SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

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

Twenty-Fourth Meeting

November 20-21, 2019

Hilton Oceanfront

Cocoa Beach, Florida

ADM (Ret. USCG) Thad Allen, *Chair*

Mr. James J. Miller, *Executive Director*

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Agenda

(https://www.gps.gov/governance/advisory/meetings/2019-11/)

WEDNESDAY, NOVEMBER 20, 2019

8:30 - 8:35

BOARD CONVENES
Call to Order, Logistics, & Announcements

Mr. James J. Miller, *Executive Director, National Space-Based PNT Advisory Board, NASA Headquarters*

8:35 - 9:30

Welcome & Kick-Off of 24th PNTAB Meeting
Priorities & Proposed Topic Focus Areas
Concise Roundtable Discussion
VIEW PDF (3 MB)

ADM Thad Allen, *Chair*; Hon. John Stenbit, *Deputy Chair*; Dr. Bradford Parkinson, *1st Vice-Chair*; Governor Jim Geringer, *2nd Vice-Chair*

9:30 - 9:45

National Coordination Office (NCO) for Space-based Positioning, Navigation, and Timing (PNT)
PNT Policy Activity Update
VIEW PDF (554 KB)

Mr. Harold 'Stormy' Martin, *Director, National Coordination Office for Space-Based PNT*

9:45 - 10:00

Update on Air Force Space Command Reorganization Activities
Role of GPS Integration Office
VIEW PDF (992 KB)

Lt Gen David Thompson, *Vice-Commander, Air Force Space Command*

10:00 - 10:30

GPS Program Status & Modernization Milestones
IIIF, OCX, & Emerging Capabilities for Users
VIEW PDF (1 MB)

Lt Col Ken McDougall, *Chief, GPS Integration Branch, GPS Integration Office, Space and Missile Systems Center (SMC)*

10:30 - 10:45

BREAK

10:45 - 11:10

U.S. Dept. of Transportation (DOT) Developments on PNT Resiliency
VIEW PDF (2 MB)

Dr. Andrew Hansen, *DOT Liaison to the GPS Program Office*

11:10 - 11:35

DHS S&T PNT Program and Conformance Framework
Science & Technology Directorate (S&T) Update
VIEW PDF (630 KB)

Mr. Ernest Wong, *Technical Manager*; Ms. Brannan Villee, *Program Manager, DHS Science & Technology Directorate*

11:35 - 12:00

The Flip
More Robust Timing Applications Using GPS
VIEW PDF (1 MB)

Dr. Arthur K. Scholz, *Lead Signal Processing Engineer, MITRE*

12:00 - 1:00

LUNCH

1:00 - 1:15

Introduction to the National Space Council (NSpC) Users' Advisory Group (UAG)
VIEW PDF (987 KB)

ADM Jim Ellis, *Chair, National Space Council UAG*

1:15 - 1:40

Socio-Economic Studies of GPS
Past, Present and Future
VIEW PDF (535 KB)

Dr. Irving Leveson, *Founder, Leveson Consulting*

1:40 - 2:05

Economic Benefits of the Global Positioning System (GPS)
VIEW PDF (3 MB)

Dr. Michael P. Gallaher, *Senior Director, Center for Applied Economics and Strategy, RTI International*

2:05 - 2:30

Why Wait?
Real-time GNSS Monitoring for Infrastructure Protection, and a JPL Perspective on Galileo vs GPS
VIEW PDF (2 MB)

Dr. Yoaz Bar-Sever, *Program Manager, Global Differential GPS (GDGPS), Jet Propulsion Lab*

2:30 - 3:00

Compatibility of Terrestrial Reference Frames used in GNSS Broadcast Messages
VIEW PDF (2 MB)

Mr. Stephen Malys, *Senior Scientist for Geodesy and Geophysics, National Geospatial-Intelligence Agency (NGA)*

3:00 - 3:15

BREAK

3:15 - 3:35

Recent developments within the International Committee on GNSS (ICG) on the Use and Applications for PNT
VIEW PDF (2 MB)

Ms. Sharafat Gadimova, *Scientific Affairs Officer, UN Office for Outer Space Affairs, Vienna*

3:35 - 3:55

GNSS for the Developing World
Collaborations for Scientific Exploration and Applications with Societal Benefits
VIEW PDF (4 MB)

Dr. Patricia Doherty, *Director of the Institute for Scientific Research at Boston College*

3:55 - 4:15

Augmenting GPS with PNT from Low Earth Orbit (LEO)
VIEW PDF (13 MB)

Dr. Peter Iannucci, *Postdoctoral Fellow, The University of Texas at Austin*

4:15 - 4:35

Ensuring PNT Robustness, Resiliency, & Interoperability
Galileo Signal Authentication services & Anti-Spoof Techniques
VIEW PDF (793 KB)

Dr. Oscar Pozzobon, *President, Qascom*

4:35 - 4:55

Interoperable GNSS Space Service Volume (SSV)
Update on European Space Agency (ESA) Activities
VIEW PDF (1 MB)

Dr. Werner Enderle, *Head of Navigation Office, Ground Systems Engineering Department, ESA*

4:55 - 5:15

Advancing Space Use of GNSS to Cislunar Space & Beyond
VIEW PDF (4 MB)

Dr. Ben Ashman, *Deputy PNT Policy Lead, NASA Goddard Space Flight Center (GSFC)*

5:15 - 5:30

Recap of Presentation Highlights & Closing Thoughts: *Action Items & Deliberation Preparation for Nov 21*

All members, led by Chairs

5:30

ADJOURNMENT

THURSDAY, NOVEMBER 21, 2019

8:30 - 8:35

BOARD CONVENES
Call to Order

Mr. James J. Miller, *Executive Director, National Space-Based PNT Advisory Board, NASA Headquarters*

8:35 - 10:35

PNT Board Roundtable Feedback & Deliberations
Preliminary Findings, Recommendations, & Work Plan

All members, led by Chairs

10:35 - 10:50

BREAK

10:50 - 12:05

Representative & International Updates & Perspectives:

Galileo and its Outage in July 2019 from the IGS-MGEX Perspective
VIEW PDF (923 KB)

Dr. Gerhard Beutler, *Switzerland*

TBD

Dr. Sergio Camacho-Lara, *Mexico*

EU Radio Equipment Directive (RED) Regulation of Receiver Performance, In Our View, Is NOT a PTA Model for Anti-jam/spoof Resilience for The United States
VIEW PDF (923 KB)

Ms. Ann Ciganer, *GPS Innovation Alliance*

Positioning Australia
VIEW PDF (3 MB)

Mr. Matt Higgins, *Australia*

Surface Transportation Report
VIEW PDF (672 KB)

Dr. Refaat M. Rashad, *Egypt*

12:05 - 12:30

Closing Thoughts, Next Steps, Schedule

All members, led by Chairs

12:30 - 1:00

LUNCH — *Working as needed*

1:00

ADJOURNMENT

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Appendices

Executive Summary

The 24th session of the National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board was held November 20-21, 2019 in Cocoa Beach, Florida. The session included a two-hour Advisory Board discussion of tasks, objectives, and priorities based on an outline submitted by Dr. Parkinson. Its purpose was to consider potential recommendations to the PNT Executive Committee (EXCOM), and advance work on a multi-year work plan. This document summarizes the key briefing points and discussions at the meeting.

High-Level Action Items & Issues:

- ADM Allen said that in the event of a near-term EXCOM meeting, the three recommendations will be: Gold Standard, threat to GPS from ultra-wide band (UWB) allocation, and hazards posed by unvetted frequencies. Each can be covered in separate one- or two-page papers.
- Mr. Shane said an additional recommendation to the EXCOM could be made in regard to unintentional interference from government-sponsored testing programs. He urged that a protocol be created whereby those in air control receive advanced notification of any planned testing.
- Dr. Parkinson will circulate to the Advisory Board all revisions to the list of tasks and priorities. ADM Allen said the Advisory Board will communicate via email or other means to further its multiple-year work plan by the end of the calendar year.
- Mr. Shane urged greater attention be paid to legislative protection of the Global Positioning System (GPS), which, as a matter of national security, needs to be protected by federal law.
- ADM Allen announced several changes in future meeting organization. First, all pertinent presentations on the same topic should consolidated. Second, single issue presenters should be informed in advance of the major areas of interest to the Advisory Board. Third, the number of briefings should be reduced to allow for additional discussion.
- ADM Allen said an organizational memory needs to be created to archive what had been presented to the Advisory Board. Topic Papers and other documents might be included there
- Dr. Parkinson noted the Gold Standard is a long-used but never defined term. We need an overarching statement of what Gold Standard means, and then inform the EXCOM what is needed to meet that standard.
- Dr. Parkinson requested a briefing on what the military plans to do on limited monitoring of civil signals as it relates to OCX.
- ADM Allen said the Advisory Board might wish to review power grid and smart ports. It might also want to look at the evolution of the conformance framework, to be included in the update of the Topics Paper.
- Lt Gen Thompson suggested a review of GPS meteorology, which he believes is underused in such areas as flood monitoring.
- Mr. Stenbit said the EXCOM should be informed that the Advisory Board is working on removing barriers and creating enablers. ADM Allen said this could be included in a letter to the EXCOM.
- Mr. Stenbit called attention to the need for worldwide standards on levels of service to GNSS users.
- ADM Allen said that he and ADM Jim Ellis, Chair, National Space Council (NSpC) Users' Advisory Group (UAG), have pledged to work closely.
- ADM Allen said more information was needed on the status of legislation to protect GPS. He noted that a U.S. Strategic Command (STRATCOM) response team worked on threats to military communications from civil interference. He will provide an update on its activities at the next session.
- Mr. Shane said the Advisory Board may wish to make a recommendation on the way spectrum decisions were made. ADM Allen said a briefing from the Federal Communications Commission (FCC) would be an appropriate way to make the Advisory Board aware of the current status of spectrum monitoring activities. Mr. Shane accepted the task of providing a brief statement on what such FCC review should entail.
- Mr. Murphy said he wishes for clarification of which services government would create augmentations and for which services users would be able to create their own augmentations. He will write a two-three sentence statement on what is necessary to define user interfaces and specifications for each user-defined augmentation that can then be used for verification.
- Dr. Camacho accepted the task of preparing a two-three sentence statement on the impact of 5G broadband.

- Dr. Parkinson said U.S. International Traffic in Arms Regulations (ITAR) needed to be addressed, as ITAR restrictions discouraged manufacturers from producing the most toughened receivers. Mr. Younes said the ITAR question could be addressed at a June 2020 symposium of the Space Council.
- Mr. Miller said that while discussion focused on protection, augmentation was also important. The largest fault was the failure to optimize use of existing infrastructure.
- Lt Col McDougall noted that as space has become a contested environment, capabilities needed to be diversified. Placing all capabilities on a single standard created a larger target. ADM Allen noted the difficulty of informing the civil sector without creating risk for the military sector.

Other Action Items & Issues

- Dr. Parkinson requested that future reports on GPS program status and modernization be built around parameters such as signal availability dates, rather than ready-for-launch dates. Further, he suggested that future reports include updates on GPS capabilities within the Space Service Volume (SSV).
- Mr. Younes requested a copy of the study about the accuracy range which Dr. Iannucci reported.
- Lt Col McDougall said he will supply the Advisory Board with an organization chart clarifying which programs are located where.
- ADM Allen said a change in the reference data would be under discussion with ADM Sharp, Director, National Geospatial-Intelligence Agency (NGA).
- Mr. Younes said he would supply Dr. Doherty with names of GNSS experts in Africa who may be able to assist with her educational programs.
- Dr. Iannucci said he would supply the Advisory Board a copy of his report on fused PNT.
- ADM Allen said previously produced Topic Papers for Administration Briefings need to be updated based on the discussions during this session.
- Mr. Higgins urged that user education be stressed, as many are unaware of the hazards posed by spoofing and jamming.
- ADM Allen said, relative to spoofing and jamming, that clarity is needed as to which agency is responsible for which task.
- Dr. Axelrad said emphasis needs to be placed on a rapid and fully capable monitoring system.
- Mr. Murphy raised the question of whether Unmanned Aircraft Systems (UAS) require a high integrity system that will follow them all the way to the ground.

Session of Wednesday, November 20, 2019

Board Convenes
Call to Order, Logistic, & Announcements
Mr. James J. Miller, *Executive Director, National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board*

Mr. Miller called to order the 24th meeting of the National Spaced-Based PNT Advisory Board. He noted a quorum is present and thanked all in attendance, particularly those who traveled internationally. He noted the meeting is occurring within miles from where, fifty years ago, Apollo 12 was launched. He gave special recognition to the following persons attending this meeting: Lt Gen David Thompson (Vice-Commander, U.S. Air Force Space Command), ADM Jim Ellis (Chair, NSpC UAG), Lt Col Ken McDougall (GPS Integration Office, formerly GPS Directorate), and Mr. Badri Younes (Deputy Associate Administrator for Space Communications and Navigation, SCaN, National Aeronautics and Space Administration, NASA). Mr. Miller also noted the Advisory Board was established to provide independent counsel to the EXCOM, which consists of the deputy secretaries of nine federal agencies. The meeting takes place under the rules of the Federal Advisory Committee Act (FACA) of 1973. Formal minutes will be taken. All briefings should already have been posted in the National Coordination Office (NCO) portal[1]. Members classed as Special Government Employees (SGEs) need to be mindful of any potential conflicts of interest. If they see a conflict then they must recuse themselves from discussion of that issue, with the recusal noted in the minutes. With that, he turned the meeting over to ADM Thad Allen, Chair.

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Welcome and Kick-Off
ADM Thad Allen, *Chair*
Hon John Stenbit, *Deputy Chair*
Dr. Bradford Parkinson, *1st Vice Chair*
Governor Jim Geringer, *2nd Vice-Chair*

ADM Thad Allen noted the Advisory Board is facing a long list of issues. The body is uniquely positioned to assist the EXCOM and to communicate with non-government bodies, thus bridging the needs of government with those of the private sector. ADM Allen then introduced Dr. Parkinson, who would provide an update on spectrum issues.

* * *

Purpose of US PNTAB: Assuring PNT For All and Exploiting Global Navigation Satellite Systems (GNSS) for Future Applications
Dr. Bradford Parkinson, *1st Vice-Chair*

Dr. Parkinson noted that that the Advisory Board, in pursuing the goal of assured PNT for all, emphasizes a path to Protect, Toughen, and Augment (PTA). This is an inherently defensive posture. It is also necessary to look ahead. Dr. Parkinson said he would be offering an amendment to broaden the PTA approach. He then provided a summary of his presentation to the 4th meeting of the NSpC UAG, held 21 October 2019, regarding threats to GPS spectrum. Signal interference is determined by two variables: strength of the signal and distance between transmitters. He presented a chart of the effects of a proposed 5G broadband provider, operating in the Mobile Satellite Services (MSS) frequency band, on GPS high precision receivers, which is the category of GPS receivers that provide the greatest economic value. While a revised proposal reduces the transmitter power to 10 W, the presumed spacing between transmitters would result in interference that is too high (by a factor of 10,000) for GPS high precision receivers. To prevent such interference with 10 W transmitters, the minimum spacing between transmitters needs to be at least 20 km.

