SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

NATIONAL SPACE-BASED POSITIONING, NAVIGATION, AND TIMING ADVISORY BOARD

Twenty-Second Meeting

December 5-6, 2018

Crown Plaza Redondo Beach
300 N. Harbor Drive, Redondo Beach, CA 90277

John Stenbit
Chair

James J. Miller
Executive Director

November 5-6, 2018

Crowne Plaza Redondo Beach
Peninsula/Pacific Rooms
300 N. Harbor Drive, Redondo Beach, CA 90277

Agenda

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WEDNESDAY, DECEMBER 5, 2018

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

9:05 - 9:20
Opening Comments: 22nd PNTAB Focus, Priorities & Recent Products: *(1) GPS Topics Paper. (2) Spectrum Memorandum*
Mr. John Stenbit, *Chair*, Dr. Bradford Parkinson, *1st Vice-Chair*

9:20 - 9:45
GPS Program Status & Modernization Milestones
VIEW PDF (3 MB)
Col John Claxton, *Deputy Director, GPS-D, Space & Missile Systems Center (SMC)*

9:45 - 10:10
PNT Efforts by the Department of Homeland Security (DHS) National Risk Management Center
VIEW PDF (446 KB)
Mr. James (Jim) Platt, *Director, PNT Office, Department of Homeland Security*

10:10 - 10:35

Real-World Receiver Testing and the 1dB Criteria Impacts
VIEW PDF (1 MB)
Mr. Guy Buesnel, *PNT Security Technologist, Spirent Communications*

10:35 - 10:50
BREAK

10:50 - 11:15
Securing GPS-based Systems against Signal-in-Space Threats
VIEW PDF (2 MB)
Mr. Jeremy Warriner, *Director of Government Systems, Microsemi*

11:15 - 11:40
European Efforts to Protect, Toughen and Augment GNSS
Maintaining RNSS as a Critical International Resource
VIEW PDF (1 MB)
Mr. Dominic Hayes, *Spectrum Management and Policy for Galileo, European Commission*

11:40 - 12:05
Alternative PNT in Europe
VIEW PDF (1 MB)
Dr. Okuary Osechas, *German Aerospace Center Institute of Communications and Navigation*

12:05 - 12:30
A Holistic Approach to Protect, Toughen, and Augment
Industry Ready to Help with Resilient PNT
VIEW PDF (2 MB)
Mr. Jean-Yves Courtois, *Chief Executive Officer, Orolia*

12:30 - 1:30
LUNCH

1:30 - 1:50
U.S. Department of State (DOS) Report - *International Committee on GNSS (ICG)-13 & Bilateral Engagements*
VIEW PDF (1 MB)
Mr. David Turner, *Deputy Director, Office of Space & Advanced Technology, DOS*

1:50 - 2:10
United Nations (UN) Office for Outer Space Affairs
Perspective on GNSS Progress & Contributions
VIEW PDF (2 MB)
Ms. Sharafat Gadimova, *UN Office for Outer Space Affairs*

2:10 - 2:30
Brazil Positioning, Navigation, and Timing (PNT)
Deployment Plans for Largest South American Nation
VIEW PDF (1 MB)
Col Claudio Olany, *Chief of Space Systems, Space Systems Commission (CCISE), Brazil*

2:30 - 2:55

2nd Generation Satellite-Based Augmentation Systems (SBAS), Capabilities & Issues
VIEW PDF (2 MB)
Mr. Robert Jackson, *Global SBAS Project Lead, Lockheed Martin*

2:55 - 3:20
Advanced Celestial Navigation Systems
VIEW PDF (791 KB)
Dr. J.P. Laine, *PNT Division Leader, DRAPER*

3:20 - 3:55
Magnetic Navigation Technologies & Techniques
VIEW PDF (1 MB)
Mr. Aaron Canciani, *Assistant Professor. Electrical Engineering, Air Force Institute of Technology*

3:55 - 4:05
BREAK

4:05 - 4:25
International GNSS Service (IGS) Initiatives
VIEW PDF (811 KB)
Ms. Allison Craddock, *Director, IGS Central Bureau*

4:25 - 4:40
Interoperable GNSS Space Service Volume (SSV)
VIEW PDF (4 MB)
Mr. Joel Parker, *PNT Policy Lead, NASA Goddard Space Flight Center (GSFC)*

4:40 - 5:00
GNSS - Medium Earth Orbit Search and Rescue (MEO SAR)
VIEW PDF (3 MB)
Dr. Lisa Mazzuca, *Search and Rescue Mission Manager, NASA GSFC*

5:00
ADJOURNMENT

THURSDAY, DECEMBER 6, 2018

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

9:05 - 9:30
Concise Roundtable Observations from Wed, Dec 6
All members, led by Chairs

9:30 - 9:50
Mission Countdown for Deep Space Atomic Clock (DSAC)
Flight Partnership with U.S. Air Force to Demo Capabilities
VIEW PDF (2 MB)
Dr. Todd Ely, *Principal Investigator, DSAC, NASA Jet Propulsion Laboratory*

Representative/International Reports & Perspectives:

9:50 - 10:10
The Evolution of Spoofing *(with contributions from C4ADS)*
VIEW PDF (4 MB)
Mr. Dana Goward, *Resilient Navigation & Timing Foundation (U.S.)*

10:10 - 10:30
Radio Equipment Directive (RED) Implementation
VIEW PDF (658 KB)
Ms. Ann Ciganer, *GPS Innovation Alliance (U.S.)*

10:30 - 10:50
Evolution of Precise Positioning from Specialty to Mass Markets: Recent Developments & Future Prospects
VIEW PDF (3 MB)
Mr. Matt Higgins, *President, International Global Navigation Satellite Systems (IGNSS) Association (Australia)*

10:50 - 11:05
BREAK

11:05 - 12:00
Roundtable Discussion -- Recommendation Formulation
2019 Work Plan Schedule -- 23rd Mtg circa May D.C. Area
All members, led by Chairs

12:00 - 1:00
LUNCH — *Working as needed*

1:00
ADJOURNMENT

Dates and times are as originally scheduled and do not reflect actual presentation times. The Advisory Board also heard the following presentation that was not on the agenda:

- The Dream - "Le Reve"
  Dr. Refaat Rashad, *Arab Institute of Navigation (Egypt)*
  VIEW PDF (2 MB)

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Executive Summary

The 22nd session of the National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board met on December 5-6, 2018, in Redondo Beach, California. The main objectives of this session were to hear and discuss expert reports and to plan the Advisory Board's future actions.

This document summarizes the key briefing points and discussions at the meeting.

High-Level Action Items:

- Mr. Stenbit urged all Advisory Board subcommittees to pursue their efforts via email, with those emails shared with the full group via Mr. Miller.
- Mr. Stenbit urged Mr. Turner (Department of State) to give Ms. Ciganer all possible assistance in the European Commission's Radio Equipment Directive (RED) desk issues pending in Europe.
- Dr. Betz urged the Advisory Board to consider some method whereby Universal Coordinated Time (UTC) could be deployed in a manner that did not involve it going through GPS.
- Mr. Stenbit urged Ms. Craddock to coordinate with Mr. Miller to determine what problems, if any, were preventing the full publishing of GPS-related data.
- Mr. Goward urged the Advisory Board to endorse the creation of a real-time interference detection and warning system.

Other Action Items:

- Mr. Stenbit announced that in the future, the Advisory Board members' discussion would be held the afternoon of the first day meeting, rather than the morning of the second.
- Mr. Stenbit urged Mr. Miller to schedule a technical presentation by an expert engaged in the Bureau of Industry and Security emerging technologies review to see how that process might affect PNT.
- Mr. Stenbit urged Dr. Beutler to inform him of what the Advisory Board needed to do to ensure the formal establishment of how data should flow.
- Mr. Stenbit proposed to address, as a future topic, how the issues of security and transparency were to be balanced, by addressing the question: "How do we inform the public of what is really going on?"
- Dr. Beutler urged that a presentation be made on the Multi-GNSS Experiment (MGEX), perhaps involving such experts as Dr. Oliver Montenbruck.
- Dr. Beutler urged that a representative of the Gravity Recovery and Climate Experiment (GRACE) Follow-On mission be invited to make a presentation.
- Mr. Goward suggested the federal government declare what type of receiver it wished to acquire, to establish a benchmark for others.
- Mr. Lewis urged that legislation be sought that established legal protection limits for the spectrum.
- Mr. Goward urged creation of a database for industry to use, as had been done with cyber activity.
- Mr. Hatch urged that a listing be made of all alternatives that had been presented to the Advisory Board, and how these might be classified.
- Mr. Horejsi (Chief Engineer, Program Office) urged the Advisory Board to secure a briefing on the merging of the GPS L5 and Galileo E5a signals, as these pertained to safety-of-life.

Session of December 5, 2018

BOARD CONVENES: Call to Order and Announcements
Mr. J.J. Miller, *Executive Director*
National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board

Mr. Miller called to order the 22nd meeting of the National Space-Based PNT Advisory Board. He thanked the attendees, in particular those traveling from a considerable distance. He also noted that today, Wednesday 5, is a National Day of Mourning for former President George H. W. Bush, who served his country honorably both in war and in peace. Mr. Miller thanked special guest Maj Gen. Kimberly Crider (Mobilization Assistant to the Under Secretary of the Air Force) for her attendance, and also thanked Col Steven Whitney (Program Executive Officer for Space Production, Space and Missile Systems Center, and former Director of the GPS-Directorate) and his team for consistently being robust partners to the Advisory Board. The Advisory Board was established over a decade ago by the President to provide independent counsel and advice on matters relating to PNT. It was established under the Federal Advisory Committee Act and, thus, the meetings are open and Meeting Minutes will be published. Also, the presentations will be posted on the National Coordination Office (NCO) website (www.gps.gov). Advisory Board members serve as volunteers, and were nominated for service by one of the member agencies of the PNT Executive Committee (PNT EXCOM) and confirmed by the NASA Administrator. If members feel they face a potential conflict of interest with a particular topic then they must identify themselves and their recusal noted in the minutes. Mr. Miller then turned the meeting over to Mr. John Stenbit, Chair, and Dr. Bradford Parkinson, 1st Vice-Chair.

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Opening Comments: 22nd PNTAB Focus and Priorities
Priorities & Recent Products: (1) GPS Topics Paper; (2) Spectrum Memorandum
Mr. John Stenbit, Chair
Dr. Bradford Parkinson, 1st Vice-Chair

Mr. Stenbit recalled his first meeting with the late President George H.W. Bush, a story he feels underscored the former President's kindness. Back then he was a young staff member at the Pentagon and had been sent to make a proposal to Mr. Bush, then director of the Central Intelligence Agency. Mr. Bush asked Mr. Stenbit if he liked tea. He responded he did not. Mr. Bush then said that as this tea had been acquired during his service as envoy to China, he would make some for both. Mr. Stenbit presented his proposal and Mr. Bush replied, "Great idea. Let's do it." As Mr. Stenbit rose to leave Mr. Bush stopped him, saying, "You haven't had your tea." Thus, Mr. Stenbit drank his tea while chatting with Mr. Bush. In summary, it is highly unusual for a junior official to be treated so graciously by a very high ranking one, and that is one of many traits that made former President George H.W. Bush a special person.

Mr. Stenbit then noted he's had to recuse himself from portions, or all of, recent meetings. He would also have to do so at today's meeting. Dr. Parkinson will take over for that portion of today's meeting.

Mr. Stenbit emphasized the need to focus on the future and the ever-rising complexities of the GPS world. The key words are Protect, Toughen, and Augment (PTA). This requires the Advisory Board to get ahead of the curve. Today the Advisory Board members have two documents before them. The first is a Topics Paper for Administration briefings that was drafted by subgroups covering many areas of the U.S. economy and military (see: https://www.gps.gov/governance/advisory/recommendations/2018-09-topic-papers.pdf). This document provides a basis for recommending how to take advantage of potentials and ward off hazards. Board members with equities in any of the areas addressed by the paper should send him their comments by email. He looks forward to the Advisory Board focusing more on where things are headed and what needs to be done. The ever-increasing complexity of GPS, and the risks it faces, makes this a substantial challenge. The second document is about spectrum, and this is a topic from which he has recused himself and, thus, will be addressed by Dr. Parkinson.

Dr. Parkinson presented a summary of the Advisory's Board Intersession Meeting held on August 6, 2018, by WebEx/Phone (note: the meeting minutes are posted at https://www.gps.gov/governance/advisory/meetings/2018-08/minutes.pdf). This was a public meeting for which Mr. Miller filed appropriate Federal Register Notice (FRN) indicating the topics that were going to be discussed. At this meeting the non-recused board members wrote a strong recommendation to the PNT EXCOM for the Ligado Proposal to not be approved (available at: https://www.gps.gov/governance/advisory/recommendations/2018-08-letter-to-excom.pdf). This recommendation, in part, reflects a transmitter density analysis. The Ligado proposal appears aimed toward a 5G application with a transmitter separation down to 100 meters. Many other organizations have filed statements of opposition to the proposal. In 2010 LightSquared sought permission from the Federal Communications Commission (FCC) to expand from space-to-ground transmission to ground-to-ground transmission. Back then the Advisory Board acted to slow down the grant of permission because of critical concerns regarding its effect on the spectrum 1 dB interference protection criterion. Since then a lot of previously unknown information has been revealed. Ligado is currently trying to exploit the 5G revolution, which includes the highly profitable undertaking of entertainment broadcast. This makes the frequency allocation very important. Also, the number and density of transmitters has provoked alarm within the Advisory Board. While Ligado is requesting high precision users to report

when problems are experienced, no information is provided as to whom such reports should be made. Also, the Ligado proposal continues to ignore the needs of modernized GPS signals. The vagueness of the broadcast tower spacing requirements is particularly alarming. The Advisory Board's recommendation to the PNT EXCOM received unanimous support from its non-recused members.

