SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

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

Twenty-First Meeting

May 16-17, 2018

Sheraton Inner Harbor in Baltimore
300 South Charles Street, Baltimore, MD 21201

Bradford W. Parkinson

Bradford Parkinson
1st Vice Chair

James J. Miller
Executive Director

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

Sheraton Inner Harbor in Baltimore / Chesapeake Ballroom
300 South Charles Street, Baltimore, MD 21201
http://www.sheratoninnerharbor.com

Agenda

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WEDNESDAY, MAY 16, 2018
9:30 - 9:35 **BOARD CONVENES** *Call to Order & Announcements* Mr. James J. Miller, *Executive Director, PNT Advisory Board, NASA Headquarters*
9:35 - 10:00 Opening Comments: 21st PNTAB Focus & Priorities *Sustaining GPS as a Utility — Protect, Toughen, & Augment* ***VIEW PDF (3 MB)*** Dr. Bradford Parkinson, *1st Vice-Chair;* Gov Jim Geringer, *2nd Vice*
10:00 – 10:15 National Coordination Office (NCO) Perspective *Policy Update* ***VIEW PDF (656 KB)*** Mr. Harold "Stormy" Martin, *Director, National Coordination Office for Space-Based PNT*

10:15 - 10:45
GPS Program Status & Modernization Milestones
GPS Directorate (GPS-D) Update
VIEW PDF (3 MB)
Lt Col Andy Menschner, *Material Leader, GPS-D, Space & Missile Systems Center (SMC)*

10:45 - 11:15
U.S. Department of Transportation (DOT) Update
Civil Agency Lead & Extended PosNav Perspective
VIEW PDF (1 MB)
Ms. Karen Van Dyke, *Director, PNT Program, Office of the Secretary, DOT*

11:15 - 11:30
BREAK

11:30 - 12:00
Federal Aviation Administration (FAA) Update
FAA Navigation Strategy
VIEW PDF (2 MB)
Ms. Deborah Lawrence, *Manager, Navigation Programs, FAA*

12:00 - 12:30
Connectivity Connected Aviation - Enabling Innovations in the Internet of Things - That Fly
VIEW PDF (2 MB)
Dr. Bruce Holmes, *Vice President, Digital Aviation, SmartSky Networks, LLC*

12:30 - 1:45
LUNCH — *Working — Annual Ethics Training for Special Government Employees (SGEs)*
VIEW PDF (873 KB)
Mr. Adam F. Greenstone, *NASA Office of General Counsel*

1:45 - 2:10
U.S. Department of State (DOS) Update
Bilateral Partnerships & International Committee on GNSS (ICG)
VIEW PDF (1 MB)
Mr. Jeff Auerbach, *Foreign Affairs Officer, Office of Space & Advanced Technology, DOS*

2:10 - 2:35
United Kingdom (UK) Progress on Resilient PNT
VIEW PDF (1 MB)
Prof. David Last, *Strategic Advisor, General Lighthouse Authorities of the UK & Ireland*

2:35 - 3:00
Initial Findings from the STRIKE3 GNSS Interference Monitoring Network
VIEW PDF (2 MB)
Dr. Mark Dumville, *General Manager, Nottingham Scientific Limited (NSL), UK*

3:00 - 3:25
Report from the Workshop on Time Receiver Resilience
VIEW PDF (392 KB)
Dr. Marc Weiss, *Spirent*

3:25 - 3:50
Superior Beamforming GPS Anti-Jamming for Airborne Platforms
VIEW PDF (759 KB)
Dr. Alex Stratton, *Principal Systems Engineer, Advanced Technology Center, Rockwell Collins*

3:50 - 4:05
BREAK

4:05 - 4:30
Current Operational Status of Low Earth Orbit (LEO) satellite-based Time and Location
VIEW PDF (1 MB)
Dr. Gregory Gutt, *Chief Technical Officer & President, Satelles Inc.*

4:30 - 4:55
Feasibility of a Nationwide Fiber-Optic Sub-nanosecond Timing Infrastructure for Terrestrial PNT & GPS Back-up
VIEW PDF (2 MB)
Dr. Jeroen Koelemeij, *Chief Technology Officer & Co-Founder, OPNT B.V., The Netherlands*

4:55 - 5:20
GPS Radio Occultation: The Real Forecast
VIEW PDF (937 KB)
Mr. Keith E. Johnson, *VP and General Manager - Government Solutions, Spire Global, Inc.*

5:20 - 5:45
National Space Council Perspective
Dr. Scott Pace, *Executive Secretary, National Space Council (NSpC)*

5:45 - 6:00
Afternoon Wrap-Up
All members

6:00
ADJOURNMENT

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THURSDAY, MAY 17, 2018

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

9:05 - 9:30
Member Concise Observations from Wednesday, May 16
All members, led by Dr. Bradford Parkinson, *1st Vice-Chair;* Gov Jim Geringer, *2nd Vice-Chair*

9:30 - 10:00
Dept. of Homeland Security (DHS) Update
Findings from JAMX17 Exercise
VIEW PDF (1 MB)
Mr. John Merrill, *Director for the Office of Interoperability and Compatibility, DHS*

10:00 - 11:00
Representative/International Reports & Perspectives:

Interface Requirements for SAE-Compliant GPS Receivers
VIEW PDF (221 KB)
Dr. James L. Farrell, *VIGIL, Inc. (U.S.)*
(Special Topic Speaker)

Sustaining Open GNSS Markets
VIEW PDF (156 KB)
Ms. Ann Ciganer, *GPS Innovation Alliance (U.S.)*

Protect, Toughen, Augment Initiatives
VIEW PDF (1 MB)
Mr. Dana Goward, *Resilient Navigation & Timing Foundation (U.S.)*

Signal-in-Space Error Assessment based on the International GNSS Service (IGS) Multi-GNSS Experiment (MGEX)
VIEW PDF (893 KB)
Dr. Gerhard Beutler, *International Association of Geodesy (Switzerland)*

Possible Arctic Space-based Augmentation System (SBAS) Coverage by Using High Elliptic Orbit Satellites
VIEW PDF (1 MB)
Mr. Arve Dimmen, *Norwegian Coastal Administration (Norway)*

Update on GNSS Activities in Australia
VIEW PDF (627 KB)
Mr. Matt Higgins, *Manager, Dept. of Natural Resources, Mines and Energy (Australia*)

Update on GNSS Issues at the United Nations (UN)
VIEW PDF (269 KB)
Dr. Sergio Camacho-Lara, *U.N. Center of Science and Space Technology (Mexico)*

Middle East Regional GNSS Cooperation Updates
VIEW PDF (653 KB)
Dr. Refaat Rashad, *Arab Institute of Navigation (Egypt)*

11:00 - 11:15
BREAK — *Time permitting*

11:15 - 12:00
Final Roundtable Review of PNT Board Topic Papers (Administration Transition / Information Package)
2018 Work Plan Schedule
22nd Mtg December 5-6, 2018 in Redondo Beach, CA
All members

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

1:00
ADJOURNMENT

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PNT Advisory Board 21st Session

Executive Summary

The 21st session of the National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board met on May 16-17, 2018, in Baltimore, Maryland. The main objectives of this session were to hear and discuss expert reports and to plan the Advisory Board's future actions.