Dr. Parkinson noted he briefed the UAG since that advisory board has a broad mandate in space matters and most of its users rely, just as GPS users do, on weak space-to-ground signals. The 5G broadband proposal under discussion would similarly affect such activities. Commercial pressure to use bandwidth is growing, and the temptation is to reduce the buffers between space user and commercial bands. This needs case-by-case examination. The Advisory Board has looked at the needs of GPS. Vigilance is needed to protect users.

The question facing PNT users is: what is it important to do now? He will present a number of slides that he and ADM Allen believe could be a blueprint for Advisory Board members over the next two years. Their purpose is to spark discussion among members as to what needs to be included and, further, what priorities exists. His own view is that the level of priority could reflect anything that might enhance robustness, safety, productivity, and convenience. The Advisory Board and the EXCOM are positioned to influence outcomes, either by removing barriers to or creating enablers for improved performance.

[1] https://www.gps.gov/governance/advisory/meetings/2019-11/

Dr. Parkinson described the categories in Figure 1. He added that the F list should be regarded as partial and encouraged Advisory Board members to propose additions.

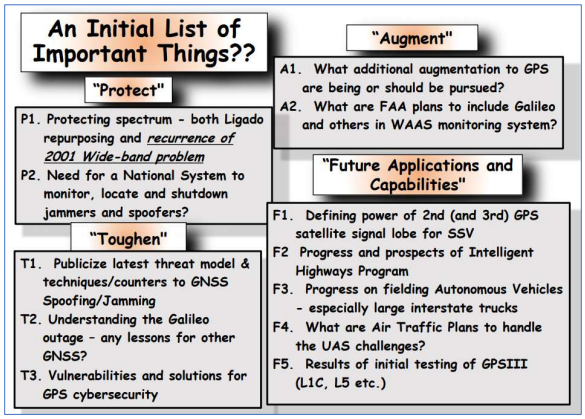

Figure 1. An Initial List of Important Things

On A1, Dr. Parkinson noted that augmentations have been under study for years. Postponement is the cruelest form of denial as not much has happened here. He noted there is continuing dialog among the central contenders. The U.S. Army has a new Mounted Assured PNT system (MAPS), which consolidates all GPS signals.

On A2, the FCC has authorized use in the U.S. of the open Galileo signals, although the Galileo E6 signal was not included in the authorization. High performance receivers have been using all GNSS signals for years. The next generation of cell phones will use dual frequency and drastically improve accuracy.

On F3, a very strong productivity argument exists for Autonomous Road Vehicles. Most trucking companies are currently trying to recruit drivers. The first semi-driving semi-truck was developed four years ago, using GPS, cameras, radar, and other devices. The ultimate configuration will include vehicle-to-vehicle communication, and he posed the question on what will constitute the minimum requirements of cybersecurity.

On F4 -- Unmanned Aerial Vehicles (UAVs) – these fly close to urban buildings and disruption of control presents a very serious challenge. While operation Beyond Visual Line of Sight has not yet been authorized, it is being done. The largest problem faced are collisions and near misses, for which he provided recent examples, including two weeks ago where 14 firefighting aircraft in California had to be grounded because someone was flying a rogue drone. Also, Amazon home delivery by UAV will begin soon. Regulation is evolving; and PNT will be its heart. Dr. Parkinson also discussed the efficacy of geofencing to prevent collisions, noting that commercial products are already available.

On F5, he asked how best to make use of the new capabilities of GPS IIIF, which includes an additional civil signal, better clocks, NASA-furnished laser retro-reflectors arrays, and other performance-enhancing improvements.

Dr. Parkinson then presented a chart that had been circulated at a recent Stanford University symposium where the various categories were prioritized (Figure 2).

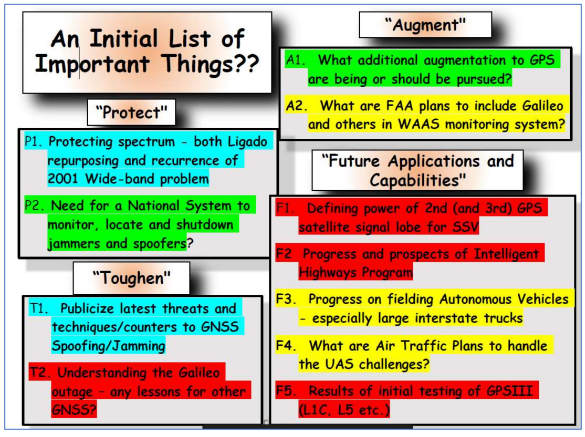

Figure 2: Prioritized Initial List of Important Things

In Figure 2, items highlighted in RED indicate a consensus as to highest priority, including:

T2. Understanding the Galileo outage – any lessons for other GNSS?

F1. Defining power of 2nd (and 3rd) GPS satellite signal lobe for the SSV

F2. Progress and prospects of Intelligent Highways Program

F5. Results of initial testing of GPSIII (L1C, L5 etc.)

Those in BLUE indicate next highest priorities:

P1. Protecting spectrum - both 5G MSS band repurposing and recurrence of 2001 issue with Ultra-Wide Band (UWB) problem

T1. Publicize latest threats and techniques/counters to GNSS spoofing/jamming

Those in GREEN indicate medium priority:

P2. Need for a National System to monitor, locate and shutdown jammers and spoofers

A1. What additional augmentation to GPS were being or should be pursued?

Those in YELLOW indicate lowest priority:

A2. What are the Federal Aviation Administration's (FAA) plans to include Galileo and others in Wide Area Augmentation System (WAAS)?

F3. Progress on fielding Autonomous Vehicles -- especially large interstate trucks

F4. What are Air Traffic Plans to handle the UAS challenge?

Dr. Parkinson then sought the reaction of Advisory Board members to this list: What might be added? What might be dropped?

Discussion:

ADM Allen referred to the power grids and the smart ports but said they need not necessarily be added to this list. He also noted the previously produced White Papers might need to be ungraded based on discussions at this session.

Capt. Burns said that under future applications, the timing applications for the financial sector will involve a huge investment.

Dr. Parkinson said he thought this should be included.

Dr. Camacho said the 5G issue might involve several hundred billion dollars and would be a big driver. Perhaps this is already covered under P1.

Dr. Parkinson asked Dr. Camacho to draft a several sentence statement that might be added to P1.

Lt Gen Thompson noted that GPS is being used to determine the level of water vapor in the atmosphere as it relates to flood prediction. He is concerned about system vulnerability.

Mr. Shane said the FCC, which controls spectrum allocation, is an independent agency and not part of the executive branch. This places various interests – among them, safety of life -- in the role of supplicants to the FCC. He noted that the President is empowered to veto an FCC action on national security grounds. Does the Advisory Board wish to make a recommendation on this?

Dr. Parkinson said a fifth category – Policy – is needed.

ADM Allen asked Dr. Parkinson to comment on ITAR.

Clearly, Dr. Parkinson said, this needs to be addressed. Equipment manufacturers could produce significantly tougher receivers, but they are dis-incentivized by ITAR regulations that prevent the sale of such equipment outside the U.S. He suggested ITAR be added to the subcommittee reviewing policy.

Mr. Younes commented that, regarding spectrum issues, an initiative has been taken to hold this June a symposium with the NSpC on spectrum. The ITAR question could be added at that time. There is poor understanding of the effort to commercialize space.

Dr. Betz said the list is good. He said the coupling between Augment and Future Applications and Capabilities needs to be stressed. A1 should be modified to emphasize the importance of future capabilities.

Dr. Parkinson welcomed this point.

ADM Ellis noted the UAG has made a recommendation on spectrum allocation. It calls for the involvement of the National Academy of Public Administration to provide process expertise on how this should be done. He urged this be added under Policy.

Mr. Higgins noted the FCC has not approved U.S. use of the Galileo E6 signal. In consequence, while Australians would benefit from Galileo high accuracy services, Americans would not.

Dr. Parkinson asked if anyone knew why E6 has been excluded.

Mr. Higgins responded that he thought it was because GPS does not offer it. He noted earlier discussion as to whether the Advisory Board should be more active as an intermediary. If so, this item could be listed under Policy.

ADM Allen mentioned that this is not a military/civil user, but also related to .gov. The Advisory Board could offer advice on functionality, something that to date it has not been doing.

Dr. Parkinson asked ADM Allen to provide a several sentence statement of his position.

ADM Allen accepted the task.

Mr. Shane said protocols are needed to make users aware in advance that testing is occurring in their environment. Several near misses are attributable to a lack of knowledge that testing was in progress.

Dr. Parkinson said this should be added under Policy.

Mr. Murphy said he believes better guidance and support could be used overall; in particular, in the autonomy world. There is a dearth of support for this, both under Augment and under Policy. He does not wish that certain technologies – particularly sensor fusion – be restricted.

Mr. Stenbit, referring to the lack of FCC approval of Galileo E6, said his understanding is that the FCC did not allocate that band, but did not want to preclude it being used for something else in the future.

Dr. Parkinson said the conclusions reached need to be actionable recommendations to the EXCOM. As possible examples, he cited ITAR, foreign GNSS, and UAVs. Under Enablers, he noted two additional items: (1) assigning of a department to publicize threat assessment; and (2) opposing any expansion of UWB allocation. These are possible matters the EXCOM could address.

Dr. Parkinson said he would, as an action item, update the list discussed above.

ADM Allen asked what should be recommended to EXCOM. He stressed that, with the EXCOM, it is best to make one recommendation; two at most. ADM Allen said the workplan will also be posted on www.gps.gov.

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National Coordination Office (NCO) for Space-based PNT
PNT Policy Activity Update
Mr. Harold (Stormy) Martin, *Director, National Coordination Office for Space-Based PNT*

Mr. Martin stated that the U.S. must maintain its leadership in the service, provision, and use of GNSS. He summarized the tenets of the 2004 PNT policy, of which the chief tenet is to maintain GPS leadership in GNSS. The 2004 policy is currently being reviewed and updated by the NSpC. While formal agreement has yet to be reached, the update will likely address: growth and value of civil applications; responsible use of PNT services; use of GPS for space navigation; GPS cybersecurity; and the protection of the GPS spectrum environment.

Mr. Martin noted that the airwaves are not safe. The number of GPS receivers in the U.S. has grown from 600 million in 2015 to 900 million in 2019. Such growth will continue. The spectrum that GPS receivers rely upon is no longer a safe haven. GPS receivers have typically been designed like 1970s radios in that they hear what they hear, and then act accordingly. However, GPS receivers now face 21st century threats, which are becoming much less expensive to mount. Videos available on YouTube provide instructions on how to create a GPS spoofer for as little as a few hundred dollars. Known, but unmitigated, vulnerabilities are among the highest cybersecurity risk. Receivers need to be designed for the 21st century environment. Approximately 99% of the 900 million U.S. receivers are operated by the private sector and consumers. The NCO is now looking to the Advisory Board because of its ability to connect with these private owner/operators.

As a response to spoofing, the Advisory Board has long advocated its PTA policy. The NCO advocates that corporations should include GPS-enabled devices in their cybersecurity plans. The federal government is producing interface specifications on how they can best address this issue. Users should be demanding customers. Corporations could use their requirements and contracting processes to ensure that new purchases adhered to the best practice standards. Mr. Martin called attention to GPS Interface Specification (IS-GPS-200K) and Department of Homeland Security (DHS) Best Practices, January 2017, both available on www.gps.gov. Also, once the GPS policy update is complete it will be posted at this site.

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Update on Air Force Space Command Reorganization Activities
Role of GPS Integration Office
Lt Gen David Thompson, *Vice-Commander, Air Force Space Command (AFSPC)*

Lt Gen Thompson noted that presence of a senior AFSPC leader at these meetings provides mutual benefit. First, it allows him to inform the Advisory Board on pertinent matters; second, he benefits from learning the thinking, challenges and concerns that surfaced at PNT sessions. Further, as the Advisory Board provides a vision on the future, it also allows the Air Force to operate its mission more effectively. While he appreciates the praise of the Advisory Board on Air Force GPS-related capability, he accepts that praise on behalf of all men and women of AFSPC who do all the necessary work.

Lt Gen Thompson addressed organizational changes taking place within the Department of Defense (DoD). Some have already occurred; others are pending. All will benefit U.S. space operations generally, and GPS in particularly. On August 29, 2019, a new U.S. combatant command had been reestablished – the U.S. Space Command, to be directed by a four-star general. Space Command had previously existed between 1995 and 2002. Its reestablishment reflects increased recognition of both the economic value of space and possible military threats from space. He welcomed this news, as it implies there will be a flag officer who, on equal footing with other commanders, focuses on the needs of space. For GPS, this means a high level of advocacy and recognition that GPS faces continuing threats.

Next, he addressed the pending question of whether a U.S. Space Force should be created. At present, the Air Force is the primary provider of space services. The Secretary of Defense has proposed separating space-related functions from the Air Force. They would be organized under the Air Force and operate in a manner like the U.S. Marines, who are a subset of the Navy. This matter is currently before Congress as part of the National Defense Authorization Act (NDAA). Negotiations in both the Senate and House have showed that members of both parties have interest in establishing a sixth branch of the Armed Services. The Air Force has also established a planning team to address how this would be accomplished, if approved. Lt Gen Thompson then turned to the Authorization of a U.S. Space Force/Corps. He provided the House and Senate versions of authorization and appropriations, and added the language from Space Policy Directive 4:

- *The Department of Defense shall take actions under existing authority to marshal its space resources to deter and counter threats in space, and to develop a legislative proposal to establish a United States Space Force as a sixth branch of the United States Armed Forces within the Department of the Air Force.*
- *Consolidate existing forces and authorities for military space activities, as appropriate, in order to minimize duplication of effort and eliminate bureaucratic inefficiencies.*

Emphasis has been placed on not creating additional overhead costs. Such costs will be minimized by placing the Space Corps within the organizational structure of the Air Force to allow leveraging of Air Force expertise.

Discussion:

Dr. Parkinson asked where the ballistic missile forces would go. Lt Gen Thompson said these would remain in the current structure.

ADM Ellis noted that his original appointment letter from the President was a half-page long. Shortly thereafter, he received a 26-page single spaced memo from the Joint Chiefs of Staff defining in greater detail what the President had meant. What was the reaction from Joint Chief of Staff to this proposal?

Lt Gen Thompson said that the Chairman of Joint Chiefs, having consulted with other chiefs, stated that a full level command is needed. Support from the other services has been full. In addition, the existing chiefs have identified additional responsibilities for Space Command. The expectation for Space Command is high.

Mr. Younes asked if there will be any civilian component to Space Command.

Lt Gen Thompson replied that U.S. Space Command has developed a special relationship with the intelligence community. A joint task force of DoD and the intelligence community is charged with protecting all U.S. space assets, including civil and partnership assets. What is entailed is largely the maintenance of and/or transfer of existing relationships.