Dr. Parkinson also reported the great news about the FCC approval for use in the U.S. of two of the Galileo Global Navigation Satellite System (GNSS) signals. This is something the board has advocated for years. The European Commission (EC) formally requested such permission in 2013. Dr. Parkinson said that in his view the issue is somewhat moot as most U.S.-built cellphones and GNSS receivers already handle Galileo signals (as well as those from other GNSS). Nonetheless, the FCC felt it had to formally authorize use of the Galileo signals E1 and E5, which are the equivalent to GPS signals L1 and L5. The FCC has not authorized E6 (the Galileo Commercial Service) because it is not in a Radio Navigation Satellite Services (RNSS) band authorized for U.S. applications. Nonetheless, the FCC action provides clarity to users, and this is very good news. Dr. Parkinson concluded by saying he hopes the Federal Aviation Administration (FAA) also incorporates the E1 and E5 signals into its Wide Area Augmentation System (WAAS).

* * *

GPS Program Status and Modernization Milestones
Col Steven P. Whitney
Program Executive Officer for Space Production
Space and Missile Systems Center (SMC)

Col. Whitney presented a chart showing the block number and age of the 31 GPS satellite vehicles that are currently in operation. The average age is 11.2 years. One of the satellites, now back in operational status (while still functioning, it was kept as a spare), was launched in October 1993 and thus is older than dozens of members in his own staff.

The GPS-D is also continuing with its efforts at international cooperation including, among other activities, a meeting last week with the European Space Agency (ESA) to discuss topics of common concern.

The Modernized Operational Control Segment (OCX) is here and working. He also presented the GPS Enterprise Roadmap and noted how considerable time has been spent in the past two years on how best to integrate the various new developments in launch and control capabilities.

The first of ten GPS Block III satellite vehicle (SV) is scheduled to be launched in 13 days. This undertaking included the integration of multiple 'firsts,' which required considerable effort. It is the first launch using OCX, and five rehearsals have been held in preparation. It is also the 1st launch on a Falcon-9, so two launch exercises were conducted with SpaceX. There is now a production line mindset for subsequent Block III launches. The other nine GPS III SVs are currently in various stages of production at Lockheed-Martin in Denver, CO. It is anticipated that the 2nd launch will occur in June-July 2019, the 3rd launch in December 2019, and subsequent launches will take place every 4.5 to 5 months. Once all 10 GPS III SVs are in orbit a total of 22 GPS SVs will broadcast the GPS L2 signal. Furthermore, GPS III SVs will have a 15- rather than 12-year life expectancy. Also, a $7.2 billion contract has been awarded to Lockheed-Martin for 22 additional satellites (referred to as GPS IIIF) over the next seven to ten years. The GPS IIIF design has built-in flexibility so that new capability can be incorporated as production proceeds. In fact, work is already proceeding in other areas, notably with atomic clocks.

The development of OCX has been a struggle. Cybersecurity concerns require considerably increased attention. Block 0 was delivered in October, and Block 1 is in final development. Of the 2.6 billion lines of code the entire system requires, only 97,000 lines remain to be written, and should be presented for operational use in 2022.

Col Whitney closed by presenting the GPS Director's perspectives. These include understanding that GPS is a global utility committed to uninterrupted service, advancing "The Gold Standard," enhancing resiliency and addressing near-term needs with current efforts. In addition, a commitment has been made to identify opportunities for resiliency improvements and maturing technical needs for future use. The need to develop alternative PNT sources is appreciated. Further, the community needs to be challenged to propose and explore new solutions that expand multi-GNSS potential.

Mr. Stenbit, Chair, noted that Col Whitney has been nominated for the rank of General.

Col Whitney noted the pending promotion reflects the work of many with whom it has been his honor to associate with.

* * *

PNT Efforts by the Department of Homeland Security
Mr. James Platt, *Director*
PNT Office, Department of Homeland Security (DHS)
National Risk Management Center

Mr. Platt noted that more than a decade has passed since the first directive to create a backup to GPS was issued. Given the high stakes, it is imperative to build additional resiliency and protection into the GPS system. DHS recognizes the close connection between physical and cybersecurity, as reflected in the Cybersecurity and Infrastructure Agency, established by President Donald Trump on November 16, 2018. The new agency's vision is to create a safe, secure, and resilient infrastructure under which the U.S. can thrive. Its mission is to lead the national effort to protect and enhance the resilience of the nation's physical and cyber infrastructure.

DHS' most important focus is to protect national critical functions, 13 of 16 which are highly dependent on GPS. At the same time, if one tries to protect everything then one can end up protecting nothing adequately. Therefore, priorities have to be established on how to reduce the risk to the general public. On December 11-12, 2018, DHS will hold its first Critical Functions session. This will draw groups from various sectors, many of whom are still not aware of their level of dependence on GPS. People often use GPS because it is the simplest thing available, but at the same time may do so without understanding its needs and requirements.

On-going efforts at DHS include the following areas:
- Conformance and Compliance Standards for GPS/GNSS receivers
- Partnerships with other federal agencies and the private sector
- Best Practices
- Assessing timing requirements and developing risk-based timing policies
- Support to National Civil PNT Policy
- Defining PNT requirements for "critical transportation, homeland security, and other critical civil and commercial infrastructure applications within the United States"
- Assessing the impacts of emerging and disruptive technologies

Mr. Platt concluded by emphasizing the importance of knowing one's timing requirements. If an entity has one clock, then time is known. If, however, 100 clocks are used then the exact time is uncertain.

* * *

Real-World Receiver Testing and the 1dB Criteria Impacts
Mr. Guy Buesnel, *PNT Security Technologist*
Spirent Communications

Mr. Buesnel said he would describe work that began as an effort to look for anomalous behavior in GNSS receiver parameters, but ended up finding much more interesting information. In 2017, his organization examined measurement parameters when GNSS receivers are subjected to adjacent band interference. Spirent determined that more data points were needed. The focus was on seeing how receivers behave, and then how that behavior changes when resistance increases. They learned how to do this with both cold and warm starts. With this, they discovered fewer anomalies than had been foreseen. Mr. Buesnel described the test set-ups and methods employed.

Mr. Buesnel noted that the experimental model was altered to make possible the gathering of information on horizontal position error and time to first-fix. This makes data gathering much more rapid. Next, he presented a series of charts on the RFI effects on Signal to Noise Ratio (CNR) and position. The 1 dB criterion is a very useful gate; once exceeded there was a rapid rise in the horizontal position error. For all receivers thus far tested, the Horizontal Position Error (HPE) increased before any degradation in Time to First Fix (TTFF). Results show that CNR is an absolute gate, and once exceeded there was unusual behavior in all the receivers. Also, TTFF increases rapidly after there have been fluctuations in the HPE. The experimental model was altered to allow focus on the question of TTFF. There was variability in GNSS measurements, which he attributes to conflicting results obtained by repeated live-sky testing. The number of measurements was small, which may well account for the difference.

Mr. Buesnel reported on Spirent insights that followed up on this work. In his view, it is important to not have standards that can quickly become obsolete. The key findings are

- Under test conditions a 1 dB degradation in CNR while subject to interference is a precursor to reduced or erratic performance in GPS receivers.
- This work highlights that testing past the 1 dB degradation in CNR provides much deeper understanding of receiver behavior.
- Results demonstrate that too few measurements in a Live Sky scenario can give misleading results.

Thus far efforts have concentrated on a single interference source. However, LTE deployment plans acknowledged the need to test for multiple interference scenarios. Spirent's further work includes: 'Big Data' characterization/certification of receiver behavior including more parameters. These parameters include, among other areas: cold, warm, and hot starts; signal reacquisition; 1 Pulse per Second (PPS) and Network Time Protocol (NTP) / Precision Time Control (PTP) accuracy; and other areas. His organization has joined the GNSS Vulnerabilities group on Linked-In to learn more about GNSS jamming and spoofing.

Mr. Stenbit noted that Spirent is doing some approximations to speed things up. First, he had always assumed that TTFF 'first fix' is a harder problem to address than horizontal error. He asked Mr. Buesnel to comment on the accuracy of TTFF achieved. Second, the Advisory Board support of the 1 dB criterion is for a single transmitter. Could Mr. Buesnel comment on how multiple interference would affect things?

Mr. Buesnel commented that work remained to be done on TTFF. As for multiple interference sources that will take longer to address, but he hopes he can return to a subsequent Advisory Board meeting to show the effects of multiple interference.

Dr. Betz said it appears to him that Mr. Buesnel was saying that the CNR measurements are more repeatable and have less spread than other measurements, such as accuracy and TTFF. Is this the case?

Ms. Buesnel said that statement is true in a laboratory setting, but caution is needed with live-sky results.

Ms. Ciganer said a key parameter is that the European Commission's Radio Equipment Directive (RED) is subject to the World Trade Organization because it is a minimum entry requirement for product placement on the EU market. A key concern for the Advisory Board should be that the ETSI RED harmonized GNSS receiver standard is required to have a test for conformity to RED Article 3.2 , which EN 303 413 (OJEU 12/2017) test of 1 dB degradation of C/No provides and which does not constitute a barrier to market entry.

Mr. Buesnel said he absolutely agrees with Ms. Ciganer.

Mr. Burgett noted this work emphasizes why the 1 dB criterion was used. He thought the work Mr. Buesnel has described was interesting. At the same time, it was generally known that 1 dB is the right answer.

Ms. Buesnel said that outcome was already known. What he feels merited attention is that his company has been able to capture many data points.

Mr. Stenbit said he finds very useful the ability to look at the distribution of data.

* * *

Securing GPS-based Systems against Signal-in-Space Threats
Mr. Jeremy Warriner
Director of Government Systems, Microsemi

Mr. Warriner began with a high-level assessment of Microsemi's messaging to its customers and the responses received. This message includes threats, solutions, and gaps. A central message is that threats may come from individuals (e.g. insider threats leaking sensitive information) or organizations (e.g. sophisticated viruses such as Stuxnet). Industry needs to do more to protect itself and the services it provides. GPS is a critical global infrastructure, but Microsemi stresses to its customers that federal government is not legally obligated to provide continuity of GPS services. Threats also include the possibility of signal spoofing and interference/jamming. However, Microsemi also tells its customers that the sky is not falling. Part of the issue is that customers commonly do not know their own timing requirements, or that they are relying on GPS to meet these requirements. There is no 'silver bullet' single solution that would end all threats to GNSS.

GNSS signal integrity is a crucial component we need to address. In an analogous way to the Advisory Board's focus on PTA, Microsemi also focuses on three approaches: (1) defend and protect PNT from threats; (2) mitigate GNSS disruptions through adoption of best practices and/or use of independent PNT sources; and (3) quickly identify and recover from PNT disruptions. We also need to remember that over time new threats will emerge.

The key issue to address is integrity, and Microsemi's proposed approach is as follows:

- Identification and Notification: A system needs to identify threats and provide notification. Microsemi promotes the model of 800-53, which supplies guidance on how to maintain one's system. This not only involves IT threats but also whatever factors are pertinent to a given operation. One change needed in receiver testing is to create a way to publicize new and emerging threats. At present, some threats were – for good reason – classified, but that is also creating difficulties to industry.

- Resiliency: Microsemi believes heavily in inertial references. The quality of an atomic clock ties to the protection of the system. The better the clock; the better the protection. Multiple PNT sources strengthen resiliency. In practice, the only

access industry has to Universal Coordinated Time (UTC) is GPS. Therefore, a practical system truly independent of GPS does not exist yet. Industry needs direct access to UTC.

- Visibility. The current attitude of 'install and forget' needs to change. Most customers do not actively monitor GPS. Industry needs to become more active in identifying risks. Commonly, users regard GPS as being so reliable that they then assume any problem must be in the receiver or other equipment. However, as we know the GPS signal can also have issues. Knowing the problem is half the battle.

Currently there are a number of gaps. Better means are needed whereby government and industry share information on emerging threats. The mindset of industry needs to change so that it takes greater responsibility. Access to UTC at appropriate levels needs to be available. There could be some benefit in using the very large number of GPS sensors in the hands of industry and, for example, enable real-time reporting of whatever issues might arise.

Dr. Betz said Mr. Warriner's second point – that UTC should be disseminated in a manner that is not solely through GPS – is one to which the Advisory Board might give some thought.

Mr. Warriner said the major challenges are likely to come from a policy perspective.

Mr. Stenbit said an analogous issue existed in cyber-security, where there was a need to ensure that information is shared.

Mr. Burgett asked what Microsemi does to ensure the integrity of its hardware through the manufacturing process.

Mr. Warriner responded that many things are involved. His company has hardware that assures a secure boot. Microsemi also has manufacturing technologies that are tied to its own supply chain. Microsemi addresses a wider range of concerns than just the threat to the GPS signal-in-space.

Mr. Goward noted that an unexecuted aspect of national policy is the creation of a database of disruption reports and immediate sharing of such information. There is no reason not to share this information with industry and the public. Legislation has been signed that calls the timing signal to be synchronized with UTC.

Mr. Warriner welcomed that step but believes a policy issue remains of how all industry can access the information.

Dr. McGurn referred to Mr. Warriner's statement that "knowledge is half the battle." However, as systems become more deeply integrated, it might become more difficult to identify where a problem is occurring. He asked if the hardware providers could assist with this issue.

Mr. Warriner said that Microsemi can provide enough information to tell customers where their problem is. However, the customer still has to be motivated to do something about it. This is a difficult message to convey.

Admiral Allen said this leads to his questions about governance. Who collects what? To whom do they report it? Who monitors to see if it is being done? How does this tie to the new risk management center at DHS? How is this institutionalized?