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

High-Level Action Items:

- Dr. Parkinson called for an Advisory Board interim half-day public meeting as soon as possible, to be conducted by WebEx, to: (1) discuss the recommendations of the Advisory Board to the PNT Executive Committee; and (2) finalize the Topics Paper.
- Mr. Miller will put out a Federal Register Notice that includes the primary topics for discussion at the interim meeting.
- Dr. Parkinson requested volunteers for a new Cybersecurity Subcommittee. The following board members expressed interest: Mr. Goward, Mr. Shields, Capt Murphy, Mr. Marquez, Mr. Higgins, and Mr. Burns. Will follow-up by e-mail.
- Dr. Parkinson asked Mr. Miller to review previous meeting minutes and create a table for the Board to track past recommendations and the resulting government-level action.
- Dr. Parkinson said appropriate steps would be taken to honor Ms. Ruth Neilan, recently retired from the ICG and the Advisory Board, at the December 2018 Advisory Board meeting.
- Dr. Parkinson noted it should be possible to encourage cellphone makers to write a Smartphone application that notes if one is being jammed or spoofed, with that information going to a database at some central location. Time could be allocated at the next Advisory Board session to discuss this, and could involve seeking a presentation from someone that knows how to build Android apps.

Other Action Items:

- At Mr. McGurn's suggestion, Dr. Parkinson urged that a presentation from an expert on fiber optic cables be placed on the agenda for the next session.
- At Dr. Camacho-Lara's suggestion, Dr. Parkinson urged that a presentation on using multi-GNSS both in scientific research and as an alternative to resilience be placed on the agenda for the next session.
- Mr. Powell urged that a presentation be made at the next Advisory Board session on GPS "rollover week."
- Mr. Powell urged that a presentation be made on the relationship between alternate PNT and open systems architecture at the next session.

Wednesday, May 16, 2018

The Wednesday, May 16, 2018 session was convened at 9:30 a.m.

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

Mr. J.J. Miller called to order the 21st meeting of the National Space-Based PNT Advisory Board (PNTAB). He noted that Mr. John Stenbit, Chair, is unable to attend and delegated chairing responsibilities jointly to Dr. Bradford Parkinson, 1st Vice-Chair, and Gov. Jim Geringer, 2nd Vice-Chair. Mr. Miller thanked all for attending, particularly those who have traveled a considerable distance. He also recognized the representatives of the U.S. Air Force (USAF), whose Air Force Space Command (AFSPC) continues to do vital work to maintain the stellar performance of the Global Positioning System (GPS).

The board was established by a presidential policy initiative to provide an independent perspective on all matters pertinent to PNT. Its deliberations are governed by the Federal Advisory Committee Act (FACA). Formal minutes are taken and posted, along with all presentations, at the National Coordination Office (NCO) website (www.gps.gov). Advisory Board members are nominated by member agencies of the PNT Executive Committee (EXCOM) and the nominations are then reviewed and confirmed by the NASA Administrator. As a FACA body, the Advisory Board is bound by standards on potential conflicts of interest. Thus, any member who perceives a potential conflict with a particular issue must recuse themselves from the discussion, and the recusal noted in the meeting minutes.

* * *

Opening Comments: 21st PNTAB Focus and Priorities
Sustaining GPS as a Utility – Protect, Toughen, & Augment
Dr. Bradford Parkinson, 1st Vice-Chair
Gov. Jim Geringer, 2nd Vice-Chair

Dr. Bradford Parkinson began by paying tribute to Dr. Per Enge, a long-time member of the Advisory Board who recently passed away. Dr. Enge was a professor of aeronautics and astronautics at Stanford University. He was born in Bergen, Norway and known as an expert in both GPS and Loran (Long-Range Aid to Navigation). He led the GPS laboratory at Stanford University, where he made critical contributions to the Federal Aviation Administration's (FAA) Wide Area Augmentation System (WAAS); held over 30 U.S. patents; was the author of over 400 peer-reviewed papers; received an award for the best book published by the American Institute of Aeronautics and Astronautics (AIAA); was inducted into the Air Force's GPS Hall of Fame; received the two highest awards of the Institute of Navigation (ION) and was a member of the National Academy of Engineering. Advisory Board members will miss their esteemed friend, his hearty laugh and the benefit of his keen insight.

Gov. Jim Geringer seconded Dr. Parkinson's comments on Dr. Enge.

At Dr. Parkinson's suggestion, the board paused for silent remembrance.

Opening Informational Topic (https://www.gps.gov/governance/advisory/meetings/2018-05/parkinson.pdf):

> Dr. Parkinson addressed a topic solely for informational purposes; no recommendations would be made. The underlying question is, "How much received power does a communications system need?" If one wishes to transmit data, the energy required is a function of the background noise. Data rate [times] energy [equals] power. If one wishes a higher data rate, then more power is required.
>
> Dr. Parkinson noted that a company has been licensed to transmit satellite-to-ground communications. Such transmissions require very little power. However, the company realized a great opportunity exists if the license can be converted to high power terrestrial transmissions, with towers located one-quarter mile apart. Such a system would support broadband. So far this effort has been thwarted because the proposal raised adjacent band interference concerns with GPS. While the proposal was subsequently modified, follow-up interference tests confirm that substantial problems remain. The most critical test is that of Adjacent Band Compatibility, where the company has claimed that, based on its own tests, harm to GPS would be minimal. However, in Dr. Parkinson's view, such a claim is contradicted by many other tests.
>
> The fundamental conflict is between the data presented by the company and the results of the Department of Transportation's (DOT) Adjacent Band Compatibility (ABC) study. Even if we were to consider a 10% degradation as acceptable, the problem remains unsolved. Indeed, the overall problem could be worse as, among other reasons, multiple towers will contribute additive noise and reflections from ground and buildings increase normal $1/R^2$ models by a factor of

over ten. The greatest hazard is to high precision receivers that give the most economic value, perhaps $65 billion annually. The ABC study undertaken by DOT enables a determination on interference levels once the spacing and strength of transmitters is known.

* * *

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

U.S. PNT policy remains stable. Its aim is to provide continuous worldwide access to GPS, without direct user charges. The USAF continues to do an outstanding job to maintain GPS as the "Gold Standard" of Global Navigation Satellite Systems (GNSS). This policy includes supporting international efforts to detect, mitigate and increase resilience to harmful interference. Strictly speaking, most GPS users don't use a receiver, but rather, a computer within a computer that talks to a GPS chip. Such machine-to-machine communication may complicate the task of identifying problems.

The PNT EXCOM last met in March. Its areas of strategic focus include: GPS sustainment and modernization, international cooperation, spectrum management, and PNT resilience and outreach. Three of these items – spectrum management, critical infrastructure and PNT resilience – need to be considered together as each affects the others. A collaborative effort is needed to protect GPS from spectrum-related interference. As GPS signals are weak, they are easy to interfere with. Problems to GPS use can be either equipment problems or with the GPS signal itself. Spectrum was once considered benign, but that is no longer the case. Further, GPS receivers lack cyber-resilience. Jamming differs from spoofing in that the latter can have aftereffects. There are a number of ongoing efforts to inform GPS equipment manufacturers and operators of the steps to take to increase system resilience. Finally, the first GPS rollover week in 20 years is scheduled for April 6, 2019. Some problems occurred during the previous rollover, so GPS users are urged to contact receiver manufacturers to learn what steps the manufacturer has taken to ensure operation through this event. The effects from this rollover may not be limited to April 6; they can occur later.

Mr. Marquez noted that Mr. Martin did not address GPS backup.

Mr. Martin said backup is a longstanding concern. The Secretaries of the Department of Defense (DoD), Department of Homeland Security (DHS) and DOT have been tasked with developing criteria for a backup capability. This effort remains in progress.

Dr. Parkinson asked when the Advisory Board will learn the outcomes of the March 2018 EXCOM meeting.

Mr. Martin said a spectrum recommendation is being developed to be communicated to the National Telecommunications and Information Administration (NTIA). Once that letter is sent he will able to say more.

Mr. Brenner noted that Mr. Martin touched on three issues – spectrum management, foreign GNSS and enforcement -– that, at least in part, fall within the purview of the Federal Communications Commission (FCC). Does the NCO, or the EXCOM, have formal interaction with the FCC? [Mr. Brenner noted that his recusal on any matters related to Ligado remains in effect.]

