 in equipment will recoup its investment within four months. Once the equipment is paid, it still has a five- to ten-year use life.

Mr. Stenbit noted that the report to the EXCOM will likely reach the Deputy Secretary of Agriculture. If the report can substantiate the savings, then it is likely to have an impact.

2. Aviation and Aerospace WG: Dr. Per Enge

Dr. Enge noted that his WG has added numbers on GPS penetration into aviation fleets. He showed a photograph of the GPS equipment on a Boeing 777 flight deck. All new commercial airlines put into service since 1990 carry GPS. Information has also been added on the use of GPS in rocket launches. Also, Terrain Awareness Warning System (TAWS), which uses GPS, has become a major life-saving innovation.

Mr. Burgett noted that use of TAWS is now mandatory.

Ms. Neilan noted that the subcommittee's presentation references reducing export control barriers for space-borne receivers. Is this a reference to ITAR (International Traffic in Arms Regulations)?

Dr. Enge said it is. While he understands the value of the ITAR prohibition, in practice it has lost force as other nations developed their own capabilities. Also, the subcommittee believes that spectrum interference represents a direct threat to aviation safety.

Mr. Stenbit said in some circumstances – e.g. rescue helicopters - ITAR prohibitions can be mitigated. The subcommittee should consider the body of issues related to ITAR.

Mr. Murphy commented existing anti-spoofing technologies are difficult to export, though he's noted some recent flexibility on this.

Mr. Stenbit said his corporation, TRW, has purchased some units from Germany. The units did not work but, ironically, because of ITAR restrictions they could not be sent back to Germany for repair.

3. Critical Infrastructure and Timing WG: Adm Thad Allen

Adm Allen noted he would cover three main points. First, GPS is ubiquitous; it enables all critical infrastructures. Second, the connection between GPS and cybersecurity needs to be made clearer. He emphasizes GPS whenever he discusses cybersecurity with any senior leader, and more often than not this comes across as an epiphany to the person listening. Third, timing is the top priority concern, followed by safety-of-life applications and the power distribution grid. The board would benefit by having a more detailed position on timing and, perhaps, this could be addressed at its next meeting.

Mr. Goward said he strongly approves of the statement on cybersecurity. GPS should be recast as, among other things, a cybersecurity tool. This would involve reorganizing the WG's presentation provided there is time to do this.

Mr. Stenbit said that, provided the group proceeds with deliberate speed, there is time to incorporate these ideas.

Mr. Miller said that Mr. Martin will undertake the preparatory work for the presentation to the next PNT EXCOM meeting.

Mr. Stenbit urged the board to make all final edits to the information package by July 3.

Dr. Axelrad asked if there is consensus on whether the WG recommendations are in line with the general thinking of the full board.

Mr. Stenbit said this is a good question, and asked Mr. Miller to circulate the draft information briefing to all board members to elicit any strong disagreements, if such exist.

Dr. Parkinson agreed, and asked Mr. Miller to include in the write-up a summary of the recommendations from all WGs.

Mr. Stenbit concurred, and changed the deadline for comments to close of business on July 7 in order to give additional time to make these changes.

Mr. Miller said that everyone involved should work from the same document version, and Dr. Oria has volunteered to undertake configuration control. Also, while July 7 is the deadline to make edits/comments, July 14 should be the deadline for completion document. This will give Mr. Martin, Ms. Van Dyke, and others the time needed to review the document.

Mr. Stenbit endorsed this plan and, hearing no objection, said he adopted it.

Mr. McGurn said the recommendations for the GPS ground control segment appeared redundant across a few WGs. Also, the discussion focuses on monitoring but not on what this is intended to achieve. For example, the National Geospatial-Intelligence Agency (NGA) currently monitors all GNSS and regional systems 24/7, but only to the extent of getting the presence of the RF signal and modulation; that is, no detailed analysis is being conducted.

Ms. Ruth Neilan said the ICG has encouraged the IGS to set up a project along those lines, and she will provide background information to the board.

Mr. McGurn asked whether this would be appropriate for the recommendations in the Military WG's write-up.

Dr. Axelrad noted the Aviation and Aerospace WG has similar recommendations. These are highly detailed technical matters.

Mr. Stenbit said his preference is to first create a long list, and then pare it down.

Dr. Parkinson said he believes that a list of more technical considerations could be added to the recommendations the board presents to the PNT EXCOM. However, the PNT EXCOM may not be conversant on such technical matters.