Mr. Goward noted that federal policy calls for the creation of a database.

Mr. Stenbit said he believes it would be useful if systems on cyber reporting and on other issues could move in parallel.

* * *

European Efforts to Protect, Toughen & Augment GNSS
Maintaining RNSS as a Critical International Resource
Mr. Dominic Hayes, *Spectrum Management and Policy for Galileo*
European Commission

Mr. Hayes expressed his appreciation to the Advisory Board for its advocacy of FCC approval of Galileo signal use in the U.S. The focus of his briefing also is on Protect, Toughen, and Augment. The problem is well known, including instances such as: a truck driver that inadvertently jammed the Newark Airport; Russian jamming of U.S. drones in Syria; Norway's request to Russia to cease jamming along their border; and an Air France jetliner that lost positioning in Munich, Germany.

Numerous similar events have occurred all over the world. Given the increased dependence on GNSS, security is a high priority. Protecting signals-in-space is not sufficient. For example, some cab drivers in Nigeria use an application that reports they have driven more miles than they really had, thereby increasing compensation. Jamming is illegal under various rules in 48 European countries. Some countries, however, do not view mere ownership of a jammer as a crime. There are also differences in how spoofing and jamming are approached. Because of various issues between European Union (EU) member states, spoofing is not being addressed in as open a way as jamming. Part of this is because jammers, in particular high-powered ones, are easier to locate compared to spoofing events.
Regarding "Protect" in PTA, national regulators are responsible for spectrum protection in each country. Use is generally based on International Telecommunication Union (ITU) standards, but there is no dedicated forum that focuses on the GNSS spectrum. The creation of such a body might be a wise move. There are on-going efforts to protect GNSS spectrum, such as the Protector Project and the Strike3 Project. Also, EUROCONTROL (Europe's air control system) is now documenting interference events. Coordination with international bodies include, at the International Committee on GNSS (ICG) level, efforts to assist less developed countries that may lack awareness of the sensitivity of operations based on GNSS. There is potential value in crowd-sourcing of information. However, significant barriers exist because of privacy laws. Crowd-sourcing requires mass participation by people who agree for their data being used. Mr. Hayes said he hopes by next year to have a proof-of-concept for such crowd-sourcing. As a legal issue, jamming crosses multiple domains. Therefore, it is not merely a technical issue. A dedicated task force is needed. The possible composition of this task force is under review, with recognition that its operations not intrude on national regulators. Task force recommendations would then go to EC, which would chair the body. Objectives would include providing an overview of jamming, raising awareness, and identifying a forum to address threats. Small jammers would be a major focus. Many think small jammers give them anonymity but, in fact, such devices have unique signatures that allow them to be tracked.

Regarding "Toughen," Mr. Hayes called attention to the recently published European Radio Navigation Plan, which was inspired by a U.S. plan. The plan will be updated every several years to identify gaps in the European PNT system. This effort had three principal components:

1) EC and GSA (European GNSS Agency) projects are considering technologies to improve receiver robustness
2) EU working actively in EU/U.S. working group on robust GNSS applications, e.g. for aviation
3) Robust encrypted Galileo Publicly Regulated Service (PRS) signals could be used by Member States for critical infrastructure as national prerogative

Finally, regarding "Resiliency," a group to study this was recently created. There is no single backup option that can be recommended.

A great number of bodies and agencies have worked on aspects of these issues. Working together in a more coordinated way is a needed step. A better effort could and should be made, given Europe's investment in GNSS and its value to the economy.

Ms. Ciganer commented that at the ITU, the different working groups could liaison with others. She wondered whether the European Commission could pursue something similar.

Mr. Hayes noted that his organization already works with member states and with the European Conference of Postal and Telecommunications (CEPT). In his view his organization has an active voice within CEPT. The primary interface with both the CEPT and the ITU are the individual member nations.

Ms. Ciganer said her concern is the frequency by which she is surprised by CEPT actions, and such actions do not seem to have involved GNSS experts. This does not allow for solid protection of the GNSS spectrum.

Mr. Higgins referred to the Galileo Commercial Service, a high precision system whose signal (E6) has not been authorized by the FCC for use in the U.S. Could Mr. Hayes comment on that?

Mr. Hayes said approval of E6 is desirable. The FCC approval only applies to non-federal users, as federal users are already cleared for E6. In his view it is an odd legal distinction as it depends on who was using the signal – an FCC employee can, but a MITRE employee could not. Hopefully, as the value of the Galileo Commercial Service becomes evident perhaps the FCC may reconsider its position.

* * *

Alternative PNT in Europe
Dr. Okuary Osechas, *German Aerospace Center*
Institute of Communications and Navigation

Dr. Osechas said much of his presentation draws from a recent paper presented earlier this year at an Integrated Communications Navigation and Surveillance (iCNS) conference where he briefed on the work being done with the Single European Sky ATM Research Joint Undertaking (SESAR). SESAR is a major research effort in Europe on Alternative PNT (A-PNT).

In the conventional approach to aerial navigation, essential information is to tell an aircraft when it needs to turn. In performance-based navigation the approach is to create a position fix and a containment area. This simplifies the air control problem, leads to increased safety, and improves the use of the airspace. This approach has been enabled by GPS. Unfortunately, for the time being A-PNT does not support integrity services.

Dr. Osechas said he is often asked why a backup system is needed now that Galileo is in place. His response is that Galileo has the same vulnerabilities as GPS, thus, while they complement each other they cannot be considered a backup to each other. A-PNT is currently based on Distance Measuring Equipment (DME), which is an aging approach. While DME is being improved, additional synergies need to be exploited. International Civil Aviation Organization (ICAO) has a directive on this, and U.S. participation would be highly desirable.

DME issues include a number of existing hazards, including: estimated position uncertainty (EPU), low ramp in DME range error not being detected in DME/DME/IRS mode (note: IRS = Inertial Reference System), and a need for range integrity to demonstrate suitability for Required Navigation Performance (RNP) reversion. Further, although executive monitors are required, no minimum integrity level exists in ICAO Annex 10. Nevertheless, integrity requirements are included in FAA and European Organisation for Civil Aviation Equipment (EUROCAE) specifications. Therefore, modern transponders comply. DME improvements are directed at, first, achieving short-term standardization and, second, mid-term hybrid ranging.

DME is the de-facto state of the art in A-PNT. A signal sent and returned from an aircraft provides a distance reading. Two transponders must be in view to obtain a position fix. Efforts are focused less on improving the hardware than improving the performance specifications of the hardware. Regarding position fix, the results achieved are above requirements. Typically at least four DME stations are available to provide the data needed by the aircraft. DME protects from most faults, except for slowly creeping ramp. When a fault exceeds the EPU, misleading information results.

Hybrid-ranging is the combination of pseudo-ranging and ranging. A further area of work is to increase the number of DME signals available to any given aircraft.

Dr. Osechas addressed long-term efforts, such as the L-Band Digital Aeronautical Communication System (LDACS). Honeywell is currently developing a robust alternative to GNSS, but its use with aviation has not yet been well established. It has complementary physical characteristics (low frequency, high power), an additional data channel, and the potential for multi-modal use: maritime, land, aviation, and time source.

Finally, the aviation community did not widely agree that eLoran (enhanced LORAN) should be used.

We should accommodate the wide variety of technologies currently in use. Work is needed not just in cross technologies but, also, cross disciplines.

* * *

A Holistic Approach to Protect, Toughen, and Augment –
Industry Ready to Help with Resistant PNT
Mr. Jean-Yves Courtois, *Chief Executive Officer*
Orolia

Mr. Courtois said the good news for the Advisory Board is that industry is well aligned on what it can and is willing to do to safeguard GNSS. His company was founded in 2006 and now has 450 employees, 40% of whom work in the U.S. where it is headquartered. Its major products include Spectracom and Spectratime.

Mr. Courtois began by addressing "Toughen" issues. His company's products specialize in integrating a variety of information sources. Resiliency reflects the combination of sources, so that if one source is compromised there are others still available. Regarding "Toughening," a great deal is already available. The decline in antenna prices from $10K to $1K has greatly assisted this. Controlled Radiation Pattern Antennas offer the most effective anti-jam protection because they prevent jamming energy from entering the field. Field tests of an anti-jamming antenna demonstrated reduced holdover events by 90% and a reduction in the average length of such events from 138 to 10 seconds. Also, multi-frequency, multi-constellation receivers are harder to jam. Other products includes software that looks at how the receiver behaves to detect jamming and spoofing. When jamming is detected then automatic adjustment occurs; if spoofing is detected then the signal is turned off. Other software products include ThreatBlocker, which can reduce jamming from 100 km to 1 km, and can also be used as a retrofit.

If problems still persist then one needs to address the "Augmentation" issue. His company's products simplify integration of resilient PNT. This includes the Satellite Time and Location signal, which broadcasts an encrypted signal that is 30 dB stronger than GPS. This means higher jamming and interference protection, and it can also operate both indoors and outdoors. Because of the variety of cases, his company began with core modules that allow customers to add the signals they require. Also, a mini-Rubidium atomic clock, to be available in 2020, will be ten times more stable than current ones. The current focus is to ensure this new clock is as reliable as those already in use. This only required basic engineering work.

As for "Protecting" GPS, this is basically a government responsibility, but one where industry is ready to help. Other options include crowd-sourced solutions. In his view mobile phones were not a practical solution because the power drain is high. Privacy issues also needed to be kept in mind. Autonomous vehicles might be a better source of data for crowdsourcing. In conclusion, many technologies are available today that can address many of the pertinent issues. Public policy could support the adoption of these technologies by:

- Requiring these technologies in government procurement
- Establishing standards for GPS receivers
- Establishing a GNSS receiver identification program
- Establishing a Nationwide Interference Detection and Reporting System

The issues being addressed are similar to those faced in cybersecurity. Everything being done in cybersecurity is broadly applicable to PNT. One example is the creation of a nationwide reporting and notification system. Also, greater cooperation is needed between the U.S. and Europe.

> Mr. Stenbit said he's thinking of the corollary to efforts at certification in the cybersecurity realm. Those have taken some time to get under way. Some lessons had been learned. Whether such effort begins through the government or industry, there will be pressure, particularly from insurance companies, to create standards.
>
> Mr. Goward suggested a good way to start would be for the federal government to declare what kind of receivers it wishes to acquire. This could be a benchmark.
>
> Mr. Stenbit said this goes beyond receiver benchmarks to standards for what is needed to detect anomalies and other events. He also said he welcomes the fact that several presentations today came from commercial organizations that believe there are financial incentives in this area.
>
> Mr. Younes asked when a flight model of the mini-Rubidium clock might be available.
>
> Mr. Courtois said in three or four years.
>
> Dr. Parkinson asked if there is a hardening specification for the mini-Rubidium clock, or is it primarily intended for use on the ground?
>
> Mr. Courtois said the current focus is on thermal constraints.
>
> Dr. Parkinson said this likely depends on what type of space flight one intends to fly.

Mr. Miller said a further clock briefing will be held on the following morning. He also noted that all of the morning's presentations are now online. He also reminded members of the planned presentation of recognition to Ms. Ruth Neilan, whose many contributions include long-term membership in the Advisory Board.

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U.S. Department of State (DOS) Report
International Committee on GNSS (ICG-13) & Bilateral Engagements
Mr. David Turner, *Deputy Director*
Office of Space & Advanced Technology, DOS

Mr. Turner began by reiterating U.S. National Space Policy, namely,

- Provide civil GPS services, free of direct user charges, on a continuous, worldwide basis
- Maintain a constellation consistent with published performance standards and interface specifications
- Make use of foreign GNSS services to augment GPS and add resiliency
- Encourage global compatibility and interoperability with GPS
- Promote transparency in civil service provision
- Enable market access to industry
- Support international activities to detect and mitigate harmful interference

Mr. Turner noted that there is, in effect, a global System-of-Systems which consists of GPS, GLONASS, Galileo, and BeiDou; two regional space-based navigation systems; and eight augmentation systems. The most recently added system is Australia's Satellite-Based Augmentation System (SBAS). The principal DOS priorities are to ensure compatibility and interoperability of civil services. These priorities are pursued through bilateral meetings with the four global GNSS providers. Also, one of the most active working groups that came out of the 2004 agreement between the U.S. and Europe focuses on the next generation GPS and Galileo civil services.

The Galileo waiver request of FCC Part 25 rules began in 2006. Between 2006 and 2010 the U.S. executive branch created a waiver process that was finally successfully used by Europe. Europe formally submitted its waiver request in 2013, which has now been approved.

Other bilateral efforts include recent dialogue with China, including a signed joint statement on China's decision to use a fully compatible L1 signal; with Australia, which was moving into a local system; two meetings with Canada; and one with the Republic of Korea.

Mr. Turner next addressed, from a U.S. perspective, the 13th meeting of the ICG held in China. The meeting drew 200 participants from 27 countries, including all six global and regional GNSS providers. Australia was also accepted as a new member. Two important ICG-related activities include: (1) a sub group is now focused on compatibility and spectrum protection; and (2) a task force is reviewing interference, detection, and mitigation across the world. Since 2014 there have been a number of ICG recommendations adopted that focus on spectrum protection. The most recent recommendation is to encourage national regulators to use the 1 dB protection criteria in relevant ITU-R recommendations.

Since 2011 there have also been a number of ICG recommendations in the area of Interoperability and Service Standards. The most recent one developed "Guidelines for Developing Performance Standards" as a template for open service performance standards. Once performance standards are established, then one needs to know whether they are being met. This requires monitoring. Also, a study has been requested on GPS orbits as these relate to each GNSS system's policy for dealing with space debris.