Mr. Martin responded that the FCC is invited to EXCOM meetings as an observer. The FCC operates under the Legislative Branch whereas the EXCOM is part of the Executive Branch. Cross communication among the agencies represented occurs daily. In his view this relationship is well established.

* * *

GPS Program Status and Modernization Milestones
GPS Directorate (GPS-D) Update
Lt Col Andy Menschner, *Material Leader*
Space & Missile Systems Center (SMC)

Lt Col Andy Menschner noted that earlier this year, Col Steven Whitney (GPS-D Director), published the organizational goals for the year. The intent is to present tangible products and measurable goals. These mandates and objectives include delivering capabilities, integrating the enterprise, defining the future and developing professionals and leaders.

One specific goal is to provide M-Code, the next major capability, to the warfighter by 2020. This requires the third generation of GPS satellites and complete modification to legacy codes. This is a complex effort; the immediate approach is smart integration across the programs. Lt Col Menschner presented a graphic depicting GPS Enterprise operation, including key milestones. He also presented the Enterprise Road to Launch (ERTL) schedule, which demonstrates the complexity of the coordination required. This process is enabled by a program which began in 2016, named GPS III Contingency Operations (COps).

Lt Col Menschner also described the current year enterprise road to M-Code for the GPS Operational Control Segment (OCS). The USAF is accelerating the deployment and adoption of M-Code for the warfighter. There have been number of recent episodes of spoofing, which highlight the need for M-Code.

In conclusion, the acceleration of deployment and adoption of M-Code, continued enhancement of GPS resiliency and the integration of programs, contracts and organization, will deliver new capabilities to the warfighter. Lt Col Menschner also noted he is aware of the need for alternative PNT sources and, thus, challenges the GPS user community to help explore new approaches.

Mr. Faga commented that the vision presented states that a GPS satellite is awaiting launch. Is this a function of constellation need or launch capability?

Lt Col Menschner noted that the launch date for GPS III satellite vehicle (SV) 01 should be known within a few weeks.

Gov. Geringer noted that the presentation largely referred to M-Code. What is the deployment schedule for the GPS civil code?

Lt Col Menschner said the civil code will be deployed with the modernized operational control segment (OCX) Block 1. There will be no change until then.

Gov. Geringer noted Lt Col Menschner's comments on alternative PNT. Does he view this as something immediately urgent? Is the need for an alternative PNT or simply for a temporary backup?

Lt Col Menschner said the present offers an opportunity. A new ground system, a new family of vehicles and other things are forthcoming. This makes it an appropriate time to look to the more general future for GPS.

Mr. Faga asked what M-Code will accomplish relative to spoofing and jamming.

Lt Col Menschner said that core M-Code will allow M-Code PNT, M-Code signal monitoring, over-the-air rekeying and code mission planning. In sum, a significant step forward for warfighters.

* * *

U.S. Department of Transportation (DOT) Update
Civil Agency Lead & Extended PosNav Perspective
Ms. Karen Van Dyke, *Director, PNT Program*
Office of the Secretary, Department of Transportation

<u>Recusals:</u> Ms. Ciganer, Mr. McGurn, Mr. Brenner, Mr. Faga, Mr. Hatch and Capt Murphy. (Note: J. Stenbit is not present for the 21st Advisory Board session)

Ms. Van Dyke noted that safety is her program's #1 task. More specifically: "The mission of the U.S. DOT is to ensure our Nation has the safest, most efficient and modern transportation system in the world, which improves the quality of life for all American people and communities, from rural to urban, and increases the productivity and competitiveness of American workers and businesses." The general slogan is: "Get there fast; get there safe."

The long-running GPS ABC Assessment study has been publicly released. It has been an extensive effort. The minimum criteria for evaluating GPS adjacent band interference is:

- Accept and strictly apply the 1 dB degradation Interference Protection Criterion (IPC) for worst case conditions
- Verify interference for all classes of GPS receivers is below criteria, especially precision and timing receivers
- Test and verify interference for receivers in all operating modes is below criteria, particularly acquisition and reacquisition of GNSS signals under difficult conditions
- Focus the analysis on worst cases
- Ensure interference to emerging GNSS signals (particularly wider bandwidth GPS L1C)is below criteria
- All testing must include GNSS expertise and be open to public comment and scrutiny.

Ms. Van Dyke described the efforts to develop interference masks for the six categories of receivers tested. She noted the decision not to limit testing to the area of certified navigation. Ms. Van Dyke also presented a chart showing the Maximum Tolerable Power Levels for GPS/GNSS Receivers at 1530 MHz. Both macro-urban and micro-urban environments have been evaluated. The existing data allows one to pick a desired distance from a transmitter and determine the tolerable interference level. These findings are driven by the requirements of high-precision receivers. The farther a receiver is located from a transmitter, the greater the power it can tolerate. This is also influenced by transmitter density. Ms. Van Dyke presented a

second table showing the Maximum Tolerable Power Level for Space-Based Receivers at 1530 MHz. Finally, Ms. Van Dyke reported on the certified avionics analysis, which was based on the RTCA interference masks. The final GPS Adjacent Band Compatibility report – 160 pages, with 11 appendices – is now posted on www.gps.gov

The 2019 Federal Radionavigation Plan will address topics such as: GPS ABC Results, Termination of Nationwide Differential GPS (NDGPS), Update to the Standard Positioning Service Performance Standard, Incorporation of L2C and L5 and Civil GPS Signal Roadmap: Initial Operating Capability (IOC) and Full Operational Capability (FOC). Also, hopefully this year there will be an update to the GPS Performance Standard.

Positive Train Control (PTC) and GPS is mandated under the Rail Safety Improvement Act for certain freight and passenger railroads. It is set for implementation by the end of this year. Approximately 20,000 locomotives and 60,000 miles of the nation's 140,000 miles of track are covered. PTC is designed to prevent train-to-train collisions, derailments due to speeding, incursions of trains into roadway work zones and movement through misaligned switches.

Ms. Van Dyke then addressed "Looking to the Future of Navigation for Autonomous Systems." This could be the topic for a future Advisory Board meeting; the matter is a high priority with the DOT Secretary. She presented a quote from a DOT plan in the 1970s: "The vital need for efficient methods of navigation is as universal and ancient as the requirement to travel. Each era of navigation history has necessarily been marked by the particular situation of mankind at the time, including use of the available tools. At issue on a continuing basis are questions of geographic coverage, the particular types of radionavigation systems which are needed and who must bear the responsibility and expense of providing the signals." In her view, this quote is just as applicable now as it was then.

> Dr. Parkinson said the real implementation issue is who will bear the cost and responsibility. Looking ahead, there is considerable discussion on resiliency. The issue is how protection can be built into the system when one is precluded from making use of what one knows works. Is there any plan for getting certain systems into the civilian domain rather than the military?
>
> Ms. Van Dyke responded that no such programs are active. Currently, the search is for guidance into what could be done.
>
> Mr. Goward noted that US$10M has been appropriated for a technology demonstration of GPS backup capability. Would that include a look at GPS autonomous systems?
>
> Ms. Van Dyke said the appropriation is clearly focused on backup capability.
>
> Mr. Dimmen noted he believes Ms. Van Dyke said the U.S. Coast Guard (USCG) has decided to phase out NDGPS. Is this correct?
>
> Ms. Van Dyke said that is correct.
>
> (Audience member) Capt Russell Holmes, Commanding Officer, USCG Navigation Center said a Federal Register Notice has been published announcing plans for the next three years, during which coastal sites operated by the USCG will be phased out. Those not phased out until 2020 are ones for which ship captains have requested additional time.

* * *

Federal Aviation Administration (FAA) Update
FAA Navigation Programs
Ms. Deborah Lawrence, *Manager*
FAA Navigation Programs

Since 2006, the FAA has been moving toward Performance Based Navigation (PBN). All of the PBN initiatives are related to NextGen (Next Generation Air Transportation System). The FAA Navigation Programs has undertaken to align its activities with FAA's goals. Additionally, it seeks to streamline activities to raise efficiency and cut costs. For example, given that lighting is used in whatever system is ultimately deployed, there is a Lighting Systems Initiative to determine the most efficient lighting that can be used.