Mr. Stenbit said he does not agree in adding the technical considerations. The document needs to be a principal set rather than a detailed set. He shares Dr. Enge's perspective: there are some things that could be done, but are difficult to do within the government coordination process. His preference is that principle be espoused with an example.

Mr. Goward said, relative to civil monitoring of GPS, that the principle should be that the U.S. monitor the civil signal to assure GPS commitments to the international community are being continuously met. A good way to do this would be through the GPS OCX system.

Adm Allen said that four or five items fall into the policy realm. Also, it is difficult to secure agreement on policy matters.

Mr. Stenbit suggested that a general statement be made, followed by one or two examples.

Mr. McGurn asked whether the U.S. military would really want to take on monitoring responsibility.

Mr. Goward noted that commitments have been made to the international community relative to signal performance standards. Thus, the U.S. government should show it is meeting those commitments.

Mr. McGurn said his concern is monitoring non-U.S. systems. Whose responsibility is it to monitor them, and how?

Mr. Stenbit said the central question is whether enough is being done.

Col Gleckel noted that multi-GNSS is a resiliency builder for the military. There are policy and funding questions. If one monitors without integrating the results into military receivers, then it has not provided a benefit. In his view this discussion belongs in the policy section, with the statement that it should also apply to military users.

Mr. Stenbit said his intent on discussing monitoring is just to get on the table issues that have to be addressed. The board is not tasked to give advice to the military. Thus, he is comfortable addressing this in the policy section. He asked if Adm Allen could re-draft the pertinent section.

Adm Allen said he has been reflecting on the circumstance of governance structure by committee (such as the PNT EXCOM). Is it, perhaps, time to rethink the governance structure? When something becomes a policy matter it falls outside the purview of the PNT EXCOM. Perhaps a conversation is needed on the national strategy. A policy document creates a framework for discussing the basic issue of how issues between agencies and departments are to be reconciled and what general principles should be applied.

Mr. Stenbit said he believes the question of what job is whose responsibility is already sufficiently confusing. While the board can achieve something by reaching consensus, it is unlikely it can undertake the task of reorganizing how the federal government does business.

Mr. Goward said the Policy WG addresses multi-GNSS issues, rather than larger issues. Its statement on multi-GNSS issues is good, but the statement on larger issues is not.

Mr. Stenbit said two examples could be cited: First, multi-GNSS; second, the question of system specification versus performance specification. These are examples of the need to reconcile questions across departmental and other barriers.

Adm Allen said he believes the Section 25 discussion needs to reach the table.

Mr. Stenbit urged Mr. Allen to consider how to best proceed on the matter. For example, it is of consequence that bureaucratic constraints prevent taking advantage of new technologies for air traffic control. This is a policy issue. In his view the air traffic control issue, and multi-GNSS, are appropriate as general cases. However, he does not wish to push too hard on them as it is unclear to whom this responsibility could be assigned.

Adm Allen said marketplace pressures will continue to push in the direction of multi-GNSS receivers and other matters.

Mr. Goward said there is a general issue about governance and policy uncertainty. He favors a general policy statement, which discusses multi-GNSS and, perhaps, one other subject as a case point.

Mr. Russell asked if it is correct that GNSS monitoring should not be a military responsibility.

Mr. Stenbit said that is his understanding.

Maj Gen Chilton said the question of monitoring will be decided between the military and the FAA. She is not going to claim responsibility for monitoring if someone else is judged as being appropriate for the task. Maximum clarity is needed on who takes responsible for what.

4. Military WG: Mr. Russell McGurn

Mr. McGurn said has concerns about the tenor and approach of the discussion. The new administration will bring a new set of appointees and few, if any, will have a strong engineering background. There is only one point that has to be made; namely, that GPS is essential. The newly-constituted PNT EXCOM is unlikely to make immediate decisions. If the board can affirm to the PNT EXCOM that GPS is essential to every department represented on that body, then that message will filter down. This is the essential thing to achieve. If too many lesser matters are put forward then this key message may get lost.

Mr. Stenbit agreed.

Adm Allen suggested that Mr. Miller could be asked to cull the recommendations from the various briefings and reduce them to a two-page document that could be included as an Executive Summary for the information package.