Additional activities at the ICG include:

- Space Service Volume (SSV): Completion of the information booklet by GNSS providers, and formally introduced at the ICG-13 meeting.
- Continued outreach effort on the benefits of an interoperable Multi-GNSS SSV and development of space-based user equipment for Search and Rescue (SAR).
- Discussion about compatibility and interoperability of Medium Earth Orbit Search and Rescue (MEOSAR) as well as Precise Point Positioning (PPP). A workshop has been proposed by WG-D to focus on multi-GNSS PPP and plans by regional and global service providers.

In summary, the U.S. encourages worldwide use of civil GPS services and cooperation with other GNSS providers. It pursues compatibility, interoperability, and transparency in civil services through bilateral and multilateral dialogues. Meanwhile, the ICG, with strong U.S. participation, continues to pursue a GNSS System-of-Systems approach to provide civil GNSS services that benefit users worldwide. Continued focus is placed on spectrum protection, interference detection and mitigation, and transparent provision of interoperable civil services.

Dr. McGurn said that in discussions with a member of the ICG Standards working group, there was some question as to whether the group was going to include integrity and continuity standards as part of the International GNSS Monitoring and Assessment (IGMA reporting). In his view omitting these very critical performance measures would be a big mistake.

Mr. Turner invited Mr. Andrew Hansen (DOT) to address these concerns.

Mr. Hansen said service providers are engaged in a lengthy process to determine what is required and what is optional, and also level of maturity is needed before it is required.

Dr. McGurn said that, in part, it depends on which systems are at stake. It appears that two-sigma is going to be the accuracy standard.

Mr. Stenbit noted that two-sigma may be questionable.

Mr. Turner noted that things proceed by consensus.

Mr. Miller noted that the ICG has become more important over time. Much of the progress made on SSV is owed to the ICG.

Mr. Turner added that the ICG could not exist without Dr. Camacho's involvement.

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United Nations Office for Outer Space Affairs
Perspective on GNSS Progress and Contributions
Ms. Sharafat Gadimova
UN Office for Outer Space Affairs

Ms. Gadimova said she would cover how the United Nations Office for Outer Space Affairs (UNOOSA), addresses GNSS-related activities. UNOOSA is the only United Nations (UN) office with General Assembly mandates to -facilitate access to space technologies and to build capacity in the use of such technologies. Use of space technologies, such as GNSS, contributes to achieving the goals of the Agenda 2030 for sustainable development which has 17 Sustainable Development Goals and 169 targets. For example, in cooperation with European partners, UNOOSA has published a document on "Supporting the Sustainable Development Goals."

The Committee on the Peaceful Uses of Outer Space (COPUOS) has a number of responsibilities, which range from space debris mitigation to the definition and delimitation of outer space. She said she would cover two areas: GNSS and space weather.

- GNSS: Her office serves as the ICG secretariat, and cooperates with the ICG Information Centers. At the technical level, the principal task of these centers is to explore the benefits of GNSS technologies, spread applications, and exchange knowledge. At the cooperative level, the principal task of UNOOSA is to facilitate collaboration with the GNSS providers, along with outreach to the wider community.

- Space Weather: There are a number of on-going activities regarding science and outreach programs. Advanced training has recently been offered at the International Space Weather Initiative School on Space Weather and GNSS program, October 8-12, 2018, in Baku, Azerbaijan. Next year's program will be held in Trieste, Italy. These workshops bring in scientists from both developed and developing countries.

United Nations Regional Workshops/training courses on the use and applications of GNSS include, for example, a workshop on GNSS capacity building in developing countries, held in Argentina in March 2018. This workshop educated participants on the importance of GNSS spectrum protection and how to reap the benefits of GNSS. Another example is the UN/Italy Long-term Fellowship Programme at the "Politecnico di Torino", in Turin, Italy, which provides extensive background knowledge in navigation/localization systems as well as a detailed analysis on NAV/COM integration and environmental monitoring applications. Finally, "Africa Array" is an educational initiative to support postgraduate studies and promote research into the structural detail of the Earth's crust and mantle, and was held in Johannesburg, South Africa, in June 2018.

In conclusion, the ICG enabled each participating country to gain knowledge, understanding, and practical experience in aspects of GNSS technology that have potential for economic impact and social development, including environmental preservation. GNSS is a cost effective and ubiquitous technology that has also helped characterize, monitor and mitigate key space weather impacts. Space weather is critical because dependence on space-based technology is continually increasing.

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Brazil Positioning, Navigation & Timing (PNT)

Deployment Plans for the Largest South American Nation
Col Claudio Olany, *Chief of Space Systems*
Space Systems Commission (CCISE), Brazil

Col Olany said his goal was to present Brazil's activities as they relate to PNT. Brazil is working on developing a dual use (defense/civilian) system. Coastal and inland systems need to be integrated.

There are a number of on-going PNT issues in Brazil. One issue is currently operational – a joint Brazil-Russia effort to introduce GLONASS monitoring stations in Brazil. A second issue is scientific – the CALIBRA project. Except for Russia, Brazil has the largest number of GLONASS monitoring sites. Third, the Brazilian Network for Continuous Monitoring of GNSS is a real-time positioning service designed to disseminate differential corrections, and other GNSS data, to allow simultaneous corrections to devices with Internet access. Brazil has 138 GNSS monitoring stations, of which 104 operate in real-time. Brazil is also well situated as it was one of Earth's most electro-magnetically affected regions. As such, it also offers a 'worst case' setting of scientific interest. The project's purpose is to correct positioning errors in the ionosphere, which is particularly important in high precision applications.

Col Olany discussed other plans. The first is to undertake studies to extend the accuracy and integrity of navigational signals, thereby improving air safety. The second is integrated use of GPS, GLONASS, and Galileo, which brings significant advantages to air safety.

Mr. Stenbit said the Advisory Board has a sub-group, headed by Mr. Hatch, on precision agriculture. He suggested Col Olany may find it mutually beneficial to consult with Mr. Hatch.

Mr. Hatch noted that his sub-group has gathered data from Brazil. The largest problem with the ionosphere is scintillation, and he wondered whether Brazil has addressed this through changes in receiver design?

Col Olany acknowledged that the problem persists and they are studying ways to address it.

Dr. Beutler asked, relative to the GLONASS receivers, whether they are combined receivers or GLONASS-only receivers.

Col Olany said they are GLONASS-only receivers.

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2nd Generation Satellite-Based Augmentation Systems (SBAS)
Capabilities & Issues
Mr. Robert Jackson, *Global SBAS Project Lead*
Lockheed Martin

Mr. Jackson said he would discuss issues Lockheed Martin and its partner, GMV, are attempting to solve. The ICAO has established a standard for providing precision approach to each runway. The vision was to have this capability by 2016, but this has not occurred because of technical, financial, and political reasons. In his view a 2nd generation SBAS can address all three. A technical matter was the initial discovery that the ionosphere is more dynamic than had been assumed, particularly in the equatorial regions. Regarding cost, for example, a report on providing SBAS to Africa strongly suggested that the financial resources are not available. Finally, the third challenge is sovereignty. For example, efforts in Mexico were halted due to the FAA's announcement that no aircraft crash could be blamed on SBAS, which meant that Mexico was being asked to base its navigation on a system controlled by another country that insisted it be held blameless.

The basis for 2nd generation SBAS is the introduction of the L5/E5a signal. This would enable user receivers to make ionospheric corrections, thus solving the challenge in equatorial regions. This, in turn, would simplify SBAS architecture. It would begin with GPS and Galileo, and then BeiDou & GLONASS would be added. The 2nd generation SBAS involves a business model based on global collaboration, with key assets and costs distributed across multiple countries. Operating companies would provide augmentation data on a fee-for-service basis.

Mr. Jackson presented diagrams showing the current performance for the SBAS L5 Dual Frequency Multi Constellation (DFMC) message including GPS (L1/L2) and Galileo (E1/E5a). The performance is well within the horizontal and vertical alert limits. Also, recently a monitoring station was established in Bangkok, Thailand, which extends monitoring of SBAS in the equatorial region.

Another aspect is a Precision Point Positioning service, which is intended to support emerging safety-of-life applications, with additional use in maritime, positive train control, and intelligent transportation. Regarding the evolving requirements for positive train control, he wishes they become more standardized. Aviation standards are good, but this is less true in other areas. His impression is that everyone building autonomous vehicles thinks it has the only workable solution. Therefore, they are unwilling to share information. In summary, his organization is investigating public and private market interest in a new delivery model. The effort is replicating what has already been done successfully in the aviation world. In his view system developers could benefit from better alignment of performance criteria.

Mr. Hatch said that some years ago considerable data was gathered for northern Brazil. While both L1 and L2 were used, there was often enough scintillation on both signals to substantially bring down the system, especially in the evening.

Mr. Jackson said the recently established Bangkok monitoring station has two objectives. The first is to look at underlying performance, and the second is to look into the scintillation issue.

Mr. Hatch urged that the data gathered included performance during the peak in the ionospheric cycle.

Mr. Jackson noted there is an 11-year cycle and a 13-year cycle. There is also unusual activity in the months of April and May.

Mr. Miller noted to Mr. Jackson, on a different topic, that antenna patterns for GPS blocks IIR and IIR(M) was available on www.gps.gov through a web link to Lockheed Martin, but the weblink has since gone down. Having such information publicly available helped encourage other GNSS providers to also make their antenna information available. He asked for Mr. Jackson's assistance in getting the weblink reestablished.

Mr. Jackson said he would relay that message. He added that a key for an SBAS service developer is having the best information possible about the core constellations, including how those constellations could fail. Being able to review failures, and other issues, is essential to developing a threat model.

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Advanced Celestial Navigation Systems
Dr. J. P. Laine, *PNT Division Leader*
DRAPER

Dr. Laine said he would present a brief introduction on celestial navigation and associated technologies. Absent cloud cover, the advantages of celestial navigation have been apparent since pre-Viking times. Mariners have used various celestial navigation techniques since ancient times, including the Sun, the Northern Star (Polaris), and the Sextant. Because stars are so far away their beams of light are, essentially, parallel. This makes it nearly impossible to triangulate position in three dimensions only using starlight. Thus, when using the sextant one needs two stars, local vertical, and a clock. On a dynamic platform, such as an airplane, the biggest challenge is determining the vertical position. The horizon is of limited value as a reference, as cloud or fog might obscure it. Errors – which include such things as refraction – add to total value error. A $1/60^{th}$ of a degree error would produce a result that was a 1 nautical mile position error on earth's surface. Thus, an additional reference measurement is needed, and this can be provided by gravity or, more specifically, inertial measurements. The apex of celestial navigation systems is the automated sextant, or astro-inertial system. Such systems were common in the mid-20^{th} century. The automated sextant consists of two elements. The first is a gimble star tracker, whose sole role is to site stars, and the second is an Inertial Measurement Unit (IMU) that is rigidly attached to the star tracker. However, it can be difficult to take vertical measurements from an aircraft that is banking (i.e. tilting to a side).

To address this problem there have been a number of improvements both on the algorithm and hardware sides.

On the algorithm side, because the lower visible portion of the Moon is subject to refraction we can take advantage of this to determine the local vertical by comparing the refracted image with its true position. Also, light rays from stars are columnated. Some of those rays hit the atmospheric band around Earth and the atmosphere refracts light at different altitudes and turns it into a focused cone. At different altitudes, these cones focus on different points. Thus, three star sightings produce three cones, which allow for a full three-dimensional solution both inside and outside the atmosphere.

On the hardware side, a major challenge for imaging systems is size. The Hubble telescope, binoculars, and cellphone cameras basically use the same imaging concept. Light enters the optical instrument, which focuses it. In conventional imaging optics, the diameter of the entrance aperture is directly connected to the focal length. The larger the diameter of the entrance aperture, the longer the focal length. The larger the entrance aperture, the better the optic is. Our current goal is to break the requirement that a larger aperture is needed to produce a better optic. This would involve large apertures but small focal length. Draper's goal is to create conformal optical imaging systems.

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Magnetic Navigation Technologies & Techniques

Dr. Aaron Canciani, *Assistant Professor*
Electrical Engineering, Air Force Institute of Technology

Dr. Canciani said he would address magnetic navigation as an alternate navigation technique. While no 'silver bullet' replacement for GPS exists, magnetic navigation has advantages. From a high-level perspective, magnetic navigation is a map-based navigation technique similar to currently fielded systems used on cruise missiles that rely on terrain recognition. In our case the 'map' in question is a map of a magnetic anomaly field. The progressive taking of magnetic measurements provides a unique locational solution.

There are a number of misunderstandings of the magnetic field. Magnetic navigation does not involve the entire magnetic field, but only one component: the lithospheric, or crustal anomaly, field. While the core magnetic field changes over time; the crustal field remains stable. Magnetic navigation is not unlike computer vision navigation. In very uniform terrain, e.g. a desert or over the ocean, it is difficult to get an adequate signal from vision navigation. Thus, terrain-following systems are disadvantaged by the fact that three fourths of earth's surface is covered by water. In contrast, magnetic navigation is available globally, including over water, and is independent of the time of day or weather conditions. Further, magnetic navigation does not rely on an infrastructure, such as GPS, that could be subject to attack.

Dr. Canciani presented information on two flight tests that show exceptional repeatability when using magnetic navigation. The second flight, originating in Monterey, California, tested magnetic navigation over water.

There are, however, a number of challenges faced by magnetic navigation. Operational magnetic navigation depends on sensors, magnetic maps and models, platform calibration, and algorithms. Sensors and algorithms are well advanced. Existing maps, however, are not uniform either in scale or accuracy. This issue is surmountable. In terms of platform navigation, work needs to be done on more standard aircraft types.

> Dr. McGurn said it appears to him that magnetic navigation may not provide good velocity readings.
>
> Dr. Canciani said velocity is provided because the system is coupled with an inertial error model, so as position is corrected, altitude and velocity are also corrected.