The central goals on resilience in navigation services include:

- Provide resilient navigation services for the PBN NAS (National Airspace System) Strategy–2016
- Rationalize infrastructure to meet the NAS Efficient, Streamlined Services (NESS) initiatives
- Discontinue redundant Very-High Frequency Omnidirectional Receiver (VORs) from about 900 to 600 to establish the Minimum Operational Network (MON) and to rationalize Instrument Landing Systems (ILS) at airports where LPV (Localizer-performance with vertical guidance) provides redundancy (this had been put on hold while progress is made on VORs)

- Innovate navigation services to enable new capabilities, such as Multi-Constellation and dual frequency operations

There are a number of efforts underway to take advantage of dual frequency, including WAAS.

Ms. Lawrence also presented on the FAA Navigation Programs Portfolio, Resilient Navigation Services, En-Route to Terminal Strategy, Approach Strategy and Instrument Approach Strategy. The general theme is to reduce approaches, which are quite costly, including the elimination of Nondirectional Beacons (NDBs) (though NDBs might be retained in Alaska, due to its far northern location). Regarding Approach Strategy, a review will be made to determine whether the Category 1 (Cat 1) infrastructure can be decreased. Meanwhile, the number of LPVs will be increased. A complicating factor is that a substantial number of FAA employees are nearing retirement, therefore their departure will hamper the expertise the agency can deploy.

The largest concern of Congress is the sustainment of NavAids (Navigation Aids). GPS is the primary basis of navigation, but because of the dangers of GPS disruption, the priority is to ensure continuation of service. The FAA is currently working on a study on sustainability in the event of disruption to GPS.

The next steps for NavAid programs are:

- NextGen Distance Measuring Equipment (DME) Program – Install approximately 125 DMEs to provide resiliency during GNSS disruption
- Very-High Frequency Omnidirectional Receiver (VOR) MON Program – Discontinue 74 VORs and prepare for an investment decision in 2020
- DME/VOR/TACAN (Tactical Air Navigation System) Sustainment – Complete DME/VOR/TACAN Supportability Study – Coordinate with DOD to identify TACAN requirements – Follow Acquisition Management System (AMS) process to develop acquisition strategy for DME, VOR, and TACAN to systems
- ILS – Continue to sustain Cat-1 ILSs at selected sites.

The GNSS program next steps include:

- Integrate 6th Geosynchronous Equatorial Orbit (GEO) satellite and establish procurement strategy for 7th GEO satellite
- Continue L5 implementation
- Continue development of Dual-Frequency Minimum Operational Performance Standards (MOPS)
- Evaluate Multi-Constellation and Advanced Receiver Autonomous Integrity Monitoring (ARAIM)
- Develop strategy for transition from Time Division Multiplexing (TDM) to Internet Protocol (IP)
- Continue technical refresh activities

Innovation initiatives underway include: (1) support Multi-Constellation GNSS and ARAIM standards development and program coordination through International Civil Aviation Organization (ICAO), RTCA, European Union (EU) and Air Navigation Service Provider (ANSP) organizations; (2) Explore the feasibility of achieving WAAS Cat-2 precision approach service (w/ single & dual frequency GPS) and (3) Support operational approval activities for WAAS LPV Cat-2 enabled by Enhance Flight Vision Systems (EFVS).

A key area the FAA needs to address is Congressional interest on ground aids. The infrastructure needs to be reviewed. While no bill has been introduced, the FAA has been queried about how much money would be required.

In summary, the goal of the Navigation Strategy is to provide the support infrastructure. The transition from NAS to PBN operations will continue. Existing NavAids being replaced by GNSS will be rationalized. Conventional NavAids will be kept to provide resiliency.

> Dr. Parkinson asked if there is a plan for WAAS to have Galileo receivers.
>
> Ms. Lawrence responded that WAAS currently has a multi-constellation dual receiver capability. However, the FAA has not picked a specific GNSS, rather, it has decided to be ready for whatever policy decision is made. WAAS continues planning a future for multi-constellation and dual-frequency use.
>
> Mr. Kenneth Hunt [audience member] added that aircraft equipment manufacturers working with Europe, recently changed the terms of reference that included GPS, SBAS and Galileo as part of the core foundation of the next generation standard, while allowing for the addition of other systems.
>
> Ms. Lawrence said measurements are being taken that would allow use of whatever multi-constellation system is approved. The agency has the equipment to respond to whatever policy decisions is made.
>
> Dr. Parkinson ironically observed that Ms. Lawrence might be engaged in violating the law, specifically an FCC provision, by listening to Galileo.

Ms. Lawrence said she could neither confirm nor deny this.

Dr. Parkinson said he was trying to recruit Ms. Lawrence's aid in getting FCC approval for the use of Galileo in the U.S.

Ms. Lawrence asked Mr. Hunt if he could clarify FCC action in this area.

Mr. Hunt said he has no update at present.

Mr. Burns noted that, as a former airline executive, sometimes newer is not proven to be better. In his view, the replacement of Cat 1 is premature.

Clarifying, Ms. Lawrence said she was not talking about high volume airports, where there is no consideration to remove Cat 1. The review will begin by looking at smaller airports to see if the Cat1 capability could be removed. Cat 2 and Cat 3 are not going to be affected.

Mr. Burns noted that he welcomes the elimination of NDB.

Ms. Lawrence said that when this was proposed, strong opposition immediately surfaced in Alaska. Subsequently, it was learned that the USCG uses NDB along the Pacific Coast.

Mr. Faga asked if Mr. Lawrence foresees a circumstance in which countries with their own GNSS system would require aircraft flying into that country to be equipped with their system.

Ms. Lawrence said she does not know.

Mr. Hunt commented that ICAO is grappling with that question. Consideration is being given to authorize – which, in effect, also means de-authorizing – which signals can be used by aircraft operating in any nation's airspace.

Mr. Burns said the FAA has not announced which GNSS elements would be authorized or when authorization would occur. Airlines need this information to plan for the development of their systems. Also, in his view, it is unfortunate that no reference had been made to Ground Based Augmentation Systems (GBAS). It appears there is a trend at the FAA to view GBAS as of declining importance.

Ms. Lawrence said her presentation should have included GBAS. The reason for its omission is bureaucratic. GBAS has not completed its business case; therefore, the FAA cannot not vote on whether to proceed with acquisition. There is no loss of support for the two non-federal systems currently in use. Ms. Lawrence noted that within the NextGen Advisory Council a subgroup has been established to focus on the Northeast, and this group is looking at the future of GBAS.

* * *

Connectivity Connected Aviation: Enabling Innovation in the Internet of Things that Fly

Mr. Joe Burns, *Member, PNT Advisory Board*
(Substituting for Dr. Bruce Holmes, *Vice President, Digital Aviation, SmartSky Networks, LLC)*

Mr. Joe Burns clarified that he has no affiliation with SmartSky Networks. He is briefing on behalf of Dr. Holmes because of his familiarity with the technology.

The topic of the Internet of Things that Fly underscores the importance of PNT. Innovations are cropping up rapidly. The objective of this briefing is to address unmanned aircraft, PNT dependencies, operational threats and PNT implications to legacy and air mobility innovations.

First, we need to understand the strategic context. The growth curve is driven by progress toward saving the consumption of fossil fuels. Major progress is occurring in aviation just as, for example, advances in battery technology are bringing progress to automotive transportation. Aviation infrastructure is more expensive than actually flying through the airspace. On-Demand Mobility (ODM) is one of the "big ideas" affecting U.S. productivity. It allows for safe, productive and efficient movement of people and goods. Also, airline consolidation has led to service reductions in smaller markets, while increasing congestion (and cost) at major hubs.