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GPS Program Status & Modernization Milestones
IIIF, OCX, & Emerging Capabilities for Users
Lt Col Ken McDougall, *Chief, GPS Integration Branch, GPS Integration Office, Space and Missile Systems Center (SMC)*

Lt Col McDougall began discussing the reorganization of the Space and Missiles Systems Center (SMC) and his role within it. Then he presented an overview on GPS, where he addressed modernization efforts at the space, ground, and user segments. In Space, he noted the launching of the GPS III satellites, which offer increased accuracy and power; broadcast all civil signals; are designed for longer service life; and include laser retro-reflectors. On Control, he noted the upgrading to the Modernized Operational Control Center (OCX). Because to delays, OCX was not been available when expected, so OCX Block 0 was created as an upgrade to support the launch the first two GPS III satellites. As for the User segment, he noted continued support for an

ever-increasing number of applications and rollout to the user community of modernized civil signals. He then presented the current status of the GPS constellation, which continues to give outstanding User Range Error (URE) performance.

Mr. Stenbit asked when enough satellites will be in operation for M-Code Initial Operational Capability (IOC).

Lt Col McDougall said there will be 24 M-Code satellites within the next year or two.

Mr. Stenbit asked if the IOC is also based on 24 satellites.

Lt Col McDougall said it is not; the IOC is defined differently and not based on the number of satellites in orbit.

Mr. Stenbit asked when users will be able to start using the new GPS III signals.

Mr. Harold Martin (Director, National Coordination Office) noted that GPS III signals will become part of the constellation in 2022. He explained that the first GPS III purchase was not for 32 satellites, just 10.

Lt Col McDougall said production of satellites is not the only issue; launch availability is also a consideration.

Mr. Lewis commented that a user does not need all satellites to have GPSIII capability; a user just needs one satellite constantly in range. That required 12 satellites, not 24 satellites.

Mr. Stenbit asked Lt Col McDougall to provide an estimate when 12 GPSIII satellites will be in operation.

Lt Col Thompson said in about a decade.

Lt Col McDougall then presented status report slides on GPS III Follow-On (GPS IIIF); Next Generation Operational Control System (OCX); GPS III Contingency Operations (COps), and GPS Military Code Early Use (MCEU).

Mr. Lewis asked when the earliest use of M-Code would occur.

Lt Col McDougall said operational acceptance is expected in 2020.

Mr. Lewis asked when it will be available to the user in the field.

Lt Col McDougall said in 2025.

Dr. Parkinson noted the series of questions related to dates for users. He suggested that future presentations be built around the availability dates, as that is the subject of most concern to the Advisory Board.

Mr. Martin said that request can be readily met.

Dr. Parkinson said the most important information is not the date when satellites are ready for launch, but the projected date when their capabilities are available to users.

Dr. Betz noted that in a year both BeiDou and Galileo will have full constellations of signals equivalent to L1C and L5. What is constraining GPS from doing likewise? Is it satellite availability? Availability of launch vehicles? What can be done to make things to move more rapidly?

Lt Col McDougall said it is also a question of budgets and priorities. The current production schedule is not limited by time, but by budget and priority.

ADM Allen said the question is one the Advisory Board needs to explore on behalf of the user.

Dr. Parkinson acknowledged that there are priorities besides GPS. However, if GPS is to regard itself as the Gold Standard, then that carries underlying issues.

Lt Col Thompson said he will work with the Advisory Board to ensure it receives the additional information that has been requested.

Lt Col McDougall then presented a slide: Preparing for Next Generation GPS

Mr. Shane noted that the development of GPSIII satellites carries the necessity of defending them. He asked if the new satellites would be better able to identify spoofers and jammers than current satellites.

Lt Col McDougall said he does not recall a requirement for enhancement in this area.

Mr. Miller said the question raised by Mr. Shane will be addressed later. He stressed it is just as important to discuss the capability of the SSV. That discussion will occur later. He suggested that SSV be included in future modernization charts.

Lt Col McDougall agreed.

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U.S. Department of Transportation (DOT) Developments on PNT Resiliency
Dr. Andrew Hansen, *DOT Liaison to the GPS Program Office*

Dr. Hansen said DOT is still working under the NSPD-39 as its umbrella. His briefing would address cybersecurity and complementary PNT. He presented charts on PNT Resiliency Initiatives and the Taxonomy of PNT Resiliency Mechanisms. Spectrum protection is a broad collaboration led by DOT, for example, in the Adjacent Band Compatibility study DOT regards GPS as a central tenet. Specific DOT initiatives include Modernized GNSS Open Signals and Specification and Complementary PNT Services. This includes the unglamorous task of digesting documents and setting standards for various modes of transportation.

Baseline activities as includes U.S. government infrastructure development and end user equipment development for industry, academia, and government. Important work is proceeding both in-band and out-of-band interference protection. Work with both manufacturers and users is necessary. Out-of-band work also serves as a pathfinder to the more difficult problems that need to be faced. In 2019 DOT has undertaken a spectrum survey across the modes, which provides an outlook as to what DOT needs to do in the future.

Regarding Civil Signal Operational Capability Interference Protection IPT, the current major focuses are, first, getting operation declarations on the open channels and, second, coordinating an early use L2C initiative. He reported on extensive efforts to engage end-users in monitoring performance. He also reported on Advanced Receiver Autonomous Integrity Monitoring (ARAIM) standards update for aviation, as well as Federal Aviation Authority (FAA) prototyping and testing. Here, there is a parallel between ARAIM and WAAS. WAAS brought a wide range of user benefits beyond those specifically intended. ARAIM will provide a limited set of services to a very broad range of users. ARAIM extends to GNSS services beyond GPS. He then reported on DOT civil signal coordination and exchanges at the international level. There is significant Congressional motivation relative to resilient PNT. Finally, he also presented the PNT Demonstration Work Plan, where he praised the level of support being received from both government and private entities.

Summarizing, Dr. Hansen stressed two areas: first, continuing work on core PNT resiliency and, second, demonstrating complementary PNT for increased resiliency across a broad range of technologies across the stakeholder base.

Capt. Burns referenced the navigation plan. He noted concern in the industry that 5G spectrum sales might create safety-of-life issues.

Dr. Hansen seconded the concern, adding that Ms. Karen Van Dyke is coordinating this on a weekly, or better, basis.

Mr. Shields raised the subject of alternative backups. Have any investigations been made of what might be accomplished by the planned, massive Low Earth Orbit (LEO) communications and whether that could also be used to support PNT?

Dr. Hansen said two vendors are scheduled to demonstrate such capability.

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DHS S&T PNT Program and Conformance Framework:

Science & Technology Directorate (S&T) Update
Mr. Ernest Wong, *Technical Manager*
Ms. Brannan Villee, *Program Manager*
DHS Science & Technology Directorate

Ms. Villee explained that the Science & Technology (S&T) Directorate is the research arm of DHS. Its four focus areas are aimed towards increasing resiliency through performance and vulnerability assessment, engagement and education, improved technologies, and diversity of PNT sources. The S&T Directorate has no control over stakeholder purchasing. Instead, engages with interagency partners and stakeholders. Its goal is to raise awareness of both sides of test results.

Mr. Wong described the Resilient PNT Conformance Framework. An important issue is clarifying what is meant by Resilient PNT? DHS has created a Best Practices document. This is a standards document, not a requirement on manufacturers. Manufacturers, in discussion with customers, frequently have difficulty identifying the differences between various products. The Conformance Framework Vision is focused on the user segment, and initially on GNSS-based timing equipment. This involves creating a common language that defines levels of resilience, from 1 (low) to 4 (high). These definitions should allow users to judge more intelligently what levels of resilience they need. A three-phased approach is being used. The first, a set of standards for guidance documentation to be used by manufacturers, should be completed by spring 2020. The second is a reference architecture to ensure that the guidance is feasible and testable. The third and most important is participation from industry and users. The four guiding principles in this approach are to be comprehensive, simple, consistent, and non-prescriptive. The goal of participation from industry is encourage manufacturers to pursue further innovations. Most status-related aspects have been shared with the major manufacturers, who are broadly on board with the effort. In closing, Mr. Wong invited end-users who wish to take part to send an e-mail to: gps4critical-infrastructure@hq.dhs.gov.

Dr. Parkinson asked which manufacturers have been involved.

Mr. Wong said that while he does not wish to publicly identify firms, almost all major system integrators are engaged.

Dr. James asked if it would be useful to try to anticipate signal challenges as part of developing a new set of signals.

Mr. Wong said that as new PNT sources come on-line, the framework will need to be updated. When GPS III comes on-line, there will be a review.

Dr. Parkinson noted that, as a concept, GPSIII dates back to the year 2000. Twenty-four GPS III satellites will not be in operation until 2030. It is difficult to imagine what new threats will emerge in the interim.

ADM Allen noted that persons present at the meeting may discuss industry participation off-line, if such discussion is desired.

Dr. Betz said this is an important area of work. In the future, infrastructure in the user segment will be the weakest link in the chain. Before a technology is recommended, one needs to be assured of the strength of its infrastructure.

* * *

The Flip
Robust Timing Applications Using GPS
Dr. Arthur K. Scholz, *Lead Signal Processing Engineer, MITRE*

Dr. Scholz said he would focus on how to address resiliency. He described two identical clocks. The first is impacted by a spoofing event, resulting in a timing error, and is similarly affected in a second attack. The second clock remains unaffected. The first clock had listened to GPS for four hours, then disconnected from GPS for 24 hours, with this pattern repeating. The second clock was disconnected in advance of the spoofing event. In consequence, the likelihood of it being spoofed was reduced by 90%. Dr. Scholz observed that a remote attacker cannot harm a free-running oscillator.

Conversations with GPS users commonly reveal an ignorance of their GPS dependency and of the threats GPS faced. Those threats include interference and jamming; measurement spoofing; data spoofing; attacks on timing equipment and through the network, and attacks on system infrastructure. The flip concept lowers the probability of successful spoofing. He explained the Basic Flip and Enhanced Flip approaches. Every power or financial company could employ this approach today. Users need better awareness of the minimal amount of GPS information they need to maintain reliable time. He stressed the importance of clock quality to timing accuracy. If a user says it needs one nanosecond accuracy, would 1.5 nanosecond accuracy be acceptable? Would 5.0 nanoseconds acceptable? The answer will influence the choices such user makes.

In summary, GPS-based timing remains critical. Alternate timing sources should be evaluated, as these might provide lower cost and/or higher quality time, but there is no near-future alternative to GPS. Timing does not become more accurate simply by adding sources, as each new source carries its own vulnerabilities. The Flip approach could be undertaken today, either on hardware or software as convenient.

ADM Allen said he assumes this concept is aspirational and that no actual use case exists. Is this correct?

Dr. Scholz said he knows of sectors that need it. They discipline their clocks around the needs of their operation.

ADM Allen asked how this approach might migrate into best practices.

Dr. Scholz said that would happen based on field reports. He wants to create a set of tools for use by an operator.

ADM Allen asked if the approach is suitable to users who needed nanosecond accuracy.

Dr. Scholz said that depends on the case.

Dr. Camacho asked if this approach is limited to certain categories of applications and, if so, would that information be available?

Dr. Scholz noted that relatively little time stamping is done to the microsecond standard. He wants organizations to look at their timing structure and determine how GPS affects them.

Mr. Higgins noted that, to date, most timing functions have used single frequency, but dual frequency is becoming more common.

Dr. Scholz said one main driver of how long one needs to discipline the clock is the variance of the output of the GPS receiver. The more one reduces that variance, the better off one will be. Dual frequency will provide an advantage.

Mr. Younes noted that any multi-GNSS receiver has diversity of timing. How could the cost of clocks be reduced?

Mr. Burgett said it appeared Dr. Scholz may be asking people to buy more clock than they needed.

Dr. Scholz said that, on the contrary, many users spend more than necessary for clocks because they do not know when they can't rely on GPS time, nor do they know how much error their various operations can tolerate.

* * *

Introduction to the National Space Council (NSpC) Users' Advisory Group (UAG)
ADM Jim Ellis, *Chair, National Space Council UAG*

ADM Ellis explained said the NSpC is an advisory body chaired by Vice President Pence and includes key Cabinet officials. The NSpC was reestablished on June 30, 2017 to coordinate all U.S. national space policy across relevant agencies in all segments (civil, commercial, national security, international, etc.) and to strengthen U.S. leadership in space. The NSpC has met six times and made the following policy recommendations:

1. A call for a U.S.-led integrated program with commercial partners to return humans to the Moon with missions to Mars and beyond to follow;
2. A call for regulatory reform for commercial launch and reentry, commercial remote sensing, and spectrum use;
3. Directing the development of a national space traffic management policy to preserve the space environment for future use, and,
4. A call for creation of the establishment of a United States Space Force.

There is a heightened awareness of the importance of space. Whether that would lead to increased appropriations is yet to be seen, but it is an exciting time in the field. The UAG included representatives from almost everyone with an interest in space. Like the PNT Advisory Board, it is a FACA committee organized under NASA. Both federal and non-federal groups are involved, meeting three or four times a year. The remit of the UAG is broad. It's first two charges are:

1. The effect of existing and potential U.S. and foreign government policies, laws, regulations, treaties and other international instruments, programs and practices on national security, civil, and private sector space activities;
2. National security space priorities, including those affecting Homeland Security, the Nation's defense and intelligence activities, as they relate to coordination, cooperation, and technology and information exchange among the civil, national security, and commercial space sectors.

Given the broad remit, the challenge to the UAG is to determine priority tasks. He listed the six UAG subcommittees, noting the high-level of expertise engaged. The UAG can select tasks. Five specific tasks have been assigned to the UAG by the Vice President: The UAG efforts are focused on lunar exploration architecture; the organizational structure of the United States Space Force; findings and recommendations on how to continue to lead; prioritizing technology needed not only to return to the Moon, but to support proceeding to Mars, and, finally, spectrum management.

At its October 21, 2019 session, the UAG made the following recommendations:

1. The NSpC should write a Space Policy Directive concerning Science, Technology, Engineering and Mathematics (STEM) education in the United States (U.S.) with the intent to prepare the future space industry workforce.
2. The NSpC should direct the UAG to define the scope of a study to be conducted by the National Academy of Public Administration, reviewing U.S. regulatory jurisdiction and governance (domestic) v. a goal of technology leadership across spectrum related technology sectors. The study should also address an assessment of the current U.S. governance model for spectrum v. alignment with multiple national technological leadership and capabilities priorities.
3. The NSpC should direct the UAG to develop a white paper, outlining and scoping a study of the means to establish and maintain a U.S. Strategic Space Propellant Reserve modeled on the U.S. Strategic Petroleum Reserve (SPR). The white paper should identify variables important to establish reference requirements, such as: (a) the size and location of initial reserves needed to stimulate sufficient infrastructure to support an eventual $1 Trillion space economy; (b) technical means; (c) identification of markets that could be enabled; and (d) models for funding, and others. It is anticipated that a detailed study undertaken by the National Academies of Sciences, Engineering and Medicine would follow initial scoping by the UAG.
4. NASA should provide a briefing to the UAG on their technology roadmap in light of Artemis and the Moon to Mars program, and, if the UAG deems it is warranted, fund a brief external review of the roadmap.