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International GNSS Service (IGS) Initiatives
Ms. Allison Craddock, *Director*
IGS Central Bureau

Ms. Craddock said she would provide an update on the IGS, a voluntary organization with over 200 contributing organizations and a goal to promote high quality GNSS data and services. Ms. Craddock noted she has taken over for her longstanding predecessor, Ms. Ruth Neilan, whom recently retired.

The IGS Multi-GNSS Working Group, led by Dr. Oliver Montenbruck, recently released a white paper on "Satellite and Operations Information for Generation of Precise GNSS Orbit and Clock Products." The paper addresses the requirements for meeting the highest possible performance standards for IGS products. The paper does not interfere with either intellectual property rights or national security, and may be downloaded from: https://kb.igs.org/hc/en-us/sections/200287408. The long-term objective of performance monitoring is to make all performance standard entries for each GNSS openly available and to provide a multi-GNSS service performance standard. Currently there are 235 multi-stations and 500 overall stations engaged in the IGS Multi-GNSS Tracking Network. Also, the Multi-GNSS Experiment (MGEX) recently published an article titled "The Multi-GNSS Experiment of the International GNSS Service (IGS)," which details its achievements over the past five years. The article was published in *Advances in Space Research*, Volume 59, Issue 7, 1 April 2017, Pages 1671–1697.

A recent workshop in Wuhan, China, has led to the creation of a new working group on PPP ambiguity resolution (PPPAR). The group will address products that might not be fully compatible with the new IGS working group, or that lack multi-GNSS support. Additionally, at Wuhan, RINEX 3.04 was officially approved by the IGS. Also, at the request of the International Laser Ranging Service (ILRS), IGS has issued two official recommendations: 2018.1 and 2018.2. The first one encouraged the extension of satellite laser ranging (SLR) stations supporting high-altitude tracking, specifically in the Asia-Pacific region, and the transition to kHz laser systems that will enable shorter normal point duration. The second addresses the increasing workload on ILRS stations caused by the increasing number of GNSS satellites equipped with laser retro-reflector arrays. Also, preparations are under way at the ICG Analysis Centers for GPS III.

Upcoming events include a dedicated Analysis Center workshop, tentatively scheduled for Potsdam, Germany, April 15-17, 2019, and the next IGS Workshop, tentatively scheduled for Boulder, Colorado, in August 2020.

Mr. Stenbit expressed some confusion. His understanding is that difficulties related to the publication of GPS technical data had been resolved. Is there, in fact, GPS-related data that is not being published?

Ms. Craddock responded that it is not always clear that the data is being made available for public distribution.

Mr. Stenbit encouraged Ms. Craddock to coordinate with Mr. Miller to determine what the problem might be.

Mr. Lewis said this issue has been around for some time with the Air Force. The good news is that action has been taken to make the requested data available. The IGS has been very responsible, particularly in providing information about bad uploads.

Mr. Stenbit said he believes the resolution of this issue is something the Advisory Board could accomplish.

Ms. Ruth Neilan [speaking as an audience member] said the Air Force has been very forthcoming. The question is: Has the IGS established a working group that identifies who is interfacing with other people and different systems?

Dr. Beutler said he is pleased to see that the IGS remains in good hands following the retirement of Ms. Neilan. He noted, however, that there does not appear to have been a formal establishment of how data is to flow.

Mr. Stenbit invited Dr. Beutler to speak with him privately about what the Advisory Board needs to do on this matter.

Ms. Neilan was asked whether the operation is a line item in the budget. She responded that while the ICG Central Bureau is funded by NASA, it is not a line item in the Agency's budget. Also, the rest of the network is funded by various countries.

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Interoperable GNSS Space Service Volume
Mr. Joel Parker, *PNT Policy Lead*
NASA Goddard Space Flight Center

Mr. Parker said he would discuss the use of GNSS in high-altitude space. The Space Service Volume (SSV) has been defined as the volume of space between Low Earth Orbit (LEO) and Geosynchronous Orbit (GEO); that is, 3,000 km to 36,000 km altitude. The SSV overlaps and extends beyond the GNSS constellations, so use of signals in this region often requires signal reception from GNSS satellites on the opposite side of Earth. The initial definition of the GPS SSV was made 18 years ago, and since then it has been adopted by other GNSS.

Mr. Parker said the last time he briefed the Advisory Board efforts were in progress to protect GPS performance for critical users. Additionally, a NASA-led team was engaged in the GPS Interagency Forum for Operational Requirements (IFOR) process. In late 2017, an Air Force/NASA Memorandum of Understanding (MOU) was signed regarding NASA participation in the GPS Block IIIF acquisition process. Since then, a positive relationship has been created between NASA and the GPS IIIF procurement team.

Also, the Antenna Characterization Experiment (ACE) has completed the first-ever mapping of all GPS transmitted antenna patterns in the L1 band for all currently operating satellites. In consequence, block averages of all on-orbit satellites have been calculated.

International activities include efforts with ICG Working Group B. Much progress has been made in this area, including SSV Capabilities Outreach, a joint international activity to raise awareness of the final policy and also publication of "The Interoperable GNSS Space Service Volume" information booklet. This booklet is the outcome of three years effort and represents the first formal publication of SSV performance data from all GNSS constellations. Its information will allow mission planners to understand how a space mission will perform at high altitudes. The booklet is available online at:

http://www.unoosa.org/res/oosadoc/data/documents/2018/stspace/stspace75_0_html/st_space_75E.pdf

Numerous benefits have flowed from working through the ICG and publishing the booklet. This information will improve navigation performance as well as enable new mission types and operations concepts and encourage development of the high-altitude GNSS user community. Publication represents a level of support for high-altitude activity by the GNSS Providers community and establishes a U.N.-based process for adapting policy to evolving user needs.

Another area of future GNSS use in space is that of lunar space. GNSS can be used all the way to the moon, and this will be a game-changer for lunar missions. If one could fly a 14-dB antenna on a spacecraft, one would receive 99% GNSS signal visibility on the moon. An International Space Exploration Coordination Group, representing 14 space agencies, have combined their plans into a single exploration roadmap. That roadmap includes a list of all lunar missions – perhaps 20 over the next decade – along with their technical requirements.

In conclusion, led by GPS, the SSV has evolved greatly in the past 20 years. Work has continued both on the GPS and international sides. Use of GNSS in lunar space is a reality and, in his view, is the approach we should use.

Mr. Stenbit complimented the effort.

Mr. Lewis asked that if there is integrity information available in other GNSS signals, is there a reason for not using it?

Mr. Parker said that use of GPS/GNSS for navigation in space is up to each mission. At this time there is not an agency position on this.

Mr. Miller said he is sponsoring work with ESA where a GPS and Galileo signal is being tracked on the International Space Station. Therefore, multi-GNSS activities are already occurring at NASA. Also, much of this work has also convinced colleagues within NASA to place a GPS receiver on the lunar-orbiting Gateway. ESA has also expressed interest to also place a Galileo receiver on the same platform. Work on this is expected to continue over next year and will be an agenda item at the ICG-14 session in India.

Dr. Camacho-Lara noted that Mr. Parker spoke of a workshop to raise awareness on GNSS use in space. Is there a policy to which the international GNSS service providers have already agreed?

Mr. Parker said the booklet represents the consensus reached by the various GNSS service providers. This may evolve as the effort continues. For example, one could address the effects of including the existing side-lobes in addition to the main-lobe signal.

Dr. Beutler noted that Mr. Parker presented a table showing that at least one GPS satellite is visible from the moon 99% of the time. Did he understand that correctly?

Mr. Parker said that is the case for a GPS-only solution when including both the main-lobe and side-lobe signals.

Dr. Beutler asked what can be accomplish with only a single GPS signal.

Mr. Parker said one key application is updating the on-board clock.

Mr. Younes noted that none of this would have happened without the assistance of the Air Force. The potential applications include enormous commercial benefits, as well. In his view this has been a great accomplishment.

* * *

GNSS – Medium Earth Orbit Search and Rescue (MEOSAR)
Dr. Lisa Mazzuca, *Search and Rescue Mission Manager*
NASA Goddard Space Flight Center

Dr. Liza Mazzuca said substantial progress has been made in satellite-assisted search and rescue. The NASA SAR program acts as the technical arm, both domestically and internationally, for the broader U.S. SAR program. Forty-four countries are engaged in international efforts. In its 40-year history, the program has been credited with saving 44,000 lives, 10,000 of which are in the U.S. Over the past decade, the program has been reinvented and modernized. The new system was called MEOSAR and spans air, land, and sea.

Dr. Mazzuca discussed the MEOSAR concept of operations. The strength of the system is that it has dual signals. In recent months BeiDou joined this effort. The number of ground stations is very close to what is wanted. Ground stations are built by individual nations.

Space segment improvements began a decade ago. At present, there are 19 GPS satellites with Distress Alerting Satellite Systems (DASS) capability. DASS is a 'proof of concept' experimental system, that is, not for operational search and rescue. Nonetheless, it has worked well. Galileo has been the 'workhorse' of the system, with 15 satellites with MEOSAR operational capability. Six months ago, China launched two BeiDou satellites with SAR payloads. Two U.S. ground stations have been in operation for nearly ten years and provide nearly full coverage over the U.S. A new ground station is being opened in New Mexico to fill the remaining gap. The U.S. currently has over 600,000 emergency location beacons in operation, and worldwide total is over 2,000,000. In 2018, through November, the system had been credited with saving 330 lives.

During the recent Soyuz launch-abort the system identified when the first parachute opened and where the capsule had landed. The program is getting closer to a second-generation location beacon. This beacon will be carried by astronauts on their vests, rather than on the raft as was done in the past. In January 2019 astronauts will be the first customers of the second-generation beacon, which will be in the commercial market by late 2019. These beacons provide an order of magnitude improvement from km-level down to 100 meters in location accuracy.

Dr. Mazzuca was asked where the qualification units are. She responded they're currently with NASA, U.S. Coast Guard, and the Air Force.

Mr. Murphy asked if she could clarify the difference between the DASS capability and MEOSAR capability.

Dr. Mazzuca said the DASS system was started as a proof-of-concept to prove it made sense to move international SAR capabilities to Medium Earth Orbit (MEO) from LEO platforms.

Mr. Stenbit, exercising the prerogative of the Chair, rescheduled Mr. Dana Goward's presentation from the following morning, and noted an Advisory Board member roundtable would follow Mr. Goward's presentation.

* * *

The Evolution of Spoofing (with contributions from C4ADS)
Mr. Dana Goward
Resilient Navigation & Timing Foundation

Mr. Goward presented a video clip from the United Kingdom regarding interference threats to GNSS. Deceptive practices are particularly devious. In 2011, Iran claimed it had spoofed and taken custody of a GPS drone. It is not clear how this was accomplished. Similar spoofing could cause a ship at sea to change course, perhaps even directing a ship into areas where piracy is active. At a hackers' convention in Las Vegas, spoofing equipment was being sold for $300. In January 2016, control was taken of two naval vessels en-route from Kuwait for Bahrein, and they had ended up in Iran. In Moscow, persons standing near the Kremlin are given a position location that places them at the Moscow airport in the outskirts. Ships in the Black Sea had previously been reported as being 39 meters underwater or moving at a speed of 50 knots instead as opposed to their standard of 12 knots. At least 1,300 individual vessels have been affected over two years.

Mr. Goward noted that papers on how one could spoof the entire GPS system had been published. Recently, the General Accountability Office (GAO) expressed concern that spoofing could redirect U.S. weapons. The Russians had accused the U.S. of using Russian drones in Syria to attack Russian targets. He noted that it was becoming simpler and less expensive to spoof the system. By such methods, he said, the entire multi-billion GNSS effort could be thwarted by limited means.

Mr. Goward emphasized that he believes interference can be detected and a real-time warning system created. As a nonprofit, the Resilient PNT Foundation urges that more be done and asks the Advisory Board take a formal position advocating such steps.

Mr. Stenbit said the Advisory Board will consider the matter.

Dr. Parkinson noted that a "jam-fest" had once been held. Perhaps a "spoof-fest" is needed now. The idea would be to match expert spoofers with spoofing preventers. However, this could quickly drift into a classified event.

ADM Allen noted that the U.S. Navy has sponsored a series of Hack-a-thons. It might be useful to look into these.

Dr. Betz said that while the Advisory Board now has an opportunity to carry this message forward, it is important to carry it clearly. In fact, one cannot spoof GPS but, rather, GPS receivers. It is important to define the matter as a receiver problem.

Mr. Stenbit noted there is an asymmetry between what people think has happened vs. people writing papers on how to do this. The tension between these two sides is something the Advisory Board could try to address.

Mr. Ken Alexander (FAA) said one should not be concerned solely with GPS spoofing, but more generally with any sort of GNSS spoofing.

Mr. Stenbit agreed.

Mr. Goward offered a reflection on federal programs for autonomous vehicles. His foundation is concerned that insufficient attention is being paid to GPS-related issues.

* * *

Mr. Stenbit, Chair, said the following day's session should begin with individual board members identifying matters they think might be worthy of action by the Advisory Board.

The Wednesday, December 5, 2018 session was adjourned at 5:07 p.m.

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Session of Thursday, December 6, 2018

BOARD RECONVENES

Advisory Board Discussion
All Members

Mr. Stenbit, Chair, noted he received a thank you telephone call from Ms. Neilan for the Advisory Board with two bits of advice: "Where focus goes, energy flows" and "Where we put our minds and collective thoughts, then much can become a reality."