Innovation in aeronautics (e.g. antenna performance, ATG network performance and others) is dependent on PNT. PNT is key to enabling the transition from 4G to 5G mobile communications. The "Vision for On-Demand Mobility will improve productivity by, for example, reducing travel time from Chicago's O'Hare airport to the city's downtown by 30 minutes. There remains work to be done on the safety standards, but the needed technology exists. Collecting six passengers in Mansfield, Ohio and flying them directly to a Washington, D.C. airport is a very real prospect for the future. However, about two-thirds of the companies exploring these technologies are new and need various forms of assistance.

Finally, most Unmanned Aerial Vehicles (UAVs) can only fly three to five minutes without GPS support. Also, most commercial UAVs cannot not take off without GPS support. Issues of spectrum encroachment and resiliency needs of UAVs also exist. Loss of GPS would cost UAVs the ability to remain within a specified area. The U.S. has always led the setting of regulatory and certification standards for aviation. Maintaining such leadership will require Protecting, Toughening, and Advanced PNT (APNT). PNT resilience, robustness and security are vital to emerging markets and companies.

Mr. Faga asked if Mr. Burns foresees autonomous systems that would not require any pilot training.

Mr. Burns said he can see that happening at some point. In the interim, piloting will be done by persons not in the vehicle. Artificial Intelligence has a major role to play.

Gov. Geringer asked whether it would be possible to take off from his driveway in Wyoming and fly the fifteen miles to the Cheyenne Airport.

Mr. Burns said that will be achieved at some point.

A question was raised of which is the bigger problem -- cybersecurity or spectrum?

Mr. Burns said both are big problems.

* * *

U.S. Department of State (DOS) Update

Bilateral Partnerships & International Committee on GNSS (ICG)
Mr. Jeff Auerbach, *Foreign Affairs Officer*
Office of Space and Advanced Technology, DOS

The U.S. policy goal to sustain GPS as the "Gold Standard" for international GNSS includes providing civil services on a continuous, worldwide basis, without direct charge to the user. It also calls for supporting international efforts to detect and mitigate harmful interference. General objectives are: ensure compatibility, achieve interoperability and promote fair competition in the global marketplace. These objectives are pursued through both bilateral and multilateral cooperation. High points of bilateral cooperation include:

- China: The most recent GNSS Plenary was held in 2015 in Washington D.C. The next session is set for Harbin, China.
- India: A U.S.-India joint statement was signed in 2007; a Civil Space Joint Working Group met in 2017.
- Europe: The GPS-Galileo Agreement was signed in 2004. The European Union's request for a waiver of FCC Part 25 rules (which affect the legal use of Galileo signals in the U.S.) has been discussed by the Working Group on Trade and Civil Applications.
- Japan: The Technical Working Group last met in December 2017 to discuss compatibility coordination.

Other bilateral undertakings include Canada, the Republic of Korea, Australia, Vietnam, the United Arab Emirates, and Ukraine.

The primary venue for multilateral cooperation was the International Committee on GNSS (ICG). ICG membership includes both GNSS-provider and non-provider nations. The ICG's 12th annual meeting was held in December 2017 in Kyoto, Japan, with 200 participants from 20 countries present. PNTAB members Dr. Betz and Dr. Rashad gave presentations at the meeting. All board members are encouraged to attend future sessions. The 13th ICG session will be held in China on November 4-9, 2018; the 14th session in India in 2019 and the 15th session in Vienna, Austria in 2020.

A key ICG focus is Interference and Spectrum Protection. This topic has been the focus of many discussions. A Task Force on Interference Detection and Mitigation (IDM) was established in 2013. Recent and pending activities in this area include three seminars on spectrum protection, a presentation to the United Nations (UN) Committee on the Peaceful Uses of Outer Space (COPUOS) and the 7th ICG-sponsored IDM workshop.

Other ICG-12 accomplishments include the following recommendations for 2018:

- Hold an ICG-sponsored workshop on the multi-GNSS monitoring trial project established between ICG and the International GNSS Service (IGS)
- Hold an ICG-sponsored workshop to promote common terminology and definitions to facilitate creating a template for providers to use to publish performance standards

Other recommendations fall in the areas of GNSS interoperability, development of a Multi-GNSS Space Service Volume (SSV) and Orbital Debris Mitigation. Orbital debris is quickly becoming a topic of high interest.

Gov. Geringer noted that earlier in the day Mr. Martin discussed the GPS rollover week. Is this a task unique to GPS? Has the ICG discussed it?

Mr. Auerbach said the matter has been presented, but not formally discussed within ICG.

Gov. Geringer asked how other GNSS providers handle the rollover.

Dr. Beutler said he believes it is a problem for each individual system.

Mr. McGurn referenced Mr. Auerbach's comments about activity with the International GNSS Monitoring and Assessment (IGMA) Task Force. The first report showed large differences, depending on who had collected and processed the data. He asked what is being planned for 2018.

Mr. Auerbach noted that the session on this topic was held the previous week and, thus, no report is yet available. The report should be available by July, and will be presented later this year at the ICG Working Group on Signals and Systems.

Mr. Higgins, referencing the interference protection monitoring workshop, asked if any presentations are available on the issue of crowdsourcing.

Mr. Auerbach said these have not yet been posted.

Mr. Murphy asked, relative to multi-GNSS constellation monitoring, whether any effort have been made to tie to the international aviation community work to that of monitoring an integrity support message.

Mr. Auerbach said he does not know.

Mr. Murphy said he believes considerable opportunities for synergies exist in this area.

* * *

United Kingdom (UK) Progress on Resilient GPS
Prof. David Last, *Strategic Advisor*
General Lighthouse Authorities of the UK & Ireland

Dr. David Last reminded the board he last addressed them in October 2015. At that time, he spoke on "Resilient PNT: An Outsider's Perspective." We have come a long way from early denials of the risk to GPS to subsequent acknowledgement. In 2015 he spoke about Enhanced Loran (eLoran). A prototype system was created, using the legacy Loran-C stations, which for three years delivered 24/7 service at seven key ports and across ten countries in northwest Europe. In 2015, he predicted this system would soon close due to a lack of transnational coordination, and that's what has happened. Many European countries still do not appreciate the vulnerability of GPS.

Dr. Last said he would focus on what the UK has done differently. Recognition that GPS is at risk has become a cabinet-level concern, which is at a higher level than the departmental level where the issue has been the subject of continued squabbling. The government decided to "follow the money"; that is, to assess what a GPS disruption would cost the country. This is different from seeking to determine the value-added by GPS; rather, it aims to determine the loss due to a standalone five-day disruption. The results are dramatic. A five-day interruption would cost the UK $7.1 Billion. Of this figure, 88% is in the areas of road transport, emergency services and maritime. Specifically:

- Transport: Road transport would be subject to congestion and delay. Estimated total loss: $2.7B
- Emergency Services: GPS is built into all UK First Responder systems at multiple levels of dispatching, navigation, and communications. Further, First Responders would be slowed by the congestion cited above. Estimated total loss: $2.2B
- Maritime: Here, the initial assumption was that GPS loss would principally lead to more collisions and accidents. The major impact is the disruption of supply lines that touch on port facilities, affecting such things as "just-in-time" delivery. Estimated total loss: $1.6B

Regarding mitigation, no single "silver bullet" can address all aforementioned concerns. However, the "best bang for the buck" is eLoran. This poses the question of whether the UK government should spend public funds on this. Economists engaged in this effort said "yes," as the public benefit is four to five times the cost of the public investment. The underlying message is clear: loss of GPS will cost the UK over $1B per day.