5) Scientific WG: Dr. Gerhard Beutler

Dr. Beutler said he would be presenting a briefing on "Multi-GNSS: Update, Latest Developments and Science Issues in Transition Documents," prepared by himself, Ms. Neilan, Mr. Higgins, and Mr. Dimmen. The presentation will be limited to issues pertinent to administration transition issues. GNSS now consists of four truly global national systems and three regional systems. It is no longer the case that all satellites are in similar MEO (Medium Earth Orbit) orbits. There are also

geosynchronous orbits (GEO) and highly elliptical orbits. From the science perspective, GNSS is fundamental to earth observation and monitoring. Should GNSS not be available, the results could be catastrophic to science. He is worried that, for example, a country might decide to ban the use of other particular GNSS within its territory. Since the 1st draft of the Scientific WG's paper was prepared there have been a number of developments. There is new information available on the Galileo satellites, and the second Quasi Zenith Satellite (QZS) has begun operations. Also, an IGS White Paper on GNSS that has been developed provides a concise format of the minimum GNSS satellite performance information needed to adequately analyze data from GNSS monitoring for highest accuracy applications. Individual GNSS providers have been reluctant to share such information for fear of revealing confidential information. Therefore, he has drafted a statement allowing it to release information for scientific use but still allowing GNSS providers to protect their intellectual capital. There are dangers in not having sufficient information; for example, this can lead to inaccurate orbital data and, in turn, result "infect" all the derived science products and modeling tools. Dr. Beutler said he is not seeking a recommendation to the PNT EXCOM but, rather, an endorsement of this position by the board.

Dr. Parkinson said the board should encourage continued use of GPS in scientific applications such as geodesy.

Dr. Axelrad said such an endorsement would be very valuable, but questioned whether the satellite manufacturers will adhere since it requires them to release information they may regard as proprietary.

Dr. Beutler said he does not expect to have the information in the immediate future, and that this information is not specific enough to adversely impact proprietary issues.

Mr. Higgins said Dr. Axelrad is correct. However, this is the first time such a request is being made where there is a deliberate compromise that does not seek every detail of every GNSS satellite.

Mr. Stenbit said it is preferable to put a compromise on the table rather than to present something that could be seen as a demand for "unilateral surrender."

Dr. Beutler said it is never the case that a satellite is so well known that there is no need to model some of its aspects. For the time being, however, he feels the request is sufficient.

Mr. Stenbit said that he, as Chair, is uncertain what he would do with this recommendation. Perhaps it could be useful to the State Department in negotiations. This matter merits further thought.

Ms. Neilan said an endorsement from the board would be very valuable within the international GNSS community. A meeting is scheduled for the following week in conjunction with an IGS workshop, and such an endorsement would be helpful.

Dr. Beutler agreed.

Dr. Parkinson noted that "openness" is a central aspect of U.S. space policy. Thus, this request is in line with other efforts to encourage other GNSS providers to be forthcoming about problems or issues that may arise.

Mr. Stenbit asked if anyone objects to the board making such an endorsement.

Dr. Enge asked if such a statement could, potentially, be irritating to the military.

Dr. Beutler said he sees this as a request from the scientific community to all GNSS providers, GPS included.

Mr. Stenbit said it would be easier for him to endorse a statement that other GNSS systems operate with openness on a par with GPS. He invited Dr. Beutler to draft a resolution so the board has clarity on what it is being asked to endorse.

Dr. Beutler said he will include the statement in the upcoming revision to Scientific WG paper.

Mr. Stenbit said he thought Dr. Beutler would prefer an endorsement made at the present meeting. If so, then a written statement of the endorsement is needed.

Dr. Beutler, quoting from the screen, noted: "The Advisory Board takes note of the IGS White Paper on GNSS metadata and endorses its application to all GNSS systems." He added that a refined wording would be presented at the final discussion of the meeting (see below p. 32, *General Advisory Board Discussion*).

Mr. Stenbit said the statement should reference a request for a degree of transparency equal to that that had been provided by GPS.