Mr. Stenbit asked the Advisory Board to reflect on the action items from yesterday. Mr. Goward yesterday presented several ideas. First is the question of who should be excluded from receiving information regarding GPS interference events and their effect. Thus, Mr. Stenbit suggested that as a future topic, the Advisory Board address the question on "how do we inform the public as to what is really going on?" Second is the issue of how to create such a database for industry to use, along the lines of what is already being done regarding cyber activity.

Dr. Betz noted that receivers, as built today, are not instrumented to capture what is happening to them. Receiver manufacturers need to be encouraged to include such capability.

Mr. Stenbit said he believes that could be a third step down the road. It needs to be preceded by establishing some level of trust. Thus, opening a bilateral dialogue with industry is. This could, perhaps, be added to one of the "Toughening" agendas.

ADM Allen noted that cyber reporting is an evolution of anecdotal reporting. It is part of a maturation process that evolves along with technology.

Dr. Betz said that having an agreement to share information is only useful if you have information to share.

Dr. Camacho-Lara noted that a point of emphasis in one of the presentations yesterday is that industry needs to take responsibility for defending GPS.

Mr. Stenbit said that's an important part of what is needed.

Dr. Camacho-Lara added that industry is interested in doing this; they do not need to be coaxed.

Mr. Stenbit said he does not wish to be proscriptive about what others might do. Mr. Stenbit added he would now go around the table for members to raise any issues they want.

Mr. Shields said he believes time should be spent analyzing the long-term positioning needs for transportation, particularly for self-driving vehicles.

Mr. Stenbit said that falls within the purview of Mr. Shields' subgroup for Transportation (Non-Aviation).

Dr. Beutler said that from the science perspective, he found yesterday afternoon's presentations quite interesting particularly the presentation on extending the use of GNSS into High Earth Orbit (HEO). Expanding the use of GNSS into the upper reaches of Earth's orbit, and beyond into lunar space, is important. He also found interesting the briefings on celestial and magnetic navigation, and discussed the latter with Mr. Higgins. Dr. Beutler said he believes issues relating to science are well captured in the Topics Paper. Still, it would be very interesting to hear at the next Advisory Board session from experts like Dr. Montenbruck about pressing issues in MGEX. Furthermore, an invitation should be extended to someone from the GRACE Follow-On (GRACE FO) mission to talk about inter-satellite measurements. In closing, he also noted that one could define GNSS as a set of perfectly synchronized clocks on earth and in space.

Mr. Higgins said his briefing later today would report on some of this.

Dr. McGurn said that magnetic navigation could be a great complement to the eLoran situation. Also, the Advisory Board has received a great many briefs, and then he asked if there are things the briefers might wish them to do? His impression is that the customer base is very passive and, thus, the Advisory Board should be more proactive in responding to the needs of such customer base. Perhaps the briefers should be asked what the Advisory Board could do to assist.

Mr. Stenbit said he noted this point.

Ms. Ciganer said she is grateful that Dr. McGurn kept the focus on the future, which includes customer-driven innovations.

Mr. Hatch asked whether it would be useful at some point to list all the different alternatives that have been briefed to the board and discuss how they could be categorized.

Mr. Stenbit seconded this, and added that eLoran has been discussed far more than many other topics.

ADM Allen said it would be wise to follow the 'arc' of the presentations. They are not individualized ideas but, rather, often overlap or reinforce each other. Matters to be addressed include the monitoring of information and collection of what was out there. In the longer term, the Advisory Board needs to define its strategic objectives. The Advisory Board, under the authority of FACA, can seek public comments on any topic of value.

Gen Crider noted that a lot is being put forward. The question is: how is everything to be tied together into the various working groups? What is the 'arc'? It is not clear to her that the working groups are addressing the same topics. She fully agrees with Dr. Betz regarding instrumentation of GPS receivers so that they can capture what is going on around them. From the Air Force perspective – indeed, also from other broad perspectives – there should be a way to focus on GPS receivers. A way is needed to build on what is being done in the cyber area.

Mr. Powell said there is great value in information awareness. He would expand this to include the entire host application. The Advisory Board's recommendations are largely focused on applications, but they should also include the industrial base and not just a single supplier. If a supplier goes out of business the Advisory Board should be able to take a step back and examine how this impacts the industrial base. As an example, there has been considerable turnover in the companies that manufacture atomic clocks.

Mr. Dimmen stated he believes that currently, or in the foreseeable future, there are no alternatives to GNSS. Backup options tie to specific uses and not to general solutions. This may be obvious to those of us around the room, but it needs to be stated clearly for others.

Mr. Stenbit said whenever the Advisory Board has talked to the PNT EXCOM it has been clear that there is no alternative to GPS, though there are some mitigating circumstances. In any case, the Advisory Board has never suggested to the PNT EXCOM that some magic potion exists.

Dr. Rashad said, at the risk of repeating himself, the Advisory Board's focus over the past 4-5 years has been on GNSS spectrum. Are there other issues we can bring in? Does the Advisory Board need to be tasked by EXCOM, or can the Advisory Board initiate its own inquiries and/or respond to inquiries brought up to it?

Mr. Stenbit and Dr. Parkinson said the Advisory Board can do all three.

Dr. Camacho-Lara said he would add to Dr. Beutler's comment by noting the GNSS SSV provides many opportunities for conducting science. The Advisory Board should explore the potential of the SSV and also look at what can be promoted through international cooperation. We also need coordination between big and small nations. Perhaps the EXCOM could be provided advice regarding policy to move forward. Also, at yesterday's presentation on MEOSAR very interesting information was presented on tracking the Soyuz capsule during the launch-abort. The Advisory Board should clearly note this effort has been done in compliance with international agreements for astronaut search and rescue.

Dr. Betz said he wished to speak further to a point raised by Mr. Warriner's presentation of the previous day. Specifically, he sees value in making UTC available to industry without having to go through GPS. This is something upon which the Advisory Board may want to make a specific recommendation. It would also be useful to know more about the available options and potential obstacles.

Mr. Stenbit said he shares that view.

Mr. Murphy noted that on November 19, 2018 there was an announcement from the Bureau of Industry and Security seeking information on emerging technologies that may be of interest to national security and therefore subject to export control. The Advisory Board may wish to respond to the announcement. Mr. Murphy expressed concern that the announcement may end up in actions with implications to PNT.

Mr. Stenbit suggested to Mr. Miller that, for the next Advisory Board meeting, he arrange for an expert presentation on how this process could affect PNT.

Mr. Murphy added that the Advisory Board regularly discusses how to protect the spectrum from others. However, it also needs to discuss how to protect spectrum from ourselves. For example, proposals described in several of the briefings on the previous

day could, in fact, raise the noise floor for everyone and yet it had not brought a real response from the Advisory Board. Is action needed?

Dr. Parkinson said that is a difficult subject. Is the Advisory Board really in a position to make useful recommendations? Clearly, at some point, the 'tragedy of the commons' will be faced; meaning, people are unwilling to pay the costs of addressing problems that are in considerable measure caused by others. We need to think more about this.

Dr. Betz said he believes "the canary in the coal mine" would be the SBAS signal on L1.

Dr. Parkinson said that, in his opinion, there should be no terrestrial transmissions in the L1. The Advisory Board should strongly oppose all intrusions into GNSS frequencies.

Mr. Stenbit observed that it is easier to keep people from getting into your spectrum than preventing those already in the spectrum from doing strange things.

Mr. Murphy said he supports the need to strike a balance between transparency and secrecy. There is not a big feeling that something bad is going to happen imminently. The Advisory Board could develop strategies and then go out on a roadshow to advocate them.

Mr. Horejsi (Chief Engineer, GPS Directorate) noted the program office recently set up a civil signal roadmap working group chartered with putting together a detailed roadmap of how the additional civil signals would be used. The first target is the L5 signal. The key question is how can we get users to take the best advantage? For example, is there a way to combine the GPS L5 and Galileo E5a signals? The L5 performance standard is going to be updated soon, and a number of questions have been raised. If these two signals were merged then what does a receiver have to do to achieve adequate safety of life capability? Would it be possible to rollout an initial capability? In his view we have an obligation to get these signals into use. Another issue is whether the User Range Error (URE) will improve if we go from one to two downloads a day. Mr. Horejsi proposed that the Advisory Board be briefed so it is aware of such efforts that are underway to make things operational. He noted his office is listening from the Advisory Board to see what it can do to make these things happen.

Mr. Ken Alexander (FAA) emphasized that, in aviation, there is a ten-year timeline to develop a product. The L5 signal is part of that. A dual frequency SBAS standard is currently in development and should be available by 2022.

Dr. Parkinson said that the Advisory Board does two main things. First, it makes recommendations to the government to do things. Second, it makes recommendations to the government *not* to do things. Relative to PTA, with "Protect," the Advisory Board had experienced some success regarding the Ligado proposal, but the threat remains. In other areas, there are things the Advisory Board could do. For example, with "Toughening" the Advisory Board could continue to encourage the manufacturers to take on more responsibility. They are beginning to do this in the area of spoofing. However, he feels that with "Augment" the Advisory Board has, broadly speaking, not been successful in the area of eLoran. We just keep hearing that we'll study the issue some more and end up going back and saying the same thing. However, there has been success, thanks in-part to the Advisory Board, in this area with the FCC approval for use of the Galileo E1 and E5a signals in the U.S. Therefore, when the Advisory Board establishes a goal, but the goal is not realized, then we should continue in our effort. Progress can be achieved through erosion.

Mr. Miller noted that the two documents recently issued by the Advisory Board – the spectrum memo and the GPS topics paper – reflect how the Advisory Board operates. The spectrum memo is essentially defensive while the cyber memo is essentially offensive. The Advisory Board should move ahead, rather than having to defend past gains.

Mr. Harold Martin (Director, NCO) noted that a new EXCOM leadership is in place and that it very much appreciates the Advisory Board's recommendations and papers.

Mr. Lewis said he prefers avoiding a continued battle with the bureaucracy about protecting GPS. Perhaps legislation is needed to establish legal protection limits for the GNSS spectrum. Absent legal protections, arguments will simply drone on. So long as the FCC has discretionary authority, problems will continue.

Mr. Stenbit said he does not see legislation as something the Advisory Board would want to be involved in. We need to establish criteria on what has to be measured; how it is to be measured; and what standards need to be met. The Advisory Board is more powerful when it establishes a set of understandings. It has already been difficult to come up with the six criteria for interference testing and, eventually, should the EXCOM not listen to the Advisory Board's advice then there is not a great deal that could be done about this. As we speak there are reports about commercial companies searching for capital infusions based on missions that are different from what they had originally been approved to do. The Advisory Board is more effective when it has a list of standards that establish boundary positions and help with the implementation of such proposals.

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Mission Countdown for Deep Space Atomic Clock (DSAC)
Flight Partnership with the U.S. Air Force to Demo Capabilities
Dr. Todd Ely, *Principal Investigator*
DSAC, NASA Jet Propulsion Laboratory (JPL)

Dr. Ely said the DSAC is, at this time, on a mission countdown and launch hold. DSAC is a collaborative effort. The clock is being built at JPL. It measures only 11" x 10" x 9". Current efforts are to prove out mercury-ion atomic clocks and their capabilities in space. A year-long demonstration in space is scheduled to begin in 2019. The demonstration will advance the technology to Technology Readiness Level (TRL) -7. The focus has been on maturing core technologies and not as much on reducing the size of the clock. A future design will be approximately one-fourth the size and extend the clock life from the current 3-5 years to 10 years.

Traditionally atomic clocks were not used in deep space. At present communications move between, say, Earth and Mars as a two-way transaction. However, this is not a scalable solution for navigation in deep space. However, if spacecraft carry DSAC then scalability becomes possible because one-way signal tracking can be used. In addition to extending the capabilities of NASA's Deep Space Network, there are new possibilities for radio science and the enabling autonomous navigation. These are compelling uses for the clock. The clock also has applications because it is notably better than existing rubidium and cesium atomic clocks– on the short-term, ten times better; on the long-term, fifty times better.

DSAC uses the resonant mercury atom as a tuning fork. In DSAC there were no wall collisions, which explains why the clock does not drift. Extended stability measurements will be taken during the flight demonstration. Installing DSAC clocks on GPS satellite vehicles would greatly reduce the clock's contribution to error. The current test version weighs less than 16 kg and requires 50 W in power consumption. It is likely that a future design will reduce this to 10 kg and 30 W.

The demonstration model is complete and the upcoming one-year validation mission is anticipated to begin in spring 2019. Because the U.S. industrial base in atomic clock technology is, at this time, fragile DSAC is a significant step to improve things.

Dr. Parkinson congratulated Dr. Ely on his efforts, adding that enormous progress has been made.

Mr. Stenbit asked when it will be known how well the DSAC works.

Dr. Ely said that information should be available within several weeks of launch.

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Representative/International Reports & Perspectives:

1) **"The Dream"**
Dr. Refaat Rashad, *President*
Arab Institute of Navigation (AIN)

Dr. Rashad presented pictures from the October 2018 AIN conference in Cairo, Egypt. At an earlier AIN conference Dr. Parkinson was presented with the Nicho award, named for an ancient Egyptian ruler who wanted to dig a canal from the Red Sea to the Nile.

There are three areas for action under assured availability of PNT: Protect a clear and truthful signal; Toughen user receivers; and Augmentation. This message has been emphasized by the Advisory Board over the last six years. In his view the message has spread nationally and internationally, rapidly and well. As a result, everyone is now talking about how to protect GNSS signals.

Dr. Rashad posed a question: "What is the problem in actuality?" Society, in general, faces threats from climate change, energy, population growth, food shortages, and man-made disasters. What was being done? His dream, is to have clouds of "something" which can come to people like rain. It does not matter where it comes from; what is important is that the user has its own capability to survive and thrive.