ADM Allen added that he and ADM Ellis have pledged to work together as closely as possible.

* * *

Economic Benefits of the Global Positioning System (GPS)
Dr. Michael P. Gallaher, *Senior Director, Center for Applied Economics and Strategy, RTI International*

Dr. Gallaher presented findings from a 2.5-year study of the economic benefits of GPS. The study attempted to quantify the retrospective benefits of GPS from 1984 to 2017; characterize the role of federal laboratory research and technology transfer, and quantify the potential impacts of a disruption in GPS service today. The study shows that since 1984 the cumulative economic benefits of GPS are $1.4 trillion for the ten sectors studied. Most benefits have occurred since 2010. Major benefits are in productivity and efficiency gains. Benefits also come from improved location features and, where measurable, lower environment impact and improved public health and safety. The $1.4 trillion figure is derived by comparing outcomes to anticipated outcomes from a Loran-C system, which became available simultaneously with GPS.

Dr. Gallaher listed the ten sectors reviewed, each of which received a standalone study. The impact of GPS varies considerably across sectors. The maritime benefit is small, as that segment was comfortable using Loran-C. Alternately, precision agriculture would not exist without GPS. As noted, the study is retrospective. For example, while nearly half the total benefit occurred in telecommunications, where the benefits came after 2011 because at the time other systems could have also been used. In the telematics sector (i.e. commercial vehicles), he estimates 2017 benefits at $50 billion and a reduction in carbon dioxide emissions by nearly 11 million metric tons. Reduced emissions could also be factored into the health benefits. For location-based services, it has not been possible to monetize all benefits. This is because no value was assigned to any reduction in greenhouse gases due to GPS-related reductions as a result of lower travel times. However, GPS service has led to an 11% percent decline in travel time and reductions in number of vehicle accidents.

Retrospective benefits are not the same as the disruptive impacts. The benefits are relative to a presumed continued used of Loran-C. The level of disruption was calculated relative to backup systems in existence. The cost of GPS disruption was estimated at $1 billion a day. This figure does not include agriculture, as those costs depend on time of year, whether it is planting season, harvesting season, or winter. In the maritime sector, the major costs are from shipment congestion at ports, which were initially rather severe. Future studies could extend beyond the ten sectors that were study reviewed. A perspective approach would be more valuable than a retrospective approach, as the former points to what potential benefits may exist. This should help better inform policy decisions.

Dr. Parkinson asked Dr. Gallaher to clarify why he said that GPS had no impact on mining.

Dr. Gallaher said he had perhaps misspoken. Mining has benefitted by GPS. Also, the finance sector at the beginning had little impact from GPS as it relied on other sources for timing.

Mr. Shane said he is surprised that aviation is in the low to medium range of benefits derived from GPS. He thinks those should be higher. A GPS outage would sharply reduce efficiency as greater spacing between aircraft would be required.

Dr. Gallaher agreed. The estimate for aviation is preliminary and does not reflect delays in takeoffs.

Mr. Shane added that while today the business case for GPS in aviation is mixed, it will become stronger as aviation congestion rises in the next twenty years.

Dr. Gallaher said the data on aviation in part reflects the retrospective nature of the study, which did not attempt to quantify future benefits. The rail sector is similar, as during the retrospective period that sector was not employing GPS for speed control.

Mr. Shane noted that GPS had prompted the decommissioning of Loran-C. Had the savings of that decommissioning been built into the study?

Dr. Gallaher said they had not.

Dr. Betz said that, absent GPS, a replacement better than Loran-C would have been devised. He suggested that such a replacement would be a better reference point.

Dr. Gallaher noted that the benefits of GPS followed from it being free. It was unknowable if, absent GPS, how the telecommunications and other sectors would have moved to go beyond Loran-C. As that was speculative it made it difficult to posit what alternate system might have been employed.

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Socio-Economic Studies of GPS
Past, Present and Future
Dr. Irving Leveson, *Founder, Leveson Consulting*

Dr. Leveson said he would address the timeline of past, current, and future benefits of GPS. His focus is on recent, publicly-available studies that stress economic benefits. Little has been done on environmental and safety-of-life considerations. Further, little has been done to address future benefits. Such studies include the 2015 report requested by the PNT EXCOM to determine the value of GPS. Benefits were determined by what would have been expected in the absence of GPS. However, his own view – which differs from the previous presenter – is that in the absence of GPS either eLoran would have been developed or atomic clocks placed on satellites to disseminate time. Earlier studies focused on GPS since Galileo and BeiDou were not yet in operation. Today, the use of multi-GNSS must be considered. The RTI study left unaddressed the role of multi-GNSS.

While the RTI study does an outstanding job in many areas, their results reflect several perspectives he does not share. RTI reported that half of GPS benefits came in telecommunications. That calculation assumes that eLoran would not have been possible and, therefore, 4G would not have happened. This is something he finds unlikely. Further, the costs of the 30-day outage assume no other GNSS system would be available. Any avoided costs of alternatives would be much lower than the potential costs of an unexpected loss of GPS timing. Also, describing the annual benefits is more useful than the cumulative ones.

The next step should be to look at both public and private sector benefits and at how to divide credit for those benefits between GPS and other GNSS systems. Current benefits might be the result of multi-GNSS, not GPS alone. Further, sectors not covered

need to be included; multiplier effects need to be included, and we need to better address safety-of-life and environmental impacts. Whatever approach is used will only yield ballpark estimates. It is crucial to look at future benefits, because of 5G and the new national spatial reference system. Information on future benefits is needed so decision-makers can make informed decisions. Addressing the costs of disruption, attention must be paid to various possibilities. For example, does the disruption affect only one sector or multiple ones? Finally, in addition to the technical studies being done on GPS, a showcase report should be prepared for a more general audience.

Dr. Parkinson said that the conservatism of the RTI approach could be an advantage, since it did not try to put a price tag on issues such as loss of life.

Dr. Betz said he believes military savings have been substantial and should also be included.

Lt Col Thompson agreed, saying that civilians benefit from such advances as precision guidance and the reduction of collateral damage.

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Why Wait?
Real-time GNSS Monitoring for Infrastructure Protection, and a JPL Perspective on Galileo vs. GPS
Dr. Yoaz Bar-Sever, *Program Manager, Global Differential GPS (GDGPS), Jet Propulsion Laboratory (JPL)*

By way of introduction, Mr. Miller noted that it is well known that OCX will not yet be able monitor GPS signals. As members listen to the presentation by Dr. Bar-Sever, they should consider whether things are moving ahead properly, or if other options should be considered. An independent assessment by the Advisory Board would be useful. He hopes to have an assessment leading to a recommendation at the spring meeting on how best to move forward on GPS monitoring.

Dr. Yoaz Bar-Sever explained that his central task is to track real-time tracking data from the GDGPS. The data goes in real-time to the Multiple Operations Center, where the main products are produced. These products include performance monitoring for the Air Force, data to support industrial operations, and data on assisted GDGPS to enhance performance of cell phone users. He presented a chart on two decades of performance for the Air Force, noting the most important figure is the URE. Extracting the age of data is also important – the average is 11.5 hours.

ADM Allen asked if all sites are terrestrial.

Dr. Bar-Sever said they are, including islands.

Dr. Bar-Sever presented comparable data for Galileo, noting that the median URE is 0.17 meters, with a reported age of data of less than one hour. This performance is primarily a product of clock quality. Tracking is robust; and he cited one Galileo satellite whose signal was tracked in four continents. Dr. Bar-Sever noted that different users track different signals, and it is necessary to track the delay associated with each. This measurement changed in 2017 with the introduction of GPS Flex Power, which alters the power provided to each GPS signal.

Dr. Axelrad asked if this affects the clock corrections for the dual frequency users.

Dr. Bar-Sever said it does, depending on which signal is impacted. In determining the constellation clock by the ground segment, only P1 and P2 were used. If one does not tamper with P1 or P2 biases, then there would be no effect and the clocks would be predictable. Only GPS L1 Coarse Acquisition (C/A) users would be affected. Unfortunately, some of the Flex Power mode do impact P1 and could negatively affect the ground segment.

Mr. Powell said any Time Group Delay (TGD) error will RSS'ed (root-sum-square) with all the other errors. It is not going to increase the positioning error by a multiplying by the Dilution of Position (DOP), because one would have to it with all other terms in the error budget.

Dr. Bar-Sever said that while the error would be subject to RSS, it could still be quite significant.

Dr. Parkinson said the situation is considerably more complicated than that. Mr. Powell's point is well taken.

Dr. Bar-Sever then addressed situation assessment and mitigation of GPS threats thanks to GDGPS. Threats included integrity, jamming, and spoofing. Greater advantage should be taken of the fact that multi-GNSS systems are more difficult to jammed or spoofed than use of a single GNSS. Threats can be either regional or at a point. A regional attack covering over 500 km would likely allow other GNSS tracking sites to be called upon. Thousands of U.S.-based sites could be drawn upon. Point attacks are more difficult if the site is connected. In support of civilian applications, his view is that Galileo is in the passing lane in terms of the Gold Standard. Galileo already has laser retro-reflectors, and it also publishes altitude model or radiation pressure properties; GPS does not. Galileo also has better clocks.

Addressing the topic query "Why Wait?", existing global and regional GPS tracking networks, technologies, and operational capabilities already enable effective mitigation of many threats to sensitive GPS infrastructure in the U.S. and beyond. Why should one wait for a better system to enhance infrastructure resiliency? Finally, if current trends continue it is not impossible that GPS

may end up becoming a backup system to Galileo for civilian applications. This may or may not be good, but it is important that those making decisions are aware.

Dr. Beutler said the presentation was very interesting. Many things suggested by Dr. Bar-Sever are already being done by the International GNSS Service (IGS). How do the efforts of Dr. Bar-Sever relate to information already available? Further, he believes the 200+ sites Dr. Bar-Sever referenced include many that were non-JPL sites.

Dr. Bar-Sever said he thinks an operational system might be preferable to the IGS. The difficulty is that it is was not clear to whom any potentially failing on the part of IGS could attributed to.

Mr. Younes asked how long it would conduct a to study on how to take advantage of existing GNSS systems and what would such a study cost? He is looking at what would be needed for information delivered in real-time.

Dr. Bar-Sever said that, provided it is clear what answers are needed, such study should not take a long time.

Mr. Younes said he wants such capability to remain ahead of criminals.

Dr. Beutler said that if one has a network of 400 stations worldwide, that is a very reliable basis from which to operate.

Dr. Bar-Sever said one also needs to learn how to take advantage of what exists.

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Compatibility of Terrestrial Reference Frames used in GNSS Broadcast Messages
Mr. Stephen Malys, *Senior Scientist for Geodesy and Geophysics*
National Geospatial-Intelligence Agency (NGA)

Mr. Malys said he would address interoperability between GNSS systems. His methodology is to compare Terrestrial Reference Frames as realized through Broadcast Navigation Messages to the Reference Frame realized through Post-Fit Multi-GNSS Experiment (MGEX) Experiment. How closely aligned are the reference frames? For GPS, he is using the 56-day period (July 21-September 14, 2019). While all systems are intended to be closely aligned to the ITRF, each system relies on different software. Data on Russian and Chinese sites within their territories are generally not shared with the world.

Mr. Malys presented a geographic chart of the operational monitoring of GPS from within the U.S. The network consists of 17 stations. He noted that the MGEX network consisted of hundreds of stations. Geodesists typically compare reference frames by using a seven-parameter transformation. He presented a simplified model of those parameters. He then showed the evolution of International Terrestrial Reference Frame (ITRF) realizations. These, from 1988 to 2008, have dropped from 17 cm. to less than 0.5 cm. This improvement traces largely to the rapid increase in the number of monitoring stations. The data set is very robust, as it is based on over 20 years of information. He also presented information on each GNSS system, the number of tracking stations used, and the mean results. The good news is the recorded differences are at the cm level. Where reference frame differences exist, those are small.

In 2016 the values for GPS were slightly better than anyone else. By 2019, Galileo was better than everybody else. This follows from the more frequent uplink of data in the Galileo system. This report does not cover vertical reference, which is a separate issue. Perhaps it can be addressed a future meeting.

ADM Allen said a change in the reference data will be under discussion with ADM Sharp, Director, National Geospatial-Intelligence Agency.

Mr. Miller called attention to Mr. Malys' central role in the seven-year effort to get approval to add laser retro-reflector arrays to GPS IIIF satellites and thanked him for excellent work.

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Recent Developments within the International Committee on GNSS (ICG) on the Use and Applications for PNT
Ms. Sharafat Gadimova, *Scientific Affairs Officer, UN Office for Outer Space Affairs, Vienna*

Ms. Gadimova reported on recent developments within the ICG and its use of PNT. The United Nations (UN) Office for Outer Space Affairs has a long history of assisting member states to use space science and to promote international cooperation. The office is a capacity-building body addressing a broad range of uses. The body has two subcommittees, addressing scientific and legal matters, respectively. Established in 1959 by the General Assembly with 24 members, it has since expanded to 92 member nations. The Legal Subcommittee addresses such topics as the five UN treaties on outer space, legal mechanisms relating to space debris mitigation, and international mechanisms for cooperation in the peaceful exploration and use of outer space. The Scientific and Technical Subcommittee discusses matters ranging from space weather, Near-Earth Objects (NEOs), the use of space technology for socioeconomic development, disaster management support, global navigation satellite systems, and the long-term sustainability of outer space activities.

The ICG, established in 2005, provides a mechanism for multi-lateral discussion on all GNSS matters. The membership consists largely of current and foreseeable providers of GNSS. The 22nd meeting of the Providers Forum occurred on June 10, 2019 in Vienna. The next meeting ICG meeting will be in Bangalore in December. She identified and gave the current recommendations

from the ICG three working groups: Systems, Signals and Services; Enhancement of GPS Performance, New Services and Capabilities; and Reference Frames, Timing and Applications.

Ms. Gadimova then described the ICG Program on GNSS applications. This program included UN regional workshops/training courses on use and applications of GNSS; GNSS spectrum protection and interference detection and mitigation, and standards for and interoperability of precise point positioning (PPP) services. The last one is as directed at supporting PNT applications in developing nations. The ICG maintains regional information centers in six countries. Additional information available is available at: www.unoosa.org and www.unoosa.org/oosa/en/ourwork/icg/icg.html.

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GNSS for the Developing World
Collaborations for Scientific Exploration and Applications with Societal Benefits
Dr. Patricia Doherty*, Director, Institute for Scientific Research at Boston College*

Dr. Doherty noted that GNSS offers transformative benefits to the developing world. This follows from the broad range of applications. She described Africa's Science and Technology Plan of Action, which emphasizes using science and technology to help integrate African nations into the world economy. The potential benefits from GNSS include greater food security; better emergency location services and disaster relief; improved mapping; wildlife conservation and management; provision for better land, sea, and air navigation, and scientific research and exploration. Her institute has designed a program to introduce those benefits, with an initial emphasis on Africa. Key to realizing these benefits is the building of a knowledgeable African-based workforce with competence in infrastructure and technology.