6) Spectrum WG: Dr. Sergio Camacho-Lara

Dr. Camacho-Lara noted that in Tuesday's discussion, a statement was made in the original draft being prepared for the administration transition team that most countries have laws against jammers, but it turns out that is not completely true as indicated below. Two key points are highlighted in the "utilization and benefits" section: (1) users are benefiting across a broad range of applications; and (2) GPS innovation is forward-looking and, therefore, is expected to produce new benefits in the future. Existing spectrum regulations have been developed by a decades-long process within ITU. The existing Radio Regulations are a result of agreement that anything that raises the threshold noise floor level is detrimental to all

applications, particularly those requiring high precision. The strongest point to convey to the transition team is that we need to respect these regulations, and lead efforts to convince the international community to enable interference detection and mitigation measures locally. All national regulations should be in accordance with the ITU standards. Dr. Camacho-Lara presented, though not as a proposal for a formal recommendation, actions that would make it easier to identify real and potential spectrum interference. These include urging all nations to enact laws against jamming. Currently there is ambiguity in that in some places it is illegal to sell jammers, but it is legal to import them. In other cases, it was not illegal to own jammers, but illegal to use them. Work is proceeding at the ICG level. Actions to ensure that the Radio Regulations are followed by monitoring the RNSS spectrum where GPS and other GNSS operate have been presented at the Scientific and Technical Subcommittee of the UN Committee on the Peaceful Uses of Outer Space (COPUOS), through which they are being socialized within the international community. The report to the Subcommittee urged adoption of the language developed by the ICG. The UN will begin to respond in 2018. The board could, potentially, provide its own endorsement in whatever language it deems appropriate.

Dr. Parkinson noted his understanding is that the State Department has accepted the position outlined by Dr. Camacho-Lara. That being the case, further action by the board could potentially cause 'congestion.'

Dr. Camacho-Lara said Dr. Parkinson's understanding is correct and, thus, he is comfortable with the board just noting that this process is of consequence.

Dr. Parkinson said this represented an extension of the "openness" policy in that it requests other providers to put forth a variety of information.

Dr. Camacho-Lara said he expects the invitation to be made by the UN General Assembly for countries to provide such reports to be accepted, at least in its early stage, only by a few countries. However, he expects that over time this will lead to reports from many more countries.

Adm Allen sought and received confirmation that the U.S. is a signatory to the treaty in question.

Mr. McGurn took issue with Dr. Camacho-Lara statement that GNSS providers already supported these steps. Many jammers come from China and Russia, both countries being major GNSS providers. Also, much of the jamming activity is local.

Dr. Camacho-Lara clarified that he meant to say that the providers of the GNSS systems support these steps. He did not intend to say that no one in GNSS provider nations is engaged in producing jammers.

Mr. Miller said he thinks the report has some excellent points, and asked Dr. Camacho-Lara provide a copy for the www.gps.gov website.

Mr. Faga urged that the board only report to the PNT EXCOM what it wants to know.

Dr. Pace said that COPUOS met in June, and the efforts of the ICG and the scientific and technical subcommittee brought forward. Several paragraphs were adopted by consensus, including one on jamming. The measure was adopted, without argument, by 84 member countries. The report will now go to the UN General Assembly. There is a benefit in having the board lend its imprimatur since it has good international standing as a technical agency. This is a good non-confrontational way to help shape norms of behavior, particularly for those nations that are not GNSS providers. The effort is not telling individual countries how to proceed, but that they should pay more attention to issues of jamming and mitigation.

Mr. Stenbit asked what is being sought from the board.

Dr. Camacho-Lara said he hopes the board will note the work that is going forward within the Scientific and Technical Subcommittee of COPUOS.

Mr. Stenbit said he will support any statement stressing the need to detect interference, but he needs a formally-worded motion.

Dr. Pace proposed: "The PNT Advisory Board notes with appreciation the work of the Scientific and Technical Subcommittee of COPUOS and encourages ongoing efforts on this most important subject of interference and mitigation of GNSS signals."

Mr. Stenbit asked if there is any opposition to the adoption of this statement. None was forthcoming.

7) Transportation (Non-Aviation) WG: Mr. Russell Shields

Mr. Shields noted he has known the deputy secretaries of the DOT since the 1990s. The current deputy was confirmed six weeks ago. He is a lawyer and has not yet had a briefing on GPS. Thus, in his view most of the items discussed so far are of no current interest to that person. GPS could make it, perhaps, to the new DOT deputy secretary's "top 100" concerns, but not the "top ten." However, many of the things that would be in his "top ten" are critically dependent on GPS. Thus, it is crucial that the new deputy secretary understand that GPS is highly important. Beyond that the deputy secretary would refer to Ms. Van Dyke for additional information.