There are a number of challenges to this. First, how PNT can provide civil protection and humanitarian aid, and monitoring of atmospheric composition? Second, how can PNT support the selection of renewable energy production sites, monitoring of critical assets like nuclear plants, or protection of vital infrastructure such as power plants or pipelines? Third, how can PNT be used to best manage our consumption and utilization of earth's natural resources and

protect the environment? Fourth, how can PNT be used to properly manage our consumption and utilization of Earth's natural resources, and to protect the environment? Fifth, how can PNT enable an improved understanding of food security assessment; and support to sustainable agricultural practices? Sixth, how can policy makers, researchers, commercial, private users, as well as the scientific community and civilians benefit from the information provided by the different PNT applications? Seventh, how can PNT be used to monitor the marine environment and shipping routes to enhance knowledge, control of maritime traffic for safety and thus support the sustainable development of the marine economy? Eighth, how important is PNT to the future of automated vehicles? Ninth, how can PNT be used to innovate services and provide high resolution maps in support of urban planning to assure balanced development of Smart Cities and contribute to the protection of natural and cultural heritage?

Dr. Rashad noted that when he brought up these challenges he mentions the terms Protect, Toughen, and Augment. The difficulty in dealing with humanity is that we are still not properly linking approaches between humanity, safety, security and economy. When people feel secure in these four areas then they will have a better life and a better understanding of PNT.

2) Evolution of Precise Positioning from Specialty to Mass Markets
Recent Developments &Future Prospects
Mr. Matt Higgins, *President*
International Global Navigation Satellite Systems (IGNSS) Association (Australia)

Mr. Higgins noted that five of the six GNSS providers are proposing PPP services. In the past we made reference measurements to a known point, or datum. Accuracy depends on the number of GNSS satellites involved, the frequencies, and the density of receivers. With PPP, such measurements are not made relative to a station, or known point, but rather they're just measurements.

Currently available augmentation services provide varying levels of service. GNSS systems providers are now presenting their own PPP systems. Galileo is delivering such services from MEO and QZSS from Geosynchronous Orbit (GEO). Australia is also offering a GEO-based service, though with lower bandwidth and, thus, more limited capabilities.

Mr. Higgins then presented a chart on GNSS PPP service characteristics and another on Australia's National Positioning Infrastructure (NPI). It is funded over four years with a total value of AU$ 225M. The system delivers three levels of service via GEO satellites: (1) GPS Single frequency standard SBAS with better than 1-meter accuracy; (2) Dual Frequency/Dual Constellation SBAS (L1/L5 GPS/Galileo) with 30 cm accuracy and with high integrity); and (3) PPP with better than 10 cm accuracy. All three service levels are already available via an SBAS Test Bed. Mr. Higgins presented a chart giving real time PPP performance results taken Aug. 28-30, 2018 and showing the SBAS signal can sustain PPP services with 5 cm horizontal accuracy and 10 cm vertical accuracy. As more L5 signals become available the system performance will further improve.

Mr. Higgins presented information on the world's first dual frequency GNSS chip to be used in a Smartphone. It tracks 28 unique satellites, and 36 channels in all because some satellites broadcast both L1 and L5. The dual frequency GNSS chip offers different levels of mass marketing positioning. A number of private companies have teamed to build hardware and services to support emerging applications.

In conclusion, it is apparent that system-provided PPP will occur. All these new technologies have had an impact on existing businesses; for example, GPS had an impact on sextants, street directories, and others. However, there are still public-good applications that require free and open services. New possibilities will benefit countries with limited communications or Continuously Operating Reference Stations (CORS). Of course, it is unrealistic to believe PPP will solve everything. Its impact will vary from one business model to another. Also, it is doubtful that existing PPP industry will be entirely driven away from the market. PPP is only part of an end-to-end service, so there is still a role for industry. On the other hand, free and open PPP will create whole new markets. Currently surveyor-grade receivers are viewed as "special," but soon high precision and reliability may become the norm. With the creation of lower cost hardware, a new generation of applications will become possible. The ubiquity of PPP will be a pressure for improved reliability, which in turn will drive continually improving algorithms and models. Addressing the general vulnerability of GNSS will also continue to grow in importance as mass market users begin to expect comparable positioning capabilities even under GNSS-restricted environments.

Mr. Higgins concluded by reminding the Advisory Board that the IGNSS 2020 conference will be held February 5-7, 2020 in Sydney, Australia.

Dr. Parkinson commented that in the early days of GPS no one really understood how extensive its impact would be. A number of techniques have been developed to further improve accuracy, one of which can be described as "self-differential." One may not be able to know an absolute position, but one can still get very

accuracy velocities. This may have an implication in addressing spoofing. The development in chip technology is and, hopefully, others such as the FAA will take a close look at developing similar capabilities.

3) Radio Equipment Directive Implementation

Ms. Ann Ciganer
GPS Innovation Alliance (GPSIA)

Ms. Ciganer opened by saying she is very pleased to have representatives of the Galileo Program present. She explained there is an issue with the current EC interpretation of the RED. It ties in with Dr. McGurn's earlier concerns about the implications of RED to the noise floor. If such an issue is left unaddressed, or is addressed in a way that leads to a rise in the noise floor, then all users of RNSS / GNSS spectrum are at risk -- not only users of commercial and consumer GNSS receivers covered under the RED.

The RED was adopted in Europe in 2014, and replaced the former equipment authorization/market entry standard called the R&TTE. Radiodetermination devices such as GNSS receivers were not directly covered under the R&TTE, but are a newly explicit category under the RED. Harmonized standards are developed by European standards organizations, such as the European Telecommunications Standards Institute (ETSI), in implementation of the RED. These standards, known as ENs, attain legal certainty when cited in the OJEU. To place a commercial product on EU markets, a manufacturer declares conformity with a RED harmonized product standard, i.e., an EN, for a "presumption of conformity" with a key RED legal requirement known as an "essential requirement for avoidance of harmful interference" (RED Article 3.2). Article 3.2 of the RED specifies that "radio equipment shall be so constructed so that it both effectively uses and supports the efficient use of radio spectrum in order to avoid harmful interference." The RED addresses market entry for radio equipment; it does not introduce or intrude upon spectrum use regulation and spectrum policy.

There is no ITU allocation for terrestrial channelized communications to operate in RNSS bands. ITU definition of harmful interference: "interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommmunication service operating in accordance with Radio Regulations.1.169. As there is no ITU allocation, a non-conforming use must not cause interference to, and must accept interference from, the primary use.

Considerable work has gone into creating EN 303 413, the EN for GNSS receivers under the RED. This EN relies on technical standards that have been developed over two decades, and is expressly based on the international standard for determining avoidance of harmful interference, that is, a 1 dB degradation in C/N_0 and adjacent frequency band selectivity test based on international allocations. EN 303 413 was cited in the Official Journal of the European Union (OJEU) in December 2017. In exchange for OJEU citation, the EC RED desk officer mandated changes in EN 303 413 to improve receiver performance. This resulted in the desk officer mandating inclusion in a revision of EN 303 413 of two new receiver characteristics for "classical" (i.e., terrestrial, channelized) radiocommunication receivers – sensitivity and co-channel rejection – which, if adopted, would displace use of the 1 dB C/N_0 interference protection criterion because the different criteria are fundamentally incompatible for assessing harmful interference to GNSS receivers.

Dr. Parkinson said he thought such an important change by the desk officer would have gone through a review process.

Ms. Ciganer said that the desk officer represents the EC review of RED harmonized standards. The desk officer works with two consultants unfamiliar with the international RNSS criterion. When another group had presented the RED desk officer with a position statement like ours (the 1dB criterion) the response was that they were required to use all ten channelized terrestrial receiver parameters from an ETSI guidance document that was not developed with input from manufacturers of radiodetermination devices generally or GNSS receivers specifically. It should be emphasized, however, that many of those ten parameters were not addressed in EN 303 413 because they do not relate to RNSS. The consequence is that a rationale must be now be presented in a revision to EN 303 413 for why the unused parameters are not used in the standard.

Dr. Parkinson said there has to be some sort of appeal process.

Ms. Ciganer responded that GPSIA understanding is that overruling an ETSI Technical Committee would be unusual, but that the RED desk officer could seek recommended action from RED Administrations. The chairman of the satellite technical committee met with the consultants and the desk officer, and the report back from the chairman is that the desk officer had rejected the rationale that many of the channelized receiver requirements are not relevant to non-channelized technologies. A very serious effort is now underway to try to address this matter, but our concerns continue to grow.

Ms. Ciganer continued explaining that the issue is with EC mandate 536, to the European standards organizations for development of harmonized standards. The mandate introduces a modified essential requirement "set out in Article 3.2 which has introduced requirements on receiver performance," and recasts the previous informative references, recitals 10 and 11 in the preamble to the RED, as prescriptive obligations that expand the straightforward equipment statement in Article 3.2 itself. This is not just about putting a burden on receivers to accommodate adjacent band operations, but also about sharing in-band. The EC Consultants are asking for values to be applied for each of the ten terrestrial channelized radiocommunication receiver parameters and minimum performance levels. Our response was that the Interface Control Documents (ICDs), to which industry builds receivers, do not include those parameters, and GNSS receiver manufacturers have no ability to modify the transmission parameters provided in the ICDs.

Several months ago we noted that the ETSI technical guide (EG 203-336) that lists the technical parameters for development of RED harmonized standards omitted radio determination, so we are participating in an ETSI effort to have the guide reopened to either include radio determination receiver parameters or indicate which of the ten parameters for receivers in EG 203 336 now do not apply to radiodetermination receivers. We had talked to the ETSI participants who had developed EG 203 336, who said it had never been their intent for the guide to be used in such a prescriptive manner. Many of the individuals who developed EG 203 agreed the guide should be reopened. However, this past week four European regulators objected to such reopening, so the status of reopening the guide at this time is unknown The RED desk officer informally communicated that the current OJEU citation of EN 303 413 could be downgraded. If this were done, then all GPS/GNSS products to be placed on the European market would have to be reviewed by RED third party test labs, which would come at significant cost to innovation and introduce tremendous uncertainty. While the RED desk technical officer has the power to overrule ETSI Technical Committees that developed the RED harmonized standard, this is rarely done. Nevertheless, GPSIA understands that the EC RED Desk officer can seek recommended action from RED Administrations. GPSIA's concern is that with EC Mandate 536, a regulatory spectrum use framework for introducing terrestrial channelized communications, potentially into the RNSS bands, has been inserted into a market entry requirement. If the noise floor rises, it does so for all stakeholders, not only for commercial and consumer GNSS receivers covered under RED. If unaddressed, this EC implementation of Mandate 536 would introduce regulation of commercial and consumer GNSS receiver performance. This risks: undermining the globally harmonized RNSS spectrum allocation for GPS/GNSS use and replacing the international RNSS standard for determining avoidance of harmful interference; substantial increases of the noise floor in excess of the international standard of 1 dB degradation of C/N_0; and allowing the noise floor to rise in the RNSS bands covered in EN 303 413 in a manner that causes harmful interference to interoperability and all GPS/GNSS stakeholders. In short, this EC RED implementation would effectively assert unilateral EC regulatory jurisdiction over the GPS/GNSS spectrum environment.

Mr. Stenbit said Ms. Ciganer has made clear the distinction between channelized and broadband communications. In his view there is a fundamental bureaucratic flaw. GNSS is not the only signal faced with this problem. What should be done is a challenge that channelized communications does not reflect all spectrum issues.

Ms. Ciganer said that what is now being sought is assurance that this will not apply to RNSS. Absent such assurance, the answer is unknown.

Mr. Stenbit asked for the views of the Galileo representative attending the meeting (Mr. Hayes).

Mr. Hayes explained he is from the directorate general responsible for the radio equipment directive. He said he wished to provide some reassurance. His own feeling is that there is no intention to have terrestrial communications enabled in the GNSS band. This is a case about legislation that had not been updated for many years, so there is a mismatch between the regulation and the technical reality. He intends to work further with his colleagues in hopes of getting them to address Ms. Ciganer's concerns and, hopefully, at a future Advisory Board meeting he will be able to provide an assurance.

Mr. Stenbit noted that the matter of technical reality outrunning regulatory updates is a common one. However, the issue raised is serious as it involves regulators who may regard themselves as infallible. Mr. Stenbit asked what pressure points might be addressed by the Advisory Board in order to assist Ms. Ciganer.

Mr. David Turner (Department of State) said the first tool is to talk and that he wished to know Ms. Ciganer's views on what is needed to move forward.

Mr. Ciganer said she would like the RED desk officer to understand the importance of RNSS and that no rise in the noise floor above 1 dB should be permitted.

Dr. Parkinson asked why equipment manufacturers in Europe are not pressing similar complaints.

Ms. Ciganer said that, in part, it is an issue of compartmentalization. Additionally, compliance officers in European companies are already overburdened with trying to meet requirements.

Dr. Parkinson said his question remains: who are the European allies in this effort?

Ms. Ciganer said she does not believe many people understand the consequences.

Dr. Parkinson asked if that means the answer to his question is that there are no allies within European industry?

Mr. Hayes said that, in Europe, it is commonly doubted that terrestrial communications would in fact be permitted in the RNSS band.

Ms. Ciganer said it is also a matter of business opportunities. There is no money to be made by protecting the spectrum, but there is a lot of money to be made by opening new uses in existing spectrum. This concern is not only with terrestrial communications, but with every other technology that operates on an unlicensed band also trying to gain entry into the spectrum.

Mr. Stenbit said he appreciates that concern and asked Mr. Dave Turner (U.S. Department of State) to see what help it could offer.

Dr. Parkinson said he remains curious on where European GNSS stakeholders are.

Mr. Hayes said he will speak with his colleagues. The Advisory Board is free to present a written position, but he would prefer to first have an internal discussion with his colleagues.