Dr. Doherty presented a photo of 50-60 participants from twelve African nations at the first workshop held in 2009. Those attending were impressed by the expertise made available to them. Ten workshops have been held to date. While each has a different curriculum, all emphasize GNSS. The next workshop is scheduled in Morocco. She also noted the importance to space weather in this region and to the shortage of infrastructure. This, through time, is improving. The most recent workshop focused on how to forecast the ionospheric effects on GNSS operations.

Dr. Doherty noted the expanding geographic range of efforts – from the original twelve African nations, the effort now enrolls persons from Asia and South America, with 29 countries represented in 2019. Each year, 300 to 400 applications are received for the 40 or 50 available slots, which is good number to work with. In 2019, 49% of participants were women. The program emphasizes hands-on applications, for example, in agriculture. The success of the effort is measured by the growth in regional workshops that it has sprung off; by the creation of a GNSS course at a Rwandan university; and by an increase in the number of PhD graduates and the high number of papers published by program graduates. The next event is the 2020 African Workshop on GNSS and Space Weather, October 5-16, 2020 in Rabat, Morocco. She invited all interested to take part. Her contact information is: Patricia.Doherty@bc.edu; http://www.bc.edu/isr

Mr. Younes noted that space agencies exist in multiple countries with which Dr. Doherty is working, including Nigeria, Egypt, Kenya, South Africa, and Morocco. He urged that an efforts be made to bring experts from these science centers to meetings whenever that may be of use.

Dr. Doherty said that would be an immeasurable benefit.

* * *

Augmenting GPS with PNT from Low Earth Orbit (LEO)
Dr. Peter Iannucci*, Postdoctoral Fellow, The University of Texas at Austin*

Dr. Iannucci explained that he works with Dr. Todd Humphreys. Their effort is on the verge of providing a substantial augmentation for GPS thanks to developments in LEO constellations. Thinking on LEO has converged. One piece is Blackjack, a platform for the rapid deployment of military satellites. The second is Kepler, which has been termed a third generation GNSS because of its use optical clock and satellite links to establish a reference frame outside the atmosphere. To-date LEO has been unattractive to PNT because each satellite covers a small area on the surface, so therefore a prohibitively large number of satellites would be needed for global coverage. However, as costs have continued decreasing this option is becoming more attractive, and there are now three commercial entities developing LEO constellations between of 2,000 to 10,000 satellites each. Each satellite could carry a hosted PNT payload at only the additional cost of the payload itself.

Questions to be faced include: Can we compromise on clock quality? Can we compromise on signal structure? Can we share spectrum, timing, and antennas with primary data customers? Existing information says the answer to these was: Yes. With minor modifications, existing hardware can do everything needed to provide adequate PNT performance. These systems could also be used in combination with GPS. Fused PNT is not new idea, but rather an idea whose time has finally come. Also, the increased number of satellites makes such a system an unattractive target for hostile attack. The bottom line is +56 dB anti-jam and 32 cm (95%) accuracy with 1 second Age of Data (AOD), or 1.21 m with 50 s AOD, and with no hardware cost to the federal government.

Mr. Younes asked if the study could be made available to the Advisory Board for closer review.

Dr. Iannucci said the study will be ready soon.

Mr. Younes asked what, in cost and complexity, is the payload needed to put these into LEO.

Dr. Iannucci said the cost is $0. The central idea of fused PNT is to start by assessing what the satellite hardware could already do and then work with the satellite designers to include a secondary PNT mission. The only needs he foresees are a dual-frequency GNSS receiver and an OXCO, which carry minimal cost.

Mr. Younes asked for the study on which the accuracy range is based.

Dr. Iannucci said the analysis is on work by Dr. Oliver Montenbruck on precision orbit determination. In consequence, he believes it is feasible to do precision orbit determination on such system.

Mr. Younes asked if orbits beyond LEO have been studied.

Dr. Iannucci said they have not.

Mr. Murphy asked if the large highly directional antenna is really needed.

Dr. Iannucci said part of the question is why a highly directional antenna was used in the example presented. Part is the desire to get everything possible out of a high rate; part is the International Telecommunication Union (ITU) instruction that forbids interference with anything else. A smaller antenna might sacrifice some ground-level anti-jam capability.

Mr. Murphy said he doubts much sacrifice would occur.

ADM Ellis said the satellite would require an L-Band receiver.

Dr. Iannucci agreed.

ADM Ellis noted the satellites would be exposed to solar radiation. He suggested their shielding might only last fifteen months.

Dr. Iannucci said this is an area of some disagreement; he believes a five-year lifespan was feasible.

Mr. Murphy noted that in LEO the radiation environment is different.

Dr. Parkinson asked when the experiment will be run.

Dr. Iannucci said a world test will occur within two or three years. He believes the risk of failure is reduced by the competence of those making the satellites.

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Ensuring PNT Robustness, Resiliency, & Interoperability
Galileo Signal Authentication Services & Anti-Spoof Techniques
Dr. Oscar Pozzobon, *President, Qascom*

Dr. Oscar Pozzobon said his company has done considerable work on signal authentication, particularly in relation to Galileo. He has personally worked 20+ years on spoofing and jamming. At times, he feels too much has been made of the subject. Fifteen years ago, early computer hackers did what they did for fun. Hacking has changed – it is no longer for fun; it is for profit. This lesson from computer cybersecurity should be applied to GPS. There are now 400-500 million attacks on computer networks each year; the total worldwide cost of such attacks is estimated to reach $6 trillion. GNSS experiences 10-20 attacks annually in the civilian sector. Such attacks cost somewhere between $5 million and $50 million. Attacks are growing because of the political cyberwarfare context and because financial payments are increasingly reliant on GPS. Rapid growth in small-scale for-profit spoofing efforts should be expected.

Currently there are two trends to mitigate this: first, user protection, with autonomous anti-spoofing devices, and, second, system-based services, including Galileo authentication services, Satellite-Based Augmentation Services (SBAS) authentication, and others. Spoofing can be very simple, even unintentional. Three factors make spoofing more likely to succeed. The first was the probability of entering the receiver at the proper power level.

Mr. Lewis noted that, presumably, the spoofer wants to decrease the value of something by spoofing it.

Dr. Pozzobon said that is so.

Mr. Lewis added that he is concerned with the time delay between a spoofing event and the user learning of that event.

Dr. Pozzobon agreed that is a challenge.

The second factor required for successful spoofing is the need to capture the dynamic in the acquisition, and tracking and shifting with intelligence. The third factor is the likelihood that one can bypass all integrity checks in the navigation solution, and stay within the other nav and time systems accuracy boundaries. Success can be extremely simple or extremely complex.

Dr. Pozzobon presented slides on: Anti-Spoofing Techniques; Autonomous Anti-Spoofing Techniques; Galileo Navigation Message Authentication; Galileo Commercial Authentication Service, and Motivational Likelihood v. Authentication Services.

The biggest challenge faced in anti-spoofing techniques is performance, detection timing, and security alert. It is difficult to devise a single response to all types of spoofing. In civil navigation, unintentional spoofing is a serious issue. In his view there is little financial advantage from spoofing an aircraft, whereas spoofing the financial world could be profitable.

Dr. Parkinson said Dr. Pozzobon did not address that one possible motivation for spoofing is be a quasi-terrorist attack.

Dr. Pozzobon responded that this is addressed in cyberwarfare.

Dr. Parkinson called attention to a major mistake made in the Second World War naval battle of Midway, where the Japanese erroneously based their actions on what they judged would be U.S. motivations, rather than on U.S. actual capabilities.

In conclusion, Dr. Pozzobon identified benefits from a combined GPS/Galileo solution. In space and deep space applications, more signals could be tracked, and longer integration permitted. Second, application robustness will increase. Third, indoor and urban canyon availability will increase. In this, the Galileo outage offers a lesson. The combination of GPS and Galileo could provide great advantages. Fourth, Galileo secure signals could be used in snapshot mode.

Dr. Betz asked if Dr. Pozzobon knows of any solid study of how autonomous anti-spoofing techniques could be implemented in the receiver, with subsequent determination of what vulnerabilities would remain and of how those vulnerabilities would be addressed by signal authentication.

Dr. Pozzobon said that has been reviewed as a European Space Agency (ESA) requirement. The question was: if one combines a good antenna, a good clock, and a good inertial system, does one still need authentication services? This is a difficult question.

* * *

Interoperable GNSS Space Service Volume (SSV)
Update on European Space Agency (ESA) Activities
Dr. Werner Enderle, *Head of Navigation Office, Ground Systems Engineering Department, ESA*

Dr. Enderle said he would describe how space users benefitted from SSV; the changing GNSS environment, and ESA activities related to the GNSS SSV. To-date ESA has only considered the main lobe signals. The ICG Space Users Sub Group has identified various new missions that could be supported through use of the side lobes signals. A report that includes side lobe signal information on Galileo is pending. There is not a space users' community, per se, but rather a number of separate regimes with an interest in space.

GNSS interoperability can be achieved only if three conditions are met. First is a common geodetic frame reference. Second is a common time reference, where at present we don't have a single agreed upon time reference in real time. Third is a common center frequency and coordinated signal design, which has been partially achieved through bilateral agreements.

Interoperable GNSS will provide benefits to performance, operations, and technology. Regarding GNSS generally, in Europe there is the real-time High Accuracy Service (HAS) from Galileo. HAS will provide information for a PPP solution at end user level. Galileo HAS will be provided on a global scale and for free.

Dr. Enderle identified eight ESA study activities related to GNSS SSV and the objective of each. ESA believes interoperable time is essential for some users, particularly with high accuracy applications. A joint effort with NASA has for the first time established a fixed position in space using the GPS L5 and Galileo E5 signals. This can only be achieved through interoperability. The ESA PROBA-3 mission, set for 2020-2021, will demonstrate high-precision formation-flying in a Highly Elliptical Orbit (HEO) orbit. An analysis has been performed using 25 GPS/Galileo L5 and E5 signals, which shows that an orbit accuracy within 15 cm can be achieved, though newly available improvements should allow us to reach 10 cm or better.

Dr. Enderle then spoke to ESA activities related to the Moon and Mars. An on-going review will determine the architecture and augmentations needed to achieve a certain accuracy level. For example, if additional satellites are needed around the Moon, what is needed and where are they needed?

Concluding, Dr. Enderle stressed that an interoperable multi-GNSS SSV offers enormous benefits to space users and will enable more advanced missions in the future. ESA has a clear roadmap for exploiting GNSS SSV possibilities, a strong interest in using GNSS in connection with the Moon mission, and is supporting a range of international activities in the area.

Dr. Camacho said he believes that last year an agreement had been reached at the Providers' Forum to work towards an interoperable SSV. Has something changed?

Dr. Enderle said Dr. Camacho is referring to the goal to which efforts are being addressed by a space users subgroup composed of ESA, NASA and the China National Space Administration (CNSA). Agreement is apparent, but there is a need to ensure interoperability by having each party include it in their respective roadmaps.

Dr. Beutler said this is an excellent example of an application where only a combination of GNSS can provide the basis for a good solution.

* * *

Advancing Space Use of GNSS to Cis-lunar Space & Beyond
Dr. Ben Ashman, *Deputy PNT Policy Lead, NASA Goddard Space Flight Center (GSFC)*

Dr. Ashman described NASA uses of GNSS, including applications such as earth sciences, launch range safety, altitude determination, time synchronization, real-time on-board navigation, and precise orbit determination. Under launch range safety, the Autonomous Flight Termination System (AFTS) is an independent flight component that allowed automatic flight decisions to be made combined with a rule set, and violations of the rules prompt termination of the flight.

Dr. Ashman then described the SSV, and called attention to the criticality of the side lobes, which a beneficial unintended consequence of the GPS signal structure. He presented a chart showing GPS signal reception within the SSV, noting that commonly the signals received come from GPS satellites transmitting from behind the Earth. Use of these signals in an operational setting has occurred in recent years, including the GOES-R series of weather satellites. He described the benefits in using the side lobe signals realized by the GOES-R weather satellite series and the latest data of the Magnetospheric Multi-Scale (MMS) mission, a constellation of four spacecraft flying in formation. The MMS mission holds the record for the highest and fastest use of GPS. Its current orbit apogee spacecraft is 29 times the diameter of the Earth, which is approximately halfway to the Moon.

Mr. Lewis asked what is the probability that only one satellite signal be in view.

Dr. Ashman responded that given the 30-satellite constellation, probability was quite low when tracking GPS main and side lobe signals.

U.S. lunar effort break into three sections. First, to take humans back to the Moon as soon as possible. Second, to create a waystation in Lunar orbit. Third, to undertake precursor robotic research on the lunar surface. He described the feasibility of using GNSS in Lunar Space, and called attention to the recent Interoperable SSV booklet published by the UN. The booklet describes the anticipated performance for each GNSS constellation[2]. High altitude PNT robustness is ensured with diverse application sources, including GPS and GNSS; augmentations; ground-based tracking; optical navigation; x-ray pulsar navigation, and other sources. In conclusion, GNSS has an important role to play in lunar exploration and that the GNSS community should seize the opportunity so offered.

Lt Gen Thompson said that on-board autonomous flight operations, thanks to GPS, are the result of tremendous partnering between NASA, the U.S. Air Force, and other entities. Space vehicles currently in operation use autonomous flight safety systems. Further, every new vehicle must have autonomous flight safety. The actual state of operations, is well beyond some of what has been presented.

Dr. Beutler said he welcomes hearing that NASA has called for the public release of pertinent information regarding GNSS constellations. He reminded the Advisory Board that the same recommendation had previously been made by the ICG. Having access to such information will also enable GNSS to help determine the scale of the terrestrial reference frame in the upcoming update of the realization of the ITRF.

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ADM Allen adjourned the Wednesday, November 20 session at 5:37 p.m.

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

Session of Thursday, November 21, 2019

Board Reconvenes
Call to Order
Mr. James J. Miller, *Executive Director, National Space-Based PNT Advisory Board, NASA*

* * *

PNT Board Roundtable Feedback & Deliberations
Preliminary Findings, Recommendations, & Work Plan
All Members, led by Chairs

ADM Allen said the task for the morning is to discuss how the Advisory Board wishes to organize its efforts. He will work with Mr. Miller on improving session organization. Briefings should cover all pertinent aspects of their subject. For example, a briefing on transportation should provide all the needed information at one meeting. Where single issue presenters are involved, they should ideally be informed in advance about the primary points of interest to Advisory Board members. Reducing the number of briefings will allow for more reflection and discussion. Any Advisory Board member with suggestions for improvements in meeting process should email him or Mr. Miller. The Advisory Board has done a very good job in making briefing materials available as soon as they were ready and posting them on www.gps.gov. It might be wise to create an archive of what had been presented to the Advisory Board, and not just what has been submitted to the EXCOM. The work of the Advisory Board should be transparent to the public. Further, he said Topic Papers and other products of the Advisory Board could perhaps be placed in an archive. This will help create an organizational memory.