Mr. Shields noted his presentation focuses on simple statements. He is confident that the value to transportation stated for GPS – e.g. $25 billion annually – is too low. Also, many of the things DOT is interested in are new: automated driving; vehicle-to-vehicle communications; drones, etc. Thus, the WG included pictures to facilitate the 'implantation' in the memory of those reading it. The basic message is: "GPS is used all over; you don't hear about it because it works. Make sure it keeps working. Do not be the administration that messes up GPS."

*[With Mr. Shields' presentation, the WG reports are completed]*

Mr. Stenbit said he believes the statements presented had been very good and could be edited down to a manageable length and handed to the appropriate individuals. There are, however, two possible sticking points: the statement on policy and the statement on spectrum. Comments from board members are due by end-of-day, Friday, July 7. Those comments would be incorporated in the document by Dr. Oria by Friday, July 14, and recirculated to the board for final review. It is important that the board get ahead of events, rather than merely reacting to things that have already occurred. The entire package should be completed by early August. This has been a very good exercise and congratulated all participants.

* * *

**General Advisory Board Discussion**
*All PNT Advisory Board Members*

The discussion turned to the statement offered by Dr. Beutler for endorsement by board:

> *"The PNT Advisory Board takes note of the IGS White Paper on 'Satellite and Operation information for Generation Precise GNSS Orbit and Clock Products' and endorses it as a minimum set of information required for the highest accuracy of GNSS applications."*

Mr. Stenbit said he wished to exercise the chairman's prerogative to add: "and we encourage all such systems to provide such data at a transparency consistent with that GPS is already providing." This is useful to establish a standard against which the U.S. could be judged and which others could use as a reference.

Dr. Beutler said some others might take offense at such a statement.

Dr. Stenbit said he does not intend to give offense, but to give a goal to be met. If the board is to endorse something, it should be something within the realm of what GPS has accomplished.

Dr. Axelrad asked if the "White Paper" referenced is available.

Dr. Beutler said he has submitted a copy to Ms. Chen (support staff member).

Ms. Chen said she would distribute it to board members.

Ms. Neilan said the endorsement would be very useful at several scheduled meetings and, in her view, particularly welcomed by Mr. Turner of the State Department.

Dr. Enge expressed concern that the new words represented a bigger request than GPS is, in fact, currently providing. The chart in the White paper does not, among other, include information on the center of mass of GPS satellites. The missing information could be obtained, but he is not prepared to speak for the Air Force on how much effort this would require.

Col Gleckel said that, given the caveats expressed, he believes the data is readily available.

Mr. Hatch said most of the items listed in the chart are equally available.

Ms. Neilan said that ICG has in the past asked for similar information from system operators. The information existed for GPS, but not for the other GNSS systems.

Mr. Stenbit said that if GPS needs to provide additional information, he has no difficulty with it being requested.

Dr. Beutler proposed postponing the discussion to the next PNT Advisory Board meeting. He expressed concern with some of the additional text being proposed. He also suggested inviting Dr. Oliver Montenbruck to discuss the topic at the next board meeting.

Mr. Goward said this is a complex issue, and that he welcomes the opportunity to study it in advance.

Mr. Stenbit said he is trying to respond to the time concerns expressed by Dr. Beutler and Ms. Neilan.

Ms. Neilan noted that the 'White Paper' is public, and Mr. Turner would be happy if at this point it remains as a draft.

Dr. Pace said recommended balancing the principle with the specifics. A more general statement about openness and reciprocity on technical data could be helpful, and proposed the following wording:

*"PNT takes note of IGS White Paper … and encourages the open sharing of technical information on GNSS systems important to the international geodetic community consistent with national security and intellectual property constraints."*

The version finally adopted by the board thus reads as:

*"The PNT Advisory Board takes note of the IGS White Paper on 'Satellite and Operation Information for Generation Precise GNSS Orbit and Clock Products' and endorses it as a minimum set of information required for the highest accuracy of GNSS applications, and encourages the open sharing of technical information on GNSS systems important to the international scientific community consistent with national security and intellectual property constraints."*

Dr. Beutler thanked Dr. Pace for his invaluable help in this scientifically relevant matter.

Dr. Enge asked if the Air Force has any objections. None were stated.

Mr. Martin said the new wording does not suggest anyone is being blamed.

Mr. Stenbit stated that, without further objection, the record will show that the PNT Advisory Board approves this statement and authorizes Ms. Neilan and others to make whatever use seems appropriate.