Mr. Stenbit said he appreciates the response, and thanked Ms. Ciganer for bringing this issue up and to please provide an update as events unfold. Perhaps the FAA could bring this up with EUROCONTROL and to suggest this was a matter of great concern to the Advisory Board. In his view any step by the Advisory Board should be informal because it is not in a position to undertake a political campaign on the issue.

Dr. Parkinson said his personal wish is to be assured that there are allies in Europe working in concert to resolve this issue.

Mr. Stenbit said that if such allies exist, he is not aware who they are.

* * *

Advisory Board Discussion
All Members

Mr. Stenbit said beginning with the next Advisory Board meeting, the discussion held on the morning of the second day should instead be held on the afternoon of the first day. Generally, Advisory Board members come to meetings already knowing their principal concerns. It is better to express these earlier. Mr. Stenbit commended board members for their efforts at this meeting. He also asked the various Advisory Board subcommittees to send him an e-mail if they will to do things differently.

Dr. Parkinson said the only remaining matter is to discuss the dates for the Advisory Board's next session.

Mr. Stenbit said the next meeting should occur in Washington, D.C., in May or June 2019. His preference is either the week prior, or the week following Memorial Day. He also thanked all attendees and said he believes it has been a good meeting and is pleased to see that the board is addressing new issues.

Mr. Miller noted that prior to the next meeting, the Advisory Board's charter will be renewed and six new members added to fill in vacancies. He will notify EXCOM agencies and departments to submit nominations.

The Thursday, December 6, 2019 session adjourned at 11:58 a.m.

* * *

Appendix A: PNT Advisory Board Membership

Biographies available at: https://www.gps.gov/governance/advisory/members/

Special Government Employees: Experts from industry or academia who temporarily receive federal employee status.

- **John Stenbit** (Chair), former Assistant Secretary of Defense
- **Bradford Parkinson** (Vice Chair), Stanford University
- **James E. Geringer** (Second Vice Chair), Environmental Systems Research Institute (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
- **Martin C. Faga**, private consultant (retired MITRE)
- **Ronald R. Hatch**, private consultant (retired John Deere)
- **Larry James**, Jet Propulsion Laboratory
- **Peter Marquez**, Andart Global
- **Terence J. McGurn**, private consultant (retired CIA)
- **Timothy A. Murphy**, The Boeing Company
- **T. Russell Shields**, Ygomi

Representatives: 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

Appendix B: PNT Presentations

The presentations are available at: https://www.gps.gov/governance/advisory/meetings/2018-12/

1. GPS Enterprise Status & Modernization Milestones/Col Steve Whitney
2. PNT Efforts by the Department of Homeland Security (DHS) National Risk Management Center/Mr. James Platt
3. Real-World Receiver Testing and the 1 dB Criteria Impacts/Guy Buesnel
4. Securing GPS-based Systems against Signal-in-Space Threats/Mr. Jeremy Warriner
5. European Efforts to Protect, Toughen, and Augment GNSS/Mr. Dominic Hayes
6. Alternative PNT in Europe/Dr. Okuary Osechas
7. A Holistic Approach to Protect, Toughen, and Augment/Mr. Jean-Yves Courtois
8. U. S. Department of State (DOS) Report/Mr. David Turner
9. United Nations Office for Outer Space Affairs:
   Perspective on GNSS Progress & Contributions/Ms. Sharafat Gadimova
10. Brazil Positioning, Navigation, and Timing/Col Claudio Olany
11. 2nd Generation Satellite-Based Augmentation Systems (SBAS)/Mr. Robert Jackson
12. Advanced Celestial Navigation Systems/Dr. J. P. Laine
13. Magnetic Navigation Technologies & Techniques/Dr. Aaron Canciani
14. International GNSS Service (IGS) Initiatives/Ms. Allison Craddock
15. Interoperable GNSS Space Service Volume (SSV)/Mr. Joel Parker
16. GNSS – Medium Earth Orbit and Search and Rescue (MEO SAR)/Lisa Mazzuca
17. Mission Countdown for Deep Space Atomic Clock/Dr. Todd Ely
18. The Evolution of Spoofing/Dana Goward
19. The Dream/Dr. Refaat Rashad
20. Evolution of Precise Positioning from Specialty to Mass Markets:
    Recent Developments & Future Projects/Mr. Matt Higgins
21. Radio Equipment Directive (RED) Implementation/Ms. Ann Ciganer

Appendix C: Sign-In List

Wednesday, December 5, 2018

PNT Advisory Board members:

John Stenbit, PNT Chair

Brad Parkinson, PNT 1st Vice-Chair

John Betz, MITRE

Gerhard Beutler, AIUB

Scott Burgett, Garmin

Ann Ciganer, GPSIA

J. Burns, Aero

Sergio Camacho, CRECTEALC

Ron Hatch, Deere [Retired]

Matt Higgins, IGNSS

James Horejsi, U.S. Air Force [?]

Terrence McGurn, self

Tim Murphy, Boeing

Refaat Rashad, AIN

Russell Shields, Ygomi

Other NASA attendees:

Frank Bauer, FB-ACS

Madeleine Bronstein, NASA Overlook

Allison Craddock, NASA JPL

Gregory Heckler, NASA HQ

Paul Kim, NASA Ames

Lisa Mazzuca, NASA

Eli Naffah, NASA

A. J. Oria, NASA/Overlook

Joel Parker, NASA

Paul Ries, NASA/JPL/IG

Victor Sparrow, NASA

Badri Younes, NASA

Jen Zhou, NSA

Other attendees:

Ken Alexander/U.S. DoT/FAA

Amanda Allen, ASRC

Robin Anderson, USAF

Dewayne Barrington, Harris Corporation

Peter Boylord, Booz Allen

Guy Buesnel, Spirent

Jim Burton, National Coordination Office

Frank Capak, Microcosm

David Choi, MITRE

Jean-Yves Courtois, Orolia

Dale Dalesio, Continental Electronics

Jim Durham, CDC

Neil Ferguson, Harris

Rich Foster, Microsemi

Sharafat Gadimova, United Nations

David Grossman, GPS Innovation Alliance

Rawna Haddad, Aerospace

Andrew Hansen, US DOT

Dominic Hayes, European Commission

Robert Jackson, Lockheed Martin

Mark W. Johnson, Collins Aerospace

Richard Keegan, Deere

David Kunkee, Aerospace

Haus J. Kunze, Sepcorela

Edward Lassiter, Aerospace

Rick Lee, iPosi, Inc

Steve Leontis, Aerospace

Harold Martin, National Coordination Office

Sam Memmen, Booz Allen

R. Neilan, self

Bill Nichols, BAH

Oknany Osechas, DLR

Michel Glenn O'Grady/URISA

James Olson, Orolia

James Platt, Department of Homeland Security

William Porter, Global Shift

Brian Ramsey, MITRE

Mark Rentz, Deere/GPSIA

Joe Rolli, Harris

Shawn Ryan, Collins

Charles Schue

Will Simon, Regulus

Joe Spitek, Heller Systems

Paul Tullis, Independent Journalist

J. Wertz, Microcosm

Jan Voss, GPS/SE&I

Jeremy Warriner, Microsemi

Steve Whitney, GPS Directorate

Kurt Zimmerman, Trimble

Jonathan Zur, Regulus

Thursday, December 6, 2018

PNT Advisory Board members:

John Betz, MITRE

Gerhard Beutler/AIUR

Ann Ciganer/GPSIA

Kim Crider, U. S. Air Force

Terrence McGurn, self

Refaat Rashad, AIN

Other NASA personnel:

Frank Bauer/NASA

Madeleine Bronstein, NASA Overlook

Allison Craddock, NASA JPL

Todd Ely, NASA/JPL

Paul Kim, NASA Ames

A. J. Oria, NASA Overlook

Other attendees:

Ken Alexander, US DOT/FAA

Peter Boylard, Booz Allen

Guy Buesnel, Spirent

Jim Burton, National Coordination Office

David Choi, MITRE

David Grossman,

Dominic Hayes/EC-EU

Joe Rolli, Harris

James Horejsi, SMC

Robert Jackson, Lockheed Martin

Jonas Olsen, Ororia

William Porter, Global Shift

Brian Ramsey, MITRE

Mark Rentz, Deere/GPSIA

Appendix D: Acronyms & Definitions

$	U.S. Dollar
5G	5th Generation Mobile Communications Standard
A-PNT	Alternative PNT
ACE	Antenna Characterization Experiment
AIN	Arab Institute of Navigation
ATM	Air Traffic Management
AU$	Australian Dollar
BeiDou	China's GNSS
CEPT	European Conference of Postal and Telecommunications
cm	centimeter
CNR	Signal to Noise Ratio
CRECTEALC	Regional Center for Space Science and Technology Education for Latin America and Caribbean, affiliated to the United Nations
COPUOS	UN Committee on the Peaceful Uses of Outer Space
CORS	Continually Operating Reference Station
DASS	Distress Alerting Satellite System
dB	decibel
DFMC	Dual Frequency Multi Constellation
DHS	U.S. Department of Homeland Security
DME	Distance Measuring Equipment
DOS	U.S. Department of State
DOT	U.S. Department of Transportation
DSAC	JPL Deep Space Atomic Clock
E1	Galileo Open Service (Galileo OS), located in the L1 frequency band. The Galileo E1 Band covers 1559 MHz to 1591 MHz with a center frequency of 1575.42 MHz.
E5	Galileo signals in the L5 frequency band to support aviation. The Galileo E5 Band covers 1164 MHz to 1214 MHz with a center frequency of 1189 MHz.
E5a	Galileo signal inside the E5 band and covering 1164 MHz to 1189 MHz with a center frequency of 1176.5 MHz (Note, there's a separate Galileo E5b Band that covers 1189 MHz to 1214 MHz with a center frequency of 1201.5 MHz)
E6	Galileo Commercial Service (Galileo CS) in the L6 frequency band. The Galileo E6 band covers 1260 MHz to 1300 MHz with a center frequency of 1278.75 MHz.
eLoran	Enhanced Loran
EC	European Commission (European Union's governing body)
EN	Each European Standard is identified by a unique reference code which contains the letters 'EN'. A European Standard is a standard that has been adopted by one of the three recognized European Standardization Organizations (ESOs): CEN, CENELEC or ETSI.
EPU	Estimated Position Uncertainty
EU	European Union
EUROCAE	European Organisation for Civil Aviation Equipment
ESA	European Space Agency

ETSI	European Telecommunications Standards Institute
EXCOM	Executive Committee
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FRN	Federal Register Notice
Galileo	Europe's GNSS
GEO	Geosynchronous Equatorial Orbit
GLONASS	Russia's GNSS
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPS-D	GPS Directorate
GPS II	GPS Block II
GPS-IIR	GPS II Replenishment
GPS-IIR(M)	Modified GPS Block IIR
GPS-IIF	GPS Block II Follow-On
GPS III	GPS Block III (usually refers to SVs 1-10)
GPS IIIF	GPS Block III Follow-On (SVs 11-32)
GPSIA	GPS Innovation Alliance
GRACE FO	Gravity Recovery and Climate Experiment Follow-On mission
GSA	European GNSS Agency
GSFC	NASA Goddard Space Flight Center
HEO	High Earth Orbit
HPE	Horizontal Position Error
ICAO	International Civil Aviation Organization
ICD	Interface Control Document
ICG	International Committee on GNSS
ICNS	Integrated Communications Navigation and Surveillance
IFOR	GPS Interagency Forum for Operational Requirements
IGMA	International GNSS Monitoring and Assessment
IGNSS	International Global Navigation Satellite Systems association in Australia
IGS	International GNSS Service
ILRS	International Laser Ranging Service
IRS	Inertial Reference System
IT	Information Technology
ITU	International Telecommunication Union
JPL	NASA Jet Propulsion Laboratory
kHz	kilohertz
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)
LDACS	L-Band Digital Aeronautical Communication System
LEO	Low Earth Orbit
Ligado	Ligado Networks is an American satellite communications company developing a satellite-terrestrial network to support 5th Generation (5G) and IoT applications in North America.
Loran	Long-Range Aid to Navigation (typical refers to the system up through Loran-C, now decommissioned in the U.S)
K	x1000
MEO	Medium Earth Orbit
MEOSAR	Medium Earth Orbit Search and Rescue
MGEX	Multi-GNSS Experiment
MHz	Megahertz
MOU	Memorandum of Understanding
NASA	National Aeronautics and Space Administration
NAV/COM	Navigation and Communications
NCO	National Coordination Office (located at the Department of Commerce in Washington, D.C.)
NTP	Network Time Protocol
OCX	Modernized GPS Operational Control System
OJEU	Official Journal of the European Union
PNT	Positioning, Navigation, and Timing
PPPAR	PPP Ambiguity Resolution
PPP	Precise Point Positioning
PPS	Pulse per Second
PTA	Protect, Toughen, and Augment
PTP	Precision Time Protocol
QZSS	Japan's Quasi-Zenith Satellite System
RED	European Commission's Radio Equipment Directive
RNSS	Radio Navigation Satellite Service
SAR	Search and Rescue
SBAS	Satellite-Based Augmentation System
SESAR	Single European Sky ATM Research Joint Undertaking
SLR	Satellite Laser Ranging
SMC	Space & Missile Systems Center
SSV	Space Service Volume
SV	GPS Satellite Vehicle
TRL	Technology Readiness Level
TTFF	Time to First Fix
U.S.	United States
UN	United Nations

UNOOSA	United Nations Office for Outer Space Affairs
URE	User Range Error
U.S.	United States of America
USAF	U.S. Air Force
USGC	U.S. Coast Guard
UTC	Universal Coordinated Time
W	watt
WAAS	FAA Wide Area Augmentation System
WTO	World Trade Organization