Mr. Stenbit offered a note of caution. The Advisory Board hears reports on and discusses a great range of topics. Generally, discussion involves consensus. However, archiving too many items from individual members might suggest such the statements are consensus rather than individual reflections. Some means is needed to determine what merits inclusion.

ADM Allen said collation could be done by topic. He believes that currently much intellectual capital is not being captured. ADM Allen then noted that the previous afternoon a letter from the Secretary of Defense to the FCC had become public. The statements in that letter about protecting GPS from 5G transmissions in adjacent frequencies align with the position of the Advisory Board. This issue has also received press coverage in *The Wall Street Journal* and elsewhere.

Dr. Parkinson said that the Secretary of Defense has gone somewhat beyond previous statements in writing that, as Secretary of Defense, he is enjoined to defend all uses of GPS. The letter also referenced the laws requiring that defense.

Mr. Miller said NASA is working to move the PNT EXCOM's letter through the chain of command.

> Editorial note: On Dec. 9, 2019, the letter was sent from the National Telecommunications and Information Administration (NTIA) to the FCC[3]

Dr. Parkinson asked if the original Advisory Board's letter to the PNT EXCOM has been made public.

Mr. Martin said it has been posted on www.gps.gov. [4]

ADM Allen said the Advisory Board may wish to develop a position paper on developing better ways to present future issues to the FCC. ADM Allen then asked Dr. Parkinson to present his amended list from the previous day.

Dr. Parkinson suggested the Advisory Board discuss, item by item, whether to add or detract topics. He has already added two new categories: creating enablers and removing barriers.

Mr. Lewis stressed that ensuring service is more important than enhancing service. The assumption has been that the most important measure of effectiveness is availability. Many items in the list assume 100% availability.

Dr. Parkinson said he had not stressed PTA in this list since we're looking at future topics of interest, that is, we assume PTA is already a key requirement for the Advisory Board. However, he is looking for wording that combines current and future topics. He welcomes a modification of the wording to make clearer the position articulated by Mr. Lewis.

Mr. Shields said emphasis needs to be shifted from robustness and security to cybersecurity, which is more likely to resonate with the policy leadership. If the statement is intended for the EXCOM, it should be brief. If its purpose is to outline the Advisory Board work plan for several years, then it should be longer. It is not clear to him which task we are trying to tackle.

ADM Allen said it is not possible to capture everything. What is needed is a work plan for the next few years that distinguished those things that are precious from the rest.

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[3] https://www.ntia.doc.gov/files/ntia/publications/ntia_letter_to_fcc_chairman_re_ligado_mss_atc_applications_dec._6_2019.pdf
[4] https://www.gps.gov/governance/advisory/recommendations/2018-08-letter-to-excom.pdf

Dr. Parkinson said his document intends to spark thinking within the Advisory Board. His intention is for both current and future. A central question is the relative importance. What items are so important that the Advisory Board would wish to make a recommendation?

Dr. James said he believes robustness is a good framework, as it contains both cybersecurity and global monitoring, which are important.

Mr. Stenbit said he does not oppose the list. Much Advisory Board discussion bridges ignorance about the impact on systems. One aspect needs to be the 'red flag' problem. He feels Preserve is not a strong enough term. One can preserve, but others can disrupt. He feels grounding is needed for what people depend on GPS, and, beyond that, the functions and opportunities in which others may wish to invest.

Mr. Shane said the key question is how can the Advisory Board add value? The Advisory Board should not overestimate the value it can add in the best of circumstance, nor should it underestimate what others are adding. Rather than developing a large scheme, the list should be more issue-specific.

Dr. Parkinson said he had cast a wide net with the expectation that the list will be amended. Eventually, it will lead to recommendations. It is important that nothing is left out.

Mr. Stenbit said the 'elephant in the room' is whether GPS will remain the Gold Standard over the next decade.

ADM Allen agreed that Gold Standard issue needs to be addressed. Redirecting the discussion, ADM Allen said that P1 (protecting spectrum) is clearly very important.

Mr. Shane suggested P1 be made generic by dropping the specific reference to a 5G broadband operator in the MSS frequency band.

ADM Allen directed attention to P2 (the need for a national system to monitor, locate, and shut down jammers and spoofers).

Mr. Stenbit said the threat vector and getting information about it effectively into the hands of users was the most important aspect.

Dr. James said this relates to performance evaluation. How does it fit into this priority?

ADM Allen said the issue is really addressing the life cycle of the threat.

Dr. James agreed.

Mr. Lewis said the Advisory Board has never heard directly from the FCC about what it is doing to monitor and mitigate threats.

ADM Allen said that is a good point.

Dr. Axelrad endorsed P2. The recommendation to act at the national level is highly important. It is not enough to simply urge users to employ better receivers.

Mr. Higgins suggested the FCC be urged to improve monitoring activities, rather than to suggest such monitoring is not occurring at all.

Dr. Parkinson said he questions whether the FCC is doing anything in the area of monitoring.

ADM Allen said a briefing from the FCC would be an appropriate way to make the Advisory Board aware of current status.

Dr. Betz said this is a critically important activity. One cannot not afford only to play 'defense' against jamming; one needs to play 'offense' as well.

Mr. Shane asked if existing law is sufficiently robust.

Dr. Parkinson said the most recent individual prosecuted paid a $40,000 fine.

Mr. Shane asked: to whom?

ADM Allen said it was a civil penalty.

Dr. Parkinson noted the FCC lacks police power. The process is complex, and involves the FCC gaining cooperation from a Federal Marshall.

ADM Allen said the matter falls under civil penalty law.

Dr. Parkinson said Mr. Shane raised a significant point. The legal status of jamming and spoofing needs to be addressed.

Mr. Shane said the FCC should not be relied upon to carry out this function. As a national security issue, it should be addressed by federal law.

ADM Allen noted, by analogy, that the National Oceanic and Atmospheric Administration (NOAA) regulates fisheries, but actual enforcement falls under the U.S. Coast Guard (USCG).

Dr. Parkinson said P2 is just a placeholder that needs expansion.

ADM Allen said more information is needed on the status of legislation. This might take the form of a recommendation. He noted that there is STRATCOM response team that works on threats to military communication from civil interference. He could provide an update on its activities as the next session.

Mr. Miller said that while discussion has focused on protection, augmentation is also pertinent. The biggest fault is the failure to optimize use of existing infrastructure.

Dr. Parkinson, turning to T1 (Publicize latest threat model and techniques to counter GNSS spoofing and jamming), said the argument against publicizing the threat model is that it would also inform individuals who would then use it against the system. In any case, manufacturers should be given the best possible basis for design.

Mr. Stenbit suggested substituting the words 'discover and disseminate' with 'publicize.'

ADM Allen said the DHS gets Malware reports and passes them on. That could be a starting point for further efforts.

Mr. Higgins stressed educating the user. Whenever he makes a presentation, he discovers people are simply unaware of the problems of spoofing and jamming. Efforts need not be punitive. He spoke of a workshop for taxi drivers that were unaware that the use of jammers has broader implications.

ADM Allen said many good ideas have been suggested. The task is to decide who is going to be assigned responsibility for what. He also suggested that discussion of T2 (Understanding the Galileo outage) be held over until Dr. Beutler has given his report on that subject. Also, much has been discussed on T3 (Vulnerabilities and solutions for GPS cybersecurity). He noted the existence of .com, .gov, and .mil. The EXCOM focuses on the .gov aspects. Something could be learned from how cybersecurity is being handled within .gov.

Mr. Martin said the Advisory Board can assist the EXCOM on the .com side.

ADM Allen said that by the next Advisory Board meeting actual guidelines should have been issued on how government agencies should approach procurement. That question has not been posed to the Advisory Board, but it should be expected.

Mr. Higgins asked whether it should be PNT cybersecurity, or just GPS? He noted that GPS differential corrections that can also hacked.

ADM Allen said there is a distinction between procurement and how one keeps focus on critical infrastructure when one has oversight responsibilities. This contributes to complicating things.

Dr. James noted that NASA is a .gov agency. It might be useful for NASA to make available to .com what it is doing in this area.

Dr. Betz said T3 should be generalized beyond GPS.

Dr. Rashad said that T3 and P2 are very similar. T3 could replace P2.

Dr. Parkinson said his intent was to identify topics on which the Advisory Board could make a recommendation. He noted that this matter overlapped. His question is whether it merits further effort from the Advisory Board, and whether further modifications are needed.

ADM Allen said he would now welcome comments on A1 (What additional augmentations to GPS are being or should be pursued, including future capabilities).

Dr. Axelrad said fully capable monitoring and detailed analysis of the performance of all GNSS are needed to ensure that GPS remains the (or a) Gold Standard. If this is not part of currently authorized/funded GPS activities, what actions are needed to address the gap.

Dr. Parkinson said Gold Standard is a long-used but never defined term. Gold Standard is not an assumable status in the future. Where does it fit as a system goal? He suggested a new category: Policy.

ADM Allen observed that the U.S. Air Force has responsibilities that Galileo does not share. When this is considered, the question of the Gold Standard becomes a policy issue beyond the scope of the Advisory Board.

ADM Ellis said the overarching question is: what do you want to be when you grow up? The implications of that question crosses into multiple areas and is bigger than any subset that has been created.

Mr. Stenbit noted this is a classic problem of time asynchronism. In the space program, it took five years to get something started and longer to get it done. Meanwhile, Moore's Law operates in 18-month cycles. Galileo will say these same things ten years from now. The Advisory Board should take a broad view and say it is pleased the FCC has approved use of Galileo. An GPS-Galileo integrated solution is best and will evolve over time.

Dr. Parkinson said that if remaining the Gold Standard is a goal, then Gold Standard needs defining. Clearly, GPS will not be the first GNSS system to have L1C on all of its satellites. Whatever policy statement is made, the user retains the prerogative of opting

out of GPS and using Galileo instead. If GPS is on the wrong trajectory, should the Advisory Board not say something about that? He would like to create an overarching statement on the Gold Standard, and then argue out what that means.

Mr. Shane noted that a similar conversation is occurring at the FAA Advisory Management Council. He is perfectly happy with the Gold Standard, so long as GPS realizes it is not the only provider of that standard. The reality is that there is a shared global environment.

Mr. Martin said current national policy is for the U.S. to maintain leadership. The Advisory Council cannot change national policy. The words Gold Standard do not appear in the policy. He believes it would be useful for the EXCOM to hear from the Advisory Council on what Gold Standard means and what would be required to maintain it.

Mr. Lewis noted a 2004 study on what was required to make GPS the world GNSS leader. That statement was less about being the Gold Standard than on GPS being the primary provider, and other countries contributing their own augmentations. That study prompted the Department of State to take various actions. The commercial world votes with its pocketbook. The real issue is what one wishes to do to ensure that among other countries GPS remains as the standard of use.

ADM Allen noted that in areas other than GPS, e.g. ICAO, the U.S. is committed to international global governance to resolve problems. That established a standard and allowed enforcement. This is not the case with GPS, as it cannot allow for enforcement through by the ITU.

Mr. Lewis noted that U.S. leadership had put forth Loran-C, which ended up in 54 countries.

Dr. Betz said he is concerned that the Advisory Board is making the matter too complicated. Until the present, GPS has been preeminent. One could probably list ten or fewer criteria that define the highest standards, and then state how GPS intends to reach them compared to other systems. It would be a simple fact sheet that informs the leadership.

ADM Allen endorsed this approach. He said it could be done soon and transmitted to the EXCOM.

Dr. Powell said he believes the Big Five criteria of the Independent Review Team (IRT) constitute a good starting point.

ADM Allen said the statement should be of no more than ten points listed in a one- or two-page letter for delivery to the EXCOM.

Dr. Parkinson said GPS is doing very well on transparency, but in other areas the trend is less favorable.

Mr. Higgins noted that preeminence is in the eye of the beholder. Is it accuracy? Is it reliability? The current Gold Standard could be giving way to a future Platinum Standard.

Lt Col McDougall noted that, as there is recognition that space is becoming a contested environment and conflicts may occur in space, there is a need to diversify capabilities. Putting all capabilities on a single standard creates a large target. Recognition is needed that from a military outlook, additional augmenting standards to GPS are be needed.

ADM Allen noted the question exists of how to inform the commercial sector without creating risk to the military sector.

Dr. Parkinson said he is adding a Point A3, to cover incorporation of global differential systems. For the moment, he regards it as a bookmark.

Mr. Higgins noted there are many augmentations. Perhaps A2 could simply be broadened to cover them.

Dr. Parkinson said he thinks A3 has a special character and stating it separately would help focus to be directed on the issue.

Mr. Murphy suggested adding a Point A4 to support sensor fusions and other augmentation. He would like to be able to augment his own systems. If Dr. Parkinson thinks this is covered under A1, he has no objection. To him, A1 seems to address the augmentation services the U.S. would put out. His concern is how other people can undertake sensor fusion.

Dr. Parkinson asked if Mr. Murphy is suggesting a division between augmentation created by a government and augmentation created by a private user?

Mr. Murphy said he is concerned with knowing what responsibility the government had in supporting private augmentation.

Dr. Parkinson said he would create an A4 on user augmentations.

Mr. Murphy said what is needed is the specification of performance with enough granularity so users are able to augment and improve further.

Mr. Stenbit said he hears this as there being services and there being service interfaces. He noted the distinction between what exists and what is promised. Once someone starts to rely on something, they need to know it will be reliable. Commercial interests do not want to expend funds on things that may be pulled out from under them.

Mr. Miller noted that at one time it had been planned that OCX would do civil signal monitoring, but due to cybersecurity concerns it became too expensive. He would welcome a look at how GDGPS could be expanded to do this to do jamming and spoofing. He believes that through GDGPS infrastructure already exists for GPS monitoring that is not being worked. This important because DOT is not going to be funded for the civil monitoring OCX initially was supposed to do.

Lt Col McDougall said the military will do limited monitoring of civil signals as they relate to OCX. Dr. Parkinson asked if OCX has civil signal monitoring capability.

Lt Col McDougall said it does to a limited degree.

Dr. Parkinson requested a ten-minute briefing on this at the next Advisory Board meeting.

ADM Allen said, regarding preeminence, no complex problem in the world can be solved by a single entity. What is needed is a better way to work together on an international basis.

Mr. Shane said U.S. leadership has emerged from the enhancing of the ability of everyone.

Mr. Higgins sought clarification on points A3 and A4.

Dr. Parkinson said A3 relates to the formal incorporation of GDGPS into the U.S. formal infrastructure. A4 relates to what user defined augmentations could be specified and certified.

Mr. Murphy said A4 touches more on what is necessary to define the user interfaces and specifications for each user-defined augmentation that could be used for verification.

ADM Allen requested Mr. Murphy to provide a two-three sentence statement on the subject.

The Advisory Board discussion then turned to F1 (Defining power of second [and third] satellite signal lobe for SSV.)

Dr. Parkinson said this is largely an accomplished fact.