* * *

*[The Thursday, June 29, 2017 session of the PNT Advisory Board adjourned at 1:00 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), Former Assistant Secretary of Defense
- **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. Tom Powell**, Aerospace Corporation
- **Dr. Scott Pace**, George Washington University

## Appendix B: List of Presentations

PNT Resilience/Mr. Harold W. Martin III

DOT GPS Adjacent Band Compatibility Assessment/Ms. Karen Van Dyke

The NASCTN "LTE Impacts on GPS" Project/Dr. William Young

Iridium Briefing on Spectrum Landscape, Impact of Proposed Adjacent Terrestrial Broadband Network on Satellite Operations/Mr. Bryan Tramont; Ms. Maureen McLaughlin

Global Positioning System Update to PNT Advisory Board/Col. Gerry Gleckel

Update on GNSS Performance Monitoring/Dr. Yoaz Bar-Sever

ScaN Next Generation Communications Capabilities/Mr. Phil Liebrecht

National Space-Based Positioning Navigation and Timing (PNT) Advisory Board: 19th meeting/Mr. David A. Turner

Cyber-Physical Security Aspects of Robust PNT/Dr. Rafal Zbikowski

GNSS Threats, Attacks and Simulations/Mr. Guy Buesnel and Mr. Mark Holbrow

Analysing GPS Jamming Incidents at the UK Border/Mr. Billy Marshall

Blended AGNSS & eLoran for Trusted Time & Location Services/Mr. Steven Bartlett and Dr. Eric Derbez

Assured PNT for the United States/Dr. Gene H. McCall

Multi-GNSS: Update, Latest Developments and Science Issues in Transition Document/Dr. Gerhard Beutler, Ms. Ruth Neilan, Mr. Matt Higgins, and Mr. Arve Dimmen

## Appendix C: Sign-In List

*Wednesday, June 28, 2017*

PNT Advisory Board:

Penny Axelrad
Gerhard Beutler, AICCB
Scott Burgett, Garmin
Sergio Camacho, CRECTEALO
Martin Faga, PNTAB
Matt Higgins, IGNSS
Ruth Neilan, JPL

NASA:

Barbara Adde, NASA/SCaN
Ben Ashman, NASA
Tony Foster, NASA
Paul Kim, Aero/NASA
John Labrecque, NASA Overlook
Phil Liebrecht, NASA
Lisa Mazzuca, NASA
William Notley/NASA Ames
Joel Parker, NASA
Amanda Shelton, NASA
Victor Sparrow, NASA
Doug Taggart, NASA Overlook
Stephanie Wan, NASA Overlook

Other:

Beau Backus, NOAA
Jean-Luc Bald, EU embassy
Yoaz Bar-Sever, JPL
Steve Bartlett
Frank Bayer, NASA
Guy Buesnel, Spirent
Pauline Cook, U.S. Coast Gard [retired]
Ben Corbin, IDA
Brad Davis, Hellen Systems
Dee Ann Davis, *Inside GNSS*
John Fischer, Spectracom
Sharon Genco, NIST/NASCTN
Adam Greenstone,
Steve Grupenhagen, SAF/AQS
Rick Hamilton, U.S. Coast Guard
Derek Khlopin, NTIA/DOC
John Kreiter, Sechan Electronics
David Kunkee, Aerospace
Max LaRosa, Thales
David Lubar, Aerospace Corporation
Brad Marshall, Chronos
Gene McCall, self
Carolyn McDonald, NavTech GPS
Mitch Navins, Strategic Synergies
Scott Pace, George Washington University
Tony Park, PPA
Lisa Perdue, Spectracom

Calvin Ramos, ASRC Federal
Brian Ramsey, MITRE
Joe Rolli, Harris
Mike Rosso, Continental
Jennifer Saldibar, Sechan Electronics
William Shvodin, NextNav
Brian Tramont, WBK
David Turner, Department of State
Frank Van Grass, Ohio University
Scott Welles, Booz Allen
William Young, NIST/NASCTN
Rafel Zbikowski, Cranfield University

*Thursday, June 29, 2017:*

PNT Advisory Board:

Penina Axelrad, PNTAB
Gerhard Beutler, AIUB
Sergio Camacho, CRECTEALC
Terry McGurn, self
Ruth Neilan, JPL

NASA:

A.J. Oria, NASA/Overlook
Joel Parker/NASA
Stephanie Wan, NASA/Overlook

Other:

Jean-Luc Bald, EU embassy
Jim Burton, National Coordination Office
Guy Buesnel, Spirent
Jason Kim, NOAA
David Lubar, Aerospace Corporation
Frank Van Graas, Ohio University

## Appendix D: Acronym & Definitions

| | |
|---|---|
| ABC | DOT GPS Adjacent Band Compatibility Study |
| AFSPC | Air Force Space Command |
| AIN | Arab Institute of Navigation |
| ARAIM | Advanced Receiver Autonomous Integrity Monitoring |
| ATC | Ancillary Terrestrial Components |
| CMPS | GPS Civil Monitoring Performance Specifications |
| CNAV | GPS Civilian Navigation Message |
| COPUOS | UN Committee on the Peaceful Uses of Outer Space |
| CRECTEALC | Center for Space Science and Technology Education for Latin America and Caribbean |
| 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 |
| EIRP | Equivalent Isotopically Radiated Power |
| eLoran | Enhanced Loran |
| EU | European Union |
| EXCOM | Executive Committee |
| FAA | Federal Aviation Administration |
| FACA | Federal Advisory Committee Act |
| FANET | Flying ad hoc network |
| FCC | Federal Communications Commission |
| FY | Fiscal Year |
| Galileo | European GNSS |
| GB | Gigabyte |
| GDGPS | Global Differential GPS System |
| GEO | Geosynchronous Orbit |
| GLONASS | Russian GNSS |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| GPS-D | GPS Directorate |
| GPS-III | GPS Block III |
| HPP | High Precision Positioning |
| HPR | High Precision |
| Hz | Hertz |
| ICD | Interface Control Document |
| ICG | International Committee on GNSS |

| | |
|---|---|
| IGS | International GNSS Service |
| IGS | International GNSS Service |
| INS | Inertial Navigation System |
| ION | Institute of Navigation |
| IT | Information Technology |
| ITAR | International Traffic in Arms Regulations |
| ISS | International Space Station |
| ITU | International Telecommunication Union |
| ITU-R | ITU Radio Communications Sector |
| JPL | NASA Jet Propulsion Laboratory |
| km | kilometer |
| L1 C/A | 1st GPS Civil Signal |
| L1C | 4th GPS Civil Signal (interoperable with Galileo) |
| L2C | 2nd GPS Civil Signal (commercial) |
| L5 | 3rd GPS Civil Signal (safety-of-life / aviation) |
| LADEE | NASA's Lunar Atmosphere and Dust Environment Explorer |
| LEO | Low Earth Orbit |
| LTE | 4th Generation Mobile Communications Standard |
| M2M | Mobile-to-Mobile |
| M-Code | GPS encrypted signal |
| MANET | Mobile ad hoc network |
| MEO | Medium Earth Orbit |
| MGUE | Military User Equipment |
| MHz | Megahertz |
| MSS | Mobile Satellite Services |
| NASCTN | National Advanced Spectrum and Communications Test Network |
| NASA | National Aeronautics and Space Administration |
| NDAA | National Defense Authorization Act |
| NGBS | Next Generation Beacon Service |
| NIST | National Institute of Standards and Technology |
| NTIA | National Telecommunications and Information Administration |
| NTSB | National Transportation Safety Board |
| NUDET | Nuclear Detonation Detection System |
| OCS | GPS Operational Control System |
| OCX | GPS Modernized Operational Control System |
| QZS | Quasi-Zenith Satellite |
| QZSS | Quasi-Zenith Satellite System, Japan's regional navigation satellite system |
| PNT | Positioning, Navigation, and Timing |
| PRS | Galileo Publicly Regulated Service |
| PVT | Positioning, Velocity, and Timing |

| | |
|---|---|
| RTK | Real Time Kinematic |
| SAE | Society of Automotive Engineers |
| SAR | Search and Rescue |
| SBAS | Space-Based Augmentation Service |
| SCaN | NASA's Space Communication and Navigation Program |
| SSV | Space Service Volume |
| SV | GPS satellite vehicle |
| TAWS | Terrain Awareness Warning System |
| TIM | Timing |
| U.S. | United States |
| UAE | United Arab Emirates |
| UAV | Unmanned Aerial Vehicle |
| UK | United Kingdom |
| UN | United Nations |
| UPS | United Parcel Service |
| USAF | U.S. Air Force |
| VANET | Vehicle ad hoc network |
| WAAS | FAA Wide Area Augmentation System |
| WG | Working Group |
| WSMR | White Sands Missile Range |