The government undertook a "Blackett Review," a process devised during the Second World War that allows for public-private consulting on technical matters. Ten recommendations were made:

- Critical National Infrastructure (CNI) operators should review and report on their GNSS reliance, with the Cabinet Office assessing the overall dependency

- Add the loss of GNSS-derived PNT to the National Risk Assessment
- In allocating radio spectrum, address the risk to PNT
- Review the legality of owning devices that create interference
- Assess the need to monitor GNSS interference at ports and other key sites
- Employ GNSS-independent backup systems
- Direct the cross-governmental working group to report to the Cabinet on how resilience may be improved
- Government must identify the requirements for GNSS equipment for CNI specific performance standards
- Map PNT testing facilities and explore how business and industry can better access them
- Leverage UK expertise to increase coordination between existing centers of excellence

As a result, the UK Cabinet Office – the top level of government – took ownership of the problem. The Blackett Process drove home an agreement as to the vulnerability of GPS. As for mitigation, the answer differs depending on the sector. The financial sector is concerned with timing; the emergency sector needs positioning; and requirements for rail and air travel will differ from one another. Every sector has a different terrestrial radio system. The day following the release of the Blackett recommendations, the UK government issued a separate report on the viability of eLoran, which concluded that the government would support operation of eLoran services.

The UK government has also established BRIG (Blackett Review Implementation Group) to meet for six-week investigation intervals, with two meetings already having occurred. Separately, a technical group has been established to offer policy advice.

* * *

Initial Findings from the Strike3 GNSS Interference Monitoring Network
Dr. Mark Dumville, *General Manager*
Nottingham Scientific Limited (NSL), UK

Strike 3 is a project that aims to protect GNSS by standardizing threat reporting and using this information to improve receivers by testing them against the identified threats. The project is funded by the European GNSS Agency, and began in February 2016 with a duration of three years. Strike3 involved creation of a 24/7 monitoring network to detect any threat, intentional or not. Monitors have been deployed at sites ranging from city centers to ports in nearly 30 countries, involving a range of entities, from power grids to frequency regulators.

The Strike3 fingerprint characterization measures size, pressure and patterns; identifies distinguishing features and classifies the signature. With this information, it is possible to detect a specific jamming device. The Strike3 "database" for January 2, 2016 through March 4, 2018 shows that the most common type of characterization (about 54%) is unintentional. Other types include 86,600 narrow band-single tones – not necessarily deliberate; 38,900 Chirps; 12,500 Code Division Multiple Access (CDMA); and 36,000 "other." There have been 50,000 GNSS denial events, of which 39,000 were jammers; 10,000 were narrow band/single tone; and 1,000 noise + CDMA + other. Regarding duration of interruption, 11% of these events lasted more than 60 seconds, nearly 6,000 lasted more than five minutes, 545 over an hour and the longest event recorded lasted five days.

Jammer waveforms come in considerable variety, varying in bandwidth, power, center, frequency and signal. Strike3 also shows how the jammer industry is evolving. Jammers are becoming more complex and new waveforms have recently been detected. This is of considerable concern. Dr. Dumville identified the most common jammers and recommended that receiver manufacturers focus on combatting these. Additionally, Universal Serial Bus (USB) jammers are beginning to become common. Also, there may be instances where, for example, taxis are lined up in rank and multiple jammers are operating in essentially the same location. One advantage of Strike3 is that it can track a jammer geographically, across national boundaries.

Next steps include: discussions with two nations to install a Strike3 reporting system, efforts to validate the Strike3 reporting standard, efforts to integrate crowd-sourced information and testing of GNSS receivers against the Strike3 "threat database." A live-sky demonstration is scheduled for later in 2018, after which the project will close out.

> Dr. Parkinson noted that, 25 years ago, one of his students demonstrated a method of triangulation that would identify the source of interference.
>
> Mr. Dumville said his organization had plans to move in that direction, but considerable problems exist in deploying Strike 3 in foreign countries.

* * *

Report on the Workshop on Time Receiver Resilience
Dr. Marc Weiss
Spirent

Dr. Marc Weiss commented that the task of creating precision GNSS time resilient receivers will be assisted by the workshop he organized on Time Receiver Resilience. The workshop focused on three critical infrastructures: telecommunications, power and finance. Members of the steering committee approached each of these from an industry perspective. While many believe the U.S. needs to establish assured PNT programs for critical infrastructure, a major barrier is the lack of clarity as to who is responsible for which aspects of resilience. Major recommendations from this workshop are, first, establish assured PNT programs for critical infrastructure and, second, establish who holds responsibility for what aspects of critical infrastructure resilience. Shorter-term actions include: the need for a clear procurement language and creation of an organizational maturity model. The latter means that infrastructures must address what risks they face, their needs for resilience and methods for establishing such resilience.

While the process used in the workshop was not a scientific survey, considerable useful information was obtained. The perceived vulnerabilities of the infrastructures are:

- Telecom: Resilience is not a high priority, as few system impairments have been caused by spoofing or jamming. The industry feels it faces more important concerns.
- Power: Timing is the principal concern regarding reliability. About 20% of responses said operations have been affected by GNSS timing issues. Also, it is noteworthy that all the operators contacted had approached vendors to seek resilience features.
- Finance Service Sector: Concern focuses on reliability, traceability and precision and accuracy. The sector would like detection and correction of signal error and extended holdover on signal loss. Finance needs to be able to demonstrate traceability in terms of time stamping, at micro-second accuracy. As most stock exchanges are in major cities, the sector would like better urban penetration, better resistance to space and terrestrial weather and access to a terrestrial-based timing source, such as eLoran and cyber protection. This industry is not sensitive to cost increases, in part because it has a limited number of receivers.

The major recommendations for each sector are as follows:

- Government: Establish an assured PNT program for U.S. critical infrastructure. Further, emphasize the role law enforcement can play against jammers and spoofers.
- Standards organizations: Define resilience and how to test for it, be aware that the significant threats will change over time and develop a procurement language.
- Users and industries: Create an organization maturity model that clarifies dependencies and vulnerabilities and, also, establish an industry-standard procurement language. Many people who were dependent on GPS did not even know that GPS is part of their system.

Dr. Weiss identified four next steps, as follows:

- Workshop of Synchronization and Timing Issues, June 18-21, in San Jose, California
- National Institute of Standards and Technology (NIST) / DHS Workshop on Timing Security, June 22
- His own group will continue to explore options for stimulating resilient receivers.
- Timing security is a larger issue than just GNSS resilience. Research results will be reported at various forums.

In conclusion, there is a need to clarify who holds responsibility for which aspects of improved resilience.

Mr. McGurn, noting that the financial sector has tens of hundreds of receivers, asked why they didn't make use of telecommunications fiber.

Dr. Weiss said this is under consideration, but it appears currently available fibers are not well designed for this purpose. This is being done in the UK.

Dr. Parkinson called attention to a talk on this subject scheduled later in the day.

* * *

Superior Beamforming GPS Anti-Jamming for Airborne Platforms
Dr. Alex Stratton, *Principal Systems Engineers*
Advanced Technology Center, Rockwell Collins

Dr. Alex Stratton said he would report on mitigation possibilities and noted they may be of more interest to the military than civilian communities. Threats to GPS are real and becoming more numerous. While mitigation technology is available, users have been slow to adopt such technology and the potential use of technology by civil users is limited by U.S. International Traffic in Arms Regulations (ITAR). Further, users' adoption of new applications encourages delay. The military is more concerned with larger jamming devices, particularly the North Korean device with 100 km range, and with claims by Iran that it is developing technology capable of re-targeting incoming missiles.

Anti-jamming technology began in the 1980s with analog nulling systems, followed by multi-beamforming electronics. The next stage was to move this technology into production, which began in 2005; about 150,000 were produced. Today a more software-based approach is used to take advantage of the economy of digital processors. Such devices are P(Y) and M-Code (GPS encrypted signals) compatible, significantly smaller and, unlike earlier systems, they're dual frequency devices. DIGAR, a digitally-integrated electronic anti-jamming unit, has demonstrated a high ability to maintain GPS despite exceptionally high jamming. One of its features is analog-protected output.