Dr. Beutler said that this is not entirely a future concept.

ADM Allen said a presentation on this had been made three years ago.

Dr. Beutler said weather prediction should be included here.

Dr. Betz suggested an F8 could be particularized to science, just as F6 is particularized to the power grid.

Mr. Murphy suggested an F9 might be included that relates to multi-constellation and multi-frequency GNSS. If GPS characteristics are to be noted, then those of other GNSS systems should be included.

Dr. Beutler commented that this, too, is not new, and for several years has been dealt with by the IGS.

Discussion then turned to F2 (Progress and prospects of intelligent highway systems).

Mr. Shields said he believes referring to transportation is generally preferable to referring specifically to highways. (Dr. Parkinson amended F2, accordingly.) DOT has a responsibility in next generation 911. Indoor positioning is a significant issue in this area. Technically it is not in the area of transportation, but it is still a DOT responsibility as it pertains to indoor emergency calls. For example, would a fire truck get an automatic green light? Is this a FirstNet responsibility or does it fit into the DOT? In his view FirstNet is not looking at indoor locations, as it focuses more on locations for emergency services for functions and people.

ADM Allen said the Advisory Board has not received a briefing from FirstNet.

Mr. Higgins thought F1 and F5 are definitively needed. The remainder seem more of a shopping list. Should there be a more explicit statement as to the role of the Advisory Board?

Dr. Parkinson said he is simply trying to create a list that will enable future applications or remove barriers and perhaps lead to a recommendation. He never intended that this list would go to the EXCOM.

ADM Allen said that perhaps they could be separate as a policy role, with the caveat that three or four be identified as a priority for the Advisory Board.

Mr. Shane said the central question is how the Advisory Board can add value. A tremendous amount of time could be invested in learning about new things, but to what end would that be done?

Mr. Higgins said he has given a conference presentation at which those present, when informed of 5G broadband transmissions in the MSS frequency band, were virtually in shock. They simply assumed that GPS would always be there. The role of the Advisory Board is to cover the backs of users.

Dr. Parkinson said he believes the subject is being overthought. The list itself is not going to lead to a recommendation to the EXCOM. The sole purpose of the list is to trigger thinking to see what matters and what the Advisory Board needs to do something about.

ADM Allen said F1 is a mixture of advice and issue-related policy. These are different roles. One was: How does the Advisory Board give advice to the EXCOM? The other is: What does the Advisory Board think about water vapor, power grid, etc. He is interested in focusing on the higher-level policy role.

Dr. Parkinson said a screen is applied before anything goes to the EXCOM. First, is it important? Second, is there anything the EXCOM can do about it?

ADM Allen moved discussion to the policy side, noting that a P4 will be added for applications.

Mr. Shane said P1 (Process of frequency allocation without additional review) could be stated with more precision. He accepted the task of providing a new phrasing.

Dr. Parkinson said perhaps a P0 is needed: Should the U.S. continue to claim to be the Gold Standard? If so, is the government willing to spend the money to make keep this status?

Mr. Stenbit said the Advisory Board should acknowledge that a gap is opening, but how long that gap lasts depends on decisions not yet made.

Mr. Shields said that in discussing gaps it is useful to separate the military and civilian users. Policy decisions on civilian users will be different from the decisions on military users.

ADM Allen said this is a difficult discussion to have in the public session.

Mr. Stenbit noted that GPS III offers different capabilities to the military and civilian sides.

Lt Col McDougall confirmed this is the case.

ADM. Allen moved the discussion to recommendations the Advisory Board can make to the EXCOM on removing trade barriers and creating enablers. All comments will be considered, revised, and distributed to the Advisory Board within seven to ten days. His goal is for the Advisory Board work plan be completed by the end of 2019. He welcomed suggestions for improvements.

Dr. Parkinson asked when the next EXCOM session will be held. Is there anything that needs to be made ready in the near term?

ADM Allen said he believes the statement on the Gold Standard is the first priority. He believes this could be presented as a one-two page statement.

Mr. Stenbit said the issue of UWB allocation should also be included.

Mr. Shane said that, regarding the topic of appropriate legislation, he will provide a more streamlined statement.

ADM Allen said the focus, then, is Gold Standard, UWB, and legislation. These will be presented in the form of three brief papers. Meanwhile, by the end of the year at least a straw paper should be completed on the work plan for the Advisory Board.

Mr. Stenbit said the EXCOM should at least be informed that the Advisory Board will be focusing on removing barriers and creating enablers and identify several.

ADM. Allen said this point could also be included in a letter to the EXCOM. Enablers and barriers will be the next topic for discussion, including: Removing Barriers #1: ITAR prevent commercial development of known, highly effective Anti-Jamming Anti-Spoofing (AJ/AS) receivers; Removing Barriers #2: Foreign GNSS do not have the integrity assurance that WAAS gives to GPS; and Removing Barriers #3: National Research Council (NRC) study to study issues and solution to burgeoning UAS population.

Dr. Parkinson said these three matters have been raised, but not framed as a recommendation.

Mr. Stenbit said the second statement is problematic as Galileo has much more integrated capabilities.

Dr. Parkinson noted the reason for bringing up the issue of barriers is because U.S. carriers lack permission to use other GNSS signals within the U.S. (even with the FCC approval of Galileo E1 and E5, the restriction remains on E6 where Galileo offers key advantages)

Dr. Hansen (presenter for DOT) said work is underway on including GNSS signals.

Dr. Parkinson asked if the FAA will be able to monitor Galileo as does GPS through WAAS?

Dr. Hansen said it is not just a monitoring question, as it will some time before we know what we need from other GNSS. Current primary service objectives can be met without use of Galileo, but may be future issue with robustness. Work is proceeding with Galileo on WAAS.

Dr. Parkinson asked if work is being done to monitor the Galileo E1 and E5 signals.

Dr. Hansen said that current receivers are only able to track GPS signals, but they were designed in such way that we can add cards to they can track other signals. Upgrades will be necessary. At the same time, it is important to know what could go wrong so that any untoward event can be addressed.

Dr. Parkinson asked if the actual commercial use of Galileo is allowed inside U.S. airspace?

Dr. Hansen said it will not be allowed with WAAS, but instead with ARAIM.

Dr. Parkinson asked if ARAIM is certified.

Dr. Hansen said it is not.

Dr. Parkinson observed that Galileo is transmitting signals that U.S. aircraft are not allowed to use.

Dr. Hansen said Galileo is pushing to have a standard by 2022 and to have operation by 2024. They will declare FOC for E1 and E5 in 2024.

ADM Allen asked if this would be more appropriately viewed as an enabler.

Dr. Hansen said it would, if one wishes to make better use of Galileo.

Dr. Parkinson said that if it is important that a U.S. airline be able to use Galileo, would that in terms of urgency be a suitable topic for a recommendation?

Dr. Hansen said the International Civil Aviation Organization (ICAO) has been asking all providers to give commitments as to what level of service they will provide. ICAO is not empowered to alter these commitments. There is not, for example, a shared definition of how much time a system has before reporting a fault; the GPS commitment to fault announcement is quick compared to, for example, BeiDou.

ADM Allen asked Dr. Hansen to suggest what could be the interest of the Advisory Board in the matter.

Dr. Hansen suggested that the case to be made is one for greater robustness.

Dr. Parkinson asked Dr. Hansen to submit a brief summation of the circumstance, a task Dr. Hansen accepted.

Mr. Stenbit called attention to the need for worldwide standards. The Advisory Board should broaden its view of what is going so it can then bring the best result.

Dr. Betz said he does not view B2 and B3 as areas where the Advisory Board could make a recommendation.

Dr. Parkinson noted the proliferation of UAS. Is there anything useful to be said on the subject?

Mr. Lewis said that may be outside the scope of the Advisory Board.

Mr. Murphy said he is uncertain the service accuracy exists to support UAS operation. That was why he wishes to know more about what augmentation may be required. Is there a need for a high integrity system that follows UAS all the way to the ground?

ADM Allen said this is a double-edged sword: both a threat and a capability, as the government is on both sides of the issue. He suggested it is a topic for continued attention.

ADM Allen restated the three priority issues to go to EXCOM: Gold Standard, UWB, and legislation.

Discussion then turned to the topic of Creating Enablers, including: (1) Assuming department responsibility and funding to field a system that will identify, locate, and shut down AJ & AS sources; (2) Publicize a threat/risk assessment for PNT; and (3) Oppose any expansion of wideband frequency allocations.

Dr. Powell said the Advisory Board may wish to discuss standards.

Dr. Parkinson noted three areas in where the Advisory Board is considering a recommendation: first, unvetted frequencies that are not in the national interest; second, what is meant by the Gold Standard; and, third, calling attention to threat of UWB to GPS.

ADM Allen said these three need to be looked into in the event the EXCOM meets early next year. The other issues will continue to be worked with a view to create an Advisory Board work plan for next several years. He added that White Papers may be reviewed to identify those the Advisory Board needs to update.

Mr. Stenbit urged that the UWB example be used in the discussions on having a better regulatory regime.

ADM Allen noted that Mr. Shane has raised the issue of potential legislative changes.

Dr. Parkinson noted that #1 (above) is a process statement and #2 is an example of how one would do it. He noted what Mr. Shane had drafted, which he regards as simple and direct: review FCC review of potential spectrum allocations that prospectively have impact on national defense, foreign relations, or safety-of-life.

Mr. Stenbit commented that this issue is topical and needs to be addressed forthwith.

Dr. Powell noted the UAG is assembling a study involving the National Academy of Public Administration. Should the Advisory Board give that study a formal endorsement?

Mr. Higgins asked whether it is worth having a general statement about enabling GNSS? He thought ‘better enabling’ might be a preferable phrase to use when approaching the FCC.

ADM Allen restated the three priority issues to go to EXCOM: Gold Standard, UWB, and legislation.

* * *

Way Forward

ADM Allen called for final remarks, as some Advisory Board members need to leave early.

Mr. Miller stated that contact by email will follow. He proposed the next Advisory Board meeting be held in the Washington DC-area in the first two weeks of May. Discussion of member availability followed. The meeting was tentatively set for the final week of April 27. Members will be contacted on their availability to attend.

ADM Allen said the structuring of presentations will also reviewed.

* * *

Representative & International Updates & Perspectives:

1) Dr. Gerhard Beutler, *Switzerland*

Dr. Gerhard Beutler said his presentation is a continuation of one he gave in 2014 regarding a GLONASS outage. He will address the July 2019 Galileo outage. The Multi-GNSS Experiment (MGEX) of the IGS monitors all GNSS performance, by individual system. It is important to note that no data gaps were shown during the Galileo outage. The maximum broadcast rate is one every ten minutes, or 144 per day. During the Galileo outage between July 11 and 18, the Galileo system was essentially dead to users relying on broadcast images. For science users, GNSS messages were replaced by the MGEX satellite and clock information. Dr. Beutler presented information on Orbit Quality, Galileo Orbit Misclosures, and Galileo Clock Performance, 2019. On orbit quality, there was no performance difference during those dates. The same is true of clocks, which provided a performance level of 0.1 nanoseconds, which underscores the quality of the Galileo clocks.

The Galileo outage was not visible to high-accuracy, post-processing users of Galileo, which implies that the Galileo Space Segment was not affected. Second, the IGS-MGEX products available through the IGS showed a continuation of high accuracy Galileo clock quality. Third, differing from the 2014 GLONASS incident, the 2019 Galileo broadcast ephemerides problem had no impact on receiver tracking. Fourth, he would not speculate as to the cause of the Galileo problem. Galileo was included in CODE's Ultra-and Rapid-Product series as of September 2019, which means that real-time information was available. Galileo will soon be leaving the IGS-MGEX environment to, along with GPS and GLONASS, become part of the IGS legacy/traditional solutions.

2) Dr. Kurt Zimmerman, *GPS Industry Alliance*

Substituting for Ms. Ann Ciganer, Dr. Zimmerman said the basic problem faced in Europe is that RED implementation could be read as imposing a regulatory framework for terrestrial broadband (that potentially overrides international spectrum allocations) in RED equipment standards where European regulators decide receiver performance possibly worldwide. This could cause harmful interference, if interference levels are imposed in commercial receiver design that allow the noise floor to rise for all GNSS Stakeholders. He recommended that U.S. stakeholders become engaged with the issue. He detailed the problem at considerable length.

Dr. Parkinson said it appears RED is attempting to promote a design environment that is more favorable to communications than navigation.

Dr. Zimmerman said the proposal will require GNSS receivers to accept a higher level of interference.

Mr. Shane asked to whom the Advisory Board might make a recommendation. He believes it might be the task of the USG to raise the matter with the European Commission (EC).

Mr. Higgins asked if the ICG has been approached on this issue.

Dr. Zimmerman said to our knowledge, the ICG has not been approached. That question might be best asked to the USG organizers.

Mr. Higgins added that he would have expected some action to be forthcoming from European interests.

Dr. Parkinson said it is unclear that the Advisory Board, which is a U.S. body, would have any influence in Europe when Europeans are not taking the lead on the issue.

Mr. Higgins said that Mr. Dominic Hayes would be a good source for learning what discussion, if any, has occurred with the ICG.

ADM Allen said it is a complicated issue and it is not clear to him that the Advisory Board has ‘a dog in the fight.’

Dr. Zimmerman said that if these standards are adopted, it will raise the prospect of a much higher noise floor for GNSS receivers.

Dr. Parkinson said he feels GPSIA needs to present a much briefer, more coherent explanation of what it sees as the problem.

Mr. Stenbit said it is not clear what the Advisory Board can do in a circumstance where it has no official standing.

ADM Allen said he finds it hard to believe that no major European entity has expressed great concern about this.

Mr. Miller said that Mr. David Turner, Department of State, is aware of the issue. The Department of Commerce might have an issue. He suggested that he and Dr. Zimmerman work off-line on what could be done.

3) Mr. Matt Higgins, *Australia*

Mr. Higgins said he would focus on the Positioning Australia Program. The SBAS part of that program has three parts: current L1 SBAS; a dual-frequency multi-GNSS SBAS that is next generation, and PPP. The request for proposals on SBAS will go out in January 2020, and the selection to be made later that year. The intent is that safety-of-life certification be reached by November 2023. The anticipated economic benefits to Australia and New Zealand include: an annual savings of A$100 per dairy cow due to virtual fencing; a 1 to 7% improvement in the efficient spraying of nutrients; avoidance of 2,700 health and safety issues in forestry; A$205 million savings due to increased efficiency in electrical blackouts; reduction of 16,000 misplaced freight containers; 1,375-day increase in vessel capacity; avoidance of 1,700 falls from heights due to virtual fencing, and an increase of 1,866 successful helicopter rescue missions in isolated locations. For example, virtual fencing is an application that encourages cows to move to better areas for grazing once a given area is depleted, which is an application with great potential.

Mr. Shane said he is very impressed with the business case that has been presented, which was both granular and amazing. He has not seen a similar one on GPS.

Mr. Higgins said it had been difficult to gain support for SBAS is Australia based on aviation needs alone. That is why the variety of benefits had been identified, since 20 different departments had to be consulted.