The civil navigation community wishes for greater protection. A solution exists to the basic safety-of-life integrity requirements. The FAA and other airspace authorities are interested in operational standards for civil aviation and are moving toward detecting and mitigating intentional threats. Regulatory issues are the major obstacle to using this technology for civilian purposes.

> Dr. Parkinson said he is concerned by the barriers mentioned. Cost is also a barrier. The military could take the low-cost approach of building technology in from the beginning to avoid retrofitting, which is more expensive. Is the military engaged in such retrofitting?
>
> Mr. Stratton said some retrofitting is being done by the military on higher-value programs, but these efforts are pre-decisional.
>
> Mr. Hatch asked if there has been examination into how this cuts down on multipath for a fixed site.
>
> Mr. Stratton said it does cut down on multipath. However, if one thinks of high beams as only taking in gain from a certain area of the sky, then this essentially increases one's DDU ratio of any signal arriving outside of that beam. A seven-antenna array has seven times the gain. There is an increase in noise floor, so the net gain means one is no longer on the curve commonly referenced in civil augmentation systems.
>
> Mr. Burns asked if in the air transport division Mr. Stratton envisions one box per aircraft or one box per system.
>
> Mr. Stratton said he sees the latter from a safety perspective and redundancy.
>
> Mr. Higgins commented that in Australia, multipath is the largest remaining problem and the ability to employ a solution is of significant consequence.

* * *

Current Operational Status of Low Earth Orbit (LEO) Satellite-based Time and Location
Dr. Gregory Gutt, *Chief Technical Officer and President*
Satelles Inc.

Dr. Gregory Gutt said his organization, having heard Dr. Parkinson's call to toughen and augment GNSS, decided to approach the problem differently by developing a PNT system separate from GNSS. In 2016, he addressed the PNTAB and provided considerable technical information on the STL system. Since then, five successful SpaceX launches (of ten Iridium satellites each) have taken place. No public funds have been used. About $3 Billion in private capital has been raised. The company is active with various sectors and its customer base is growing rapidly.

While many consider STL to be an augmentation to GPS, there are important differences. STL is the world's only high-powered, global solution for time and location. It works anywhere, including the Polar Regions, provides 3D location and can be integrated into smart phones with no additional equipment cost. As the Iridium signal is adjacent to GPS in the L-Band, it allows STL to take advantage of the enormous investment that has been made in chipsets. STL meets three important criteria: it provides worldwide coverage and offers high power broadcasts and localized spot beams. The high power makes the signal harder to disrupt; the link margin for the STL signal is about 1,000 times stronger than GPS.

One of the late Dr. Enge's prime interests was proving one's location. This is among the most basic of questions. STL accomplishes this using Iridium satellites orbiting at only $1/25^{th}$ the altitude of GPS. Solar panels allow one to direct very strong signals at the earth. Fewer satellites are in range, relative to GNSS – one or two as opposed to seven or eight. However, as LEO

satellites move faster compared to those in Medium Earth Orbit (MEO), accurate location can be determined even if only one or two are in view at any one time.

STL is targeting three market segments: time synchronization, deep indoor penetration and trusted location. STL is serving several of the most important world stock exchanges worldwide. Earlier Mr. Goward asked how the system operates in tall buildings. A year ago, a time and money conference was held at the New York Stock Exchange where various equipment suppliers tried to show how they would provide accurate timing with satellite-based systems. The only system that worked was one that leverages STL. No GPS equipment worked inside the building.

Mr. Goward commented that an eLoran system had worked.

Dr. Gutt acknowledged this, but said he was referring to satellite-based capabilities.

Overlapping spot beams provide specific encryption codes that change every second for maximum security. Because satellites are closer to the surface (compared to GNSS), the receivers can't get information from the 'wrong' satellite. Satelles is, of course, concerned with potential interference. The Satelles STL service depends on Iridium operating free from harmful interference. STL believes that Ligado's out-of-band emission may cause harmful interference to Iridium services and that proposed interference protection is insufficient.

Mr. Faga asked if ancillary equipment is used, or is the information simply derived out of the Iridium payload.

Dr. Gutt said no ancillary payload exists. Rather, the company has worked for years on a way to reprogram a group of channels.

Mr. Martin asked how a user purchases the service.

Dr. Gutt said his company is currently focusing on large enterprises that wish to integrate many sites, such as fleet users.

* * *

Feasibility of a National Fiber-Optic Sub-nanosecond Timing Infrastructure
For Terrestrial PNT & GBS Back-Up
Dr. Jeroen Koelemeij, *Chief Technology Officer and Co-Founder*
OPNT B.V., The Netherlands

Dr. Jeroen Koelemeij commented that this technology has potential to serve as a one-nanosecond terrestrial timing backup and augmentation. This briefing also discusses concepts developed by others. The objective is to cover a "wish list" for PNT improvement, how to overcome the sub-nanosecond time wide-area synchronization problem and a possible terrestrial PNT backup system.

The PNT "wish list" has two parts: First, the need for a backup system that is fully equivalent of GPS, and, second, a system superior to GPS. Currently, there are a number of obstacles, such as the lack of alternative wide-area nanosecond-level timing technology as a backup to GPS timing. The needs of autonomous driving might better be met by a terrestrial rather than a space-based system. A limit with terrestrial systems is that even a 600-meter tower can only provide coverage at distances up to 54 miles; therefore, 1,500 such towers would be required to cover the U.S. "Copying" GPS on earth would also require 1,500 atomic clocks; a considerable expense. The alternate solution is to achieve synchronization through telecom optical fiber and replacing atomic clocks with low-cost oscillators.

Dr. Koelemeij said his working group has become interested in "White Rabbit," a 1 GB Ethernet developed by CERN. The building blocks of White Rabbit are a timing switch, a timing node and a bidirectional amplifier. This allows for the synchronization of time to a 1 nanosecond standard at each of the system's nodes. His group has replicated this capability and had undertaken several demonstrations.

Dr. Koelemeij presented two scenarios for serving the U.S. with this system: a "coast-to-coast" scenario and a "coast-to-coast fishbone" scenario, which makes far greater use of standby linkages. Such a system has some advantages over GPS. A terrestrial system provides higher received power levels, involves no ionospheric effort, requires a smaller clock and PNT error and provides a smaller ephemeris error and simplified PNT algorithm. In the future, the development of new smartphone may be able to use this approach as part of the 5G infrastructure.

Mr. Hatch said that in GPS, correction is needed for the rotation of the earth. Does his system require the same correction?

Dr. Koelemeij said such correction is required.

Gov. Geringer noted the reference to spectrum and asked what spectrum allocation would be made.

Dr. Koelemeij said it would certainly be far away from that used by GPS, perhaps in the 900 MHz band.

Ms. Ciganer stated she is pleased that the pseudolites discussed would be operating outside the Radio Navigation Satellite Service (RNSS) spectrum. Pseudolites operating within the RNSS band create considerable interference.

Dr. Axelrad asked whether the time transfer function is separate and could be implemented without pseudolites, using only fiber?

Dr. Koelemeij said it could, and is.

Dr. Parkinson said a possible barrier to using fiber optic cables is that they move around and that made it difficult to get a stable path.

Dr. Koelemeij noted that fiber changes occur with temperature changes, but such changes can be figured in.

Dr. Parkinson said persons sometimes confuse time and time interval. When Dr. Koelemeiji says 'time,' which is he referring to?

Dr. Koelemeij said he is referring to the maximum time offset from Universal Time Coordinated (UTC).

Dr. Parkinson said in his experience there is always some 'devil in the details.' Does Dr. Koelemeiji believe all problems can be solved?

Dr. Koelemeij said this matter has mostly been solved by the White Rabbit community.