4) Dr. Refaat M. Rashad, *Egypt*

Dr. Refaat Rashad said he would focus on ground transportation. It is very important to keep the ground spectrum used by surface transportation separate from the spectrum used by GNSS. On maritime transportation, he noted the remarkable presentation on the previous day's which underscored the costs of a GPS outage. Much of the loss in maritime is in the movement of cargo, or cranes, and efficient utilization of port facilities generally. A 5G transmitter in the MSS frequency band placed near a port will have very negative effects. Ships away from shore would lose use of the safety systems mandated by the International Maritime Organization (IMO). With shipping, location is not as critical as timing. In his view Enhanced Loran (eLoran) remains the best option of maritime applications, and urged that it be once again supported by the Advisory Board. Many entities are tied to GPS. The Advisory Board is well-positioned to act as a bridge between government and users. He recommends that Advisory Board chairs attend other committee meetings -- such as UAG, RPNT, CGSIC, and others -- to strengthen PNT assurance. Dr. Rashad then spoke to future activities in the areas of cybersecurity, GPS adjacent band, and domains – including agriculture, aviation, critical infrastructure, and others. Those working in cybersecurity and adjacent band should never grow tired of the work, because it is essential. The past few years have seen a major increase around the world of interest in PTA. A Gold Standard set today would be much more demanding than twenty years ago.

ADM Allen noted that no one in Europe is investing in eLoran.

Mr. Shane said he believes that eLoran is a ship that has already sailed.

* * *

Final Comments

ADM Allen said he feels clarity has been achieved on the next steps for the Advisory Board. He asked if anyone has anything they wish to add.

Mr. Shane referred to a fourth possible point to be made to the EXCOM, relating to intentional interference that follows from testing activities.

ADM Allen said while such tests are announced, it is not clear that a robust system is in place to inform users directly.

Dr. Parkinson said there is a placeholder for this under P2, but it needs further elaboration.

ADM Ellis said a more active approach is needed. One cannot not rely on everyone reading everything that is put out.

Mr. Stenbit agreed that better notification is needed.

Dr. Parkinson said it should be possible to drop into a GPS map information on where interference could exist.

Mr. Shane said it is not only pilots who need to know this; navigators need to be informed as well.

ADM Ellis said that test sites generally do not move around, it may be simply a matter of noting the times they are being used.

Mr. Higgins noted that the possibility of a telecon has been raised.

ADM Allen said that the Advisory Board always has that option. However, his preference is to follow up by e-mail.

Mr. Shane thanked the support group headed by Ms. Lesha Zvosec and Mr. J.J. Miller's staff for its efforts.

* * *

ADM Allen adjourned the 24th session of the PNT Advisory Board at 12:08 p.m.

Appendix A: National Space-Based PNT Advisory Board Membership

Special Government Employees

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

- **Thad Allen** (Chairman), Booz Allen Hamilton
- **John Stenbit** (Deputy Chairman), former Assistant Secretary of Defense
- **Bradford Parkinson** (1st Vice Chair), Stanford University
- **James E. Geringer** (2nd Vice Chair), Environmental Systems Research Institute (ESRI)
- **Penina Axelrad**, University of Colorado Boulder
- **John Betz**, MITRE
- **Scott Burgett**, Garmin International
- **Joseph D. Burns**, Airo Drone
- **Patrick Diamond**, Diamond Consulting
- **Dorota A. Grejner-Brzezinska**, The Ohio State University
- **Ronald R. Hatch** (until 2019), private consultant (retired John Deere)
- **Larry James**, Jet Propulsion Laboratory
- **Timothy A. Murphy**, The Boeing Company
- **T. Russell Shields**, RoadDB
- **Gary Thompson**, North Carolina Emergency Management/Geodetic Survey
- **Frank van Diggelen**, Google
- **Todd Walter**, Stanford University

Representatives:

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

- **Gerhard Beutler**, International Association of Geodesy (Switzerland)
- **Sergio Camacho-Lara**, United Nations Regional Education Center of Science and Space Technology - Latin America and Caribbean (Mexico)
- **Ann Ciganer**, GPS Innovation Alliance
- **Dana Goward**, Resilient Navigation and Timing Foundation
- **Matt Higgins**, International GNSS Society (Australia)
- **Terry Moore**, University of Nottingham (UK)
- **Refaat M. Rashad**, Arab Institute of Navigation (Egypt)
- **Jeffrey N. Shane**, International Air Transportation Association

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

Subject Matter Experts

- **Martin Faga**, former CEO, The MITRE Corporation
- **Kirk Lewis**, Institute for Defense Analyses (IDA)
- **Tom Powell**, Aerospace
- **Brian Ramsay**, The MITRE Corporation

Appendix B: List of Presentations

1. Purpose of U.S. PNTAB: Assuring PNT for All and Exploiting GNSS for Future Applications /Dr. Bradford Parkinson
2. What are Possible Criteria for "Important"? /Dr. Bradford Parkinson
3. Policy Update: National Coordination Office /Harold W. Martin III
4. Space Force Planning Task Force /Lt Gen David Thompson
5. Global Positioning System Program Status /Lt Col Ken McDougall
6. U.S. DOT Developments on PNT Resiliency /Dr. Andrew Hansen
7. PNT Program & Conformance Framework /Ms. Brannan Villee; Mr. Ernest Wong
8. The Flip: Most Robust Timing Applications Using GPS /Dr. Arthur J. Scholz
9. National Space Council Users' Advisory Group – An Introduction /ADM Jim Ellis
10. Socio-Economic Studies of GPS: Past, Present and Future /Dr. Irving Leveson
11. Economic Benefits of the Global Positioning System /Dr. Michael P. Gallaher
12. Why Wait? Real-Time GNSS Monitoring for Infrastructure Protection and a Perspective on Galileo vs GPS /Dr. Yoaz Bar-Sever
13. Compatibility of Terrestrial Reference Frames used in GNSS Broadcast messages /Mr. Stephen Malys
14. Recent developments within the International Committee on GNSS on the use and applications for PNT /Ms. Sharafat Gadimova.
15. GNSS for the Developing World: Collaborations for Scientific Exploration and Applications for Societal Benefits /Dr. Patricia H. Doherty
16. Augmenting GPS with PNT from Low Earth Orbit (LEO) /Dr. Peter Iannucci
17. Ensuring PNT Robustness, Resiliency, & Interoperability: The Upcoming E Galileo Signal Authentication Services & Anti-Spoof Techniques /Dr. Oscar Pozzobon
18. Interoperable GNSS Space Service Volume – Update on ESA Activities /Dr. Werner Enderle
19. Advancing Space Use of GNSS /Dr. Ben Ashman
20. Galileo and its Outage in July 2019 from the IGS-MGEX Perspective /Dr. Gerhard Beutler
21. GPS Innovation Alliance /Dr. Kurt Zimmerman
22. Australian Update /Mr. Matt Higgins
23. Surface Transportation Report /Dr. Refaat Rashad

Appendix C: Sign-In Sheets

Attendees: Wednesday, November 20

Advisory Board Members

- Penina Axelrad, Colorado University/Boulder
- Gerhard Beutler, AIUB
- Sergio Camacho, CRECTEALC
- Refaat Rashad, AIN
- Jeff Shane, IATA
- Russ Shields, RoadDB

NASA Personnel

- Ben Ashman, NASA
- Yoaz Bar-Sever, NASA JPL
- Frank Bayer, NASA
- DeeAnn Davis, Inside GNSS
- Jennifer Donaldson, NASA/GSFC
- Alexandra Doten, NASA
- Clifford Bruce Ledford, NASA KSC
- A.J. Oria, NASA
- Nick Pack, NASA
- Cindy Tran, NASA
- Rachel Vasquez-Owens, NASA/Next
- Lisa Valencia, NASA

Other Attendees

- Jeffrey Auerbach, Department of State
- Dewayne Barrington, L3Harris
- Randy Brudzinski, Microchip
- Gerhard Buchle, AIUB
- David Buckner, Microchip
- Jim Burton, National Coordination Office
- Paul Crampton, Spirent
- Robert Crane, Department of Homeland Security
- Patricia Doherty, Boston College
- Werner Enderle, ESA
- Rich Foster, Microchip
- Sharafat Gadimova, United Nations
- Mike Gallaher, RTI
- David Grossman, GPSIA
- Scott Hammond, Viziv Technologies
- Jeff Hathaway, RNTF
- Steve Hickling, Spirent
- Stephen Hirst, Boeing
- Peter Iannucci, University of Texas/Austin
- Charlene King, Satelles
- Avid Kunkee, Aerospace
- Deborah Lawrence, FAA
- Irv Leveson, Leveson Consulting

David Lubar, Aerospace
Steve Malys, NGA
Ken McDougall, SMC
Marcianna Pease, AFSPC
Mauricio Pedemonte, Microchip
James Platt, Department of Homeland Security
Oscar Pozzobon, QASCOM check
Brian Ramsey, MITRE
Joe Rolli, L3Harris
Mike Rosso, Continental
David Sambrano, United Airlines
Arthur Scholz, GET
David Thompson, AFSPC
Brannan Villee, Department of Homeland Security
Todd Walter, Stanford University
Ernest Wong, Department of Homeland Security
Kurt Zimmerman, Trimble
Two illegible

Attendees – Thursday, November 21

Advisory Board Members

John Betz
Gerhard Beutler, AIUB
Sergio Camacho, CRECTEALC
Michael Higgins, GET

NASA Personnel

Frank Bauer, NASA
Alexandra Doten, NASA
A. J. Oria, NASA
Victor Sparrow, NASA
Weiping Yu, NASA

Other Attendees

Jeffrey Auerbach, Department of State
Jim Burton, National Coordination Office
Paul Crampton, Spirent
Robert Crane, Department of Homeland Security
DeeAnn Divis, Inside GNSS
David Grossman, GPSIA
Steve Hickling, Spirent
Charlene King, Satelles
David Kunkee, Aerospace
Irving Leveson, Leveson Consulting
David Lubar, Aerospace
Steve Malys, NGA
Joe Rolli, L3Harris
Mike Rosso, Continental
David Sambrano, United Airlines
Ernest Wong, Department of Homeland Security

Appendix D: Acronyms & Definitions

$	U.S. Dollar Currency
4G	4th Generation Mobile Communications Standard
5G	5th Generation Mobile Communications Standard
911	Emergency telephone number in the U.S.
A$	Australian Dollar Currency
ADM	Admiral
AFSPC	Air Force Space Command
AFTS	(NASA) Autonomous Flight Termination System
AJ	Anti Jamming
AOD	Age of Data
ARAIM	Advanced Receiver Autonomous Integrity Monitoring
AS	Anti Spoofing
BeiDou	China's GNSS
C/A	GPS Coarse Acquisition
CGSIC	Civil GPS Service Interface Committee
cm	centimeter
CNSA	China National Space Administration
CODE	Center for Orbit Determination in Europe (Switzerland)
COps	GPS Contingency Operations
dB	decibel
DHS	Department of Homeland Security
DME	Distance Measuring Equipment
DoD	Department of Defense
DOP	Dilution of Precision
DOT	Department of Transportation
EC	European Commission
eLoran	Enhanced Loran
E1	Galileo Open Service
E5	Galileo Safety-of-Life Service
E6	Galileo High Accuracy Service (formerly Commercial Service)
EU	European Union
ESA	European Space Agency
EXCOM	National Space-Based Executive Committee
FAA	Federal Aviation Administration
FACA	Federal Advisory Committee Act
FCC	Federal Communications Commission
FOC	Full Operational Capability
Galileo	European GNSS
GDGPS	Global Differential GPS System
GEO	Geosynchronous Equatorial Orbit
GHz	Gigahertz
GLONASS	Russian GNSS
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPS-D	GPS Directorate (now GPS Integration Office)

GPS III	Typically refers to GPS Block III SVs 1-10
GPS IIIF	GPS III Follow-On, which refers to GPS Block III SVs 11-32
GPSIA	U.S. GPS Innovation Alliance
HAS	(Galileo) High Accuracy Service
HEO	Highly Elliptical Orbit
Hz	Hertz
ICAO	International Civil Aviation Organization
ICG	International Committee on GNSS
IGS	International GNSS Service
IMO	International Maritime Organization
IOC	Initial Operating Capability
ITAR	U.S. International Traffic in Arms Regulations
ITRF	International Terrestrial Reference Frame
ITU	International Telecommunication Union
JPL:	Jet Propulsion Laboratory
km	kilometer
L1 C/A	1st GPS Civil Signal
L1C	4th GPS Civil Signal (interoperable with Galileo)
L2C	2nd GPS Civil Signal (commercial)
L5	3rd GPS Civil Signal (safety-of-life / aviation)
L-Band	Operating frequency range of 1–2 GHz in the radio spectrum.
LEO	Low Earth Orbit
LORAN	Long-Range Aid to Navigation
m	meter
M-Code	GPS encrypted signal
MAPS	Mounted Assured PNT Systems
MCEU	(GPS) Military Code Early Use
MGEX	Multi-GNSS Experiment
MHz	Megahertz
MMS	NASA's Magnetospheric Multi-Scale mission
MSS	Mobile Satellite Services
NASA	National Aeronautics and Space Administration
NCO	National Coordination Office (located at the Department of Commerce in Washington, D.C.)
NDAA	National Defense Authorization Act
NEO	Near-Earth Object
NGA	National Geospatial-Intelligence Agency
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NSpC	National Space Council
NSPD-39	National Security Presidential Directive 39 (U.S. Space-Based Position, Navigation, and Timing Policy)
NTIA	National Telecommunications and Information Administration
OCXO	Oven-Controlled Crystal Oscillator
OCX	Modernized GPS Operational Control System
PNT	Positioning, Navigation, and Timing
PPP	Precise Point Positioning
PROBA-3	Third satellite mission in ESA's series of Project for On-Board Autonomy (PROBA) low-cost satellites that are being used to validate new spacecraft technologies while also carrying scientific instruments.
PTA	Protect, Toughen, and Augment

RED	Radio Equipment Directive
RF	Radio Frequency
RSS	Residual Sum of Squares
RTI	RTI International (formerly Research Triangle Institute) is a nonprofit organization headquartered in North Carolina.
S&T	Science and Technology
SBAS	Satellite-Based Augmentation System
SCaN	Space Communications and Navigation
SGE	Special Government Employee
SMC	Space & Missile Systems Center
SPR	Strategic Petroleum Reserve
SSV	Space Service Volume (region of space between 3000km and GEO altitudes)
STRATCOM	U.S. Strategic Command
TGD	Time Group Delay
UAG	Users' Advisory Group (National Space Council)
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UN	United Nations
U.S.	United States of America
URE	User Range Error
USAF	U.S. Air Force
USCG	U.S. Coast Guard
UWB	Ultra-Wide Band, a technology for the transmission of data using techniques which cause a spreading of the radio energy over a very wide frequency band, with a very low power spectral density.
W	Watt
WAAS	FAA Wide Area Augmentation System