* * *

GPS Radio Occultation: The Real Forecast
Mr. Keith E. Johnson, *VP and General Manager*
Government Solutions, Spire Global, Inc.

Spire Global, Inc was founded in 2013, started launching satellites in 2015 and currently has 58 satellites in operation. These satellites have a useful life of two to three years. The company builds one satellite per week, with launches occurring every six weeks. The Spire satellites view earth 100 times per day, with a revisit rate of 45-60 minutes. The goal is to reach 175 satellites in operation, which is the number needed to support applications in maritime, weather and air traffic. The critical weather function will revolutionize the weather forecasting field. A fourth area of interest is that of 'custom' programs. Satellites for custom programs could be ready for launch in six to twelve months. In general, Spire Global, Inc is an earth observation organization. It is currently exploring, with a European client, the possibility that a radio frequency (RF) wave precedes earthquakes by three or four days and, thus, could potentially be detected and an Earthquake warning issued.

The Spire Weather Data Chain accepts data from 1,500 sources. At full deployment, there will be over 100,000 profiles per day. At present, Spire is the first commercial GPS-RO (Radio Occultation) profile. The system offers precise orbit determination with 5 cm accuracy. It penetrates all the way down to the surface to enable measuring ground moisture, as it did last year in a pilot project for the National Oceanic and Atmospheric Administration (NOAA). Regarding the future, reception/processing dates have been established with GLONASS and Galileo. By June 30, 2018, the U.S. Air Force will make a contract decision. A second pilot project with NOAA is also anticipated. ESA deliverables include radio occultation measurements using Galileo signals, GNSS signal reflectometry and total electron content (TEC) for earthquake prediction. The company's objective is to scale up to 100,000 profiles per day by 2019. Spire Global, Inc. intends to be a 'listener' that makes data available to anyone who needs it.

Gov. Geringer asked for more information about earthquake detection.

Mr. Johnson said his understanding is that several days prior to an earthquake a RF signature is released. His company will put satellites in space to see if this can be measured.

Mr. Burns asked for more information about the company's space-based ADS-B (Automatic Dependent Surveillance-Broadcast) product.

Mr. Johnson said that for ADS-B they will be offering a low-cost full-service capability targeted to the international market. Pilot projects are underway with Airbus and Flight24. The market estimate is $50-75 million for Automated Identification Systems (AIS), several hundred million for ADS-B and at the billion-level for RO.

Mr. Hatch asked how the data gathered is brought down.

Mr. Johnson said the company owns and operates 28 ground stations worldwide.

Dr. Parkinson noted that one person's wonderful satellite is someone else's space debris.

Mr. Johnson said the satellites operate at 450 km altitude. After their service life they reenter and burn.

Dr. Beutler noted that in classical occultation missions, one has two antennas: one for occultation and the other for timing. He asked Mr. Johnson to comment on this.

Mr. Johnson said each satellite has two sensors. The satellites are not sweeping in all RF signals, rather they are attuned to certain signal sources.

Mr. Higgins asked if GPS is used for orbit determination.

Mr. Johnson said he believes it is.

Mr. Brenner asked about whether Galileo and GLONASS will become part of this system.

Mr. Johnson said they will be incorporated as information sources.

Mr. Miller said that, speaking as a representative of NASA, he is interested in this program. RO has been foreseen as a valuable weather forecasting tool, though he's sometimes heard statements that radio occultation is not an appropriate use of RNSS. He asked whether the regulators may need additional education on this topic.

Mr. Johnson agreed that education is needed. Testing being done by NOAA and NASA will show whether radio occultation has added value to existing weather forecasting capabilities. Spire Global, Inc. can achieve 5 cm accuracy measurements. It can also put a satellite in space for several million dollars, which contrasts with traditional approaches where several billion dollars and five or more years are needed to deploy a satellite. Once testing is complete, the value of this novel approach will become clear.

* * *

Advisory Board Discussion
All Members

Dr. Parkinson announced that the next scheduled speaker, Dr. Scott Pace, is delayed, he recommended the Advisory Board conclude the day's session with a roundtable discussion.

Gov. Geringer complimented Mr. Miller on his work in assembling the speakers and agenda for the 21st PNTAB session.

Dr. Parkinson commented that he feels wonderful support has been received over the years from the U.S. Coast Guard, and wished to recognize Capt. Russell Holmes, in the audience, as a friend and supporter for many years.

Gov. Geringer asked when the Advisory Board should begin preparing a plan of action on the topics it needs to address.

Dr. Parkinson said he believes there are three issues the Advisory Board will find of interest. Given that the mission of the Advisory Board is assured PNT, part of the response is to move in the direction of Protect, Toughen and Augment. Under "Protect" various discussions are needed on gathering data. It should be possible to encourage cellphone makers to write a Smartphone application that notes if one is being jammed or spoofed, with that information going to a database at some central location. We need to discuss how the board could make this happen.

Mr. Higgins said his understanding is that the Android OS (Operating System) enables chips to report on jamming.

Dr. Parkinson said that time could be allocated at the next Advisory Board session to discuss this. It could involve seeking a presentation from someone that knows how to build Android apps.

Dr. Parkinson added that the second issue is "Toughen." The question here is how to enable civil safety critical applications to use the advanced capabilities that have already been developed. There are a number of barriers to overcome, such as cost and usual reluctance to embrace new technologies. The question remains: What can the Advisory Board do about this?

Mr. Murphy said he believes the biggest barrier was exportability.

Dr. Parkinson agreed. This, in turn, frames the third question. How could the Advisory Board prompt someone in the federal government to take this matter as a cause and try to strike a balance between national security needs and airline safety?

Mr. Shields suggested considering police cars. It should be simple to equip police cruisers so that officers are made aware if jamming is occurring. Greater capabilities can be added over time. There may be a 10-year adaptation cycle, but if a start is made then it will eventually happen. Another issue to consider is how to accelerate FCC licensing of all GNSS signals received in the U.S. The Department of State has been pushing for this.

Mr. Goward said that, once again, a champion is needed. While U.S. Air Force is responsible for GPS signals, its responsibility is limited to assuring PNT for the military. Establishing someone in charge of this issue could be a first step.

Dr. Parkinson agreed. In his view, the Department of Homeland Security had not been sufficiently active in the past, but it appears to be better as of late. The Advisory Board needs to make a list of where a "champion" would be most effective.

Gov. Geringer said there also needs to be a person responsible for the overall enforcement of laws regarding jamming and spoofing.

Mr. Goward said he thinks it would be fine for the FCC to assign this responsibility. Perhaps the FCC needs a legislative change that assigns responsibility and creates a budget for enforcement. At present, there is no individual whose job performance evaluation depends on carrying out any of these tasks.

Dr. Parkinson noted that Mr. Martin and Ms. Van Dyke each have roles to play. Identifying a catalyst within the federal government is by itself insufficient, as that catalyst will need resources with which to work.

Mr. Brenner said he does not understand why the question of use of foreign GNSS remains unresolved as a policy question.

Dr. Parkinson said clarity is needed on what the barriers are. It is not obvious to the Advisory Board why this matter persists.

Mr. Higgins said that several years ago, Australia held that if something is licensed in the International Civil Aviation Organization (ICAO) then it is also licensed in Australia; no service-by-service approval is required.

Mr. Goward urged creation of a "report card" of what the Advisory Board believes the federal government should do, who in the federal government is responsible for undertaking it and then publish the results every six months. The Advisory Board should clearly state who is placing a critical national infrastructure at risk.

Dr. Parkinson agreed. This is the "stick side" of the equation; perhaps the "carrot side" should also be created.

Dr. Parkinson encouraged Advisory Board members to consider what other PNT-related steps should be taken.

The Wednesday, May 16, 2018 session was adjourned at 5:42 p.m.

* * *

Thursday, May 17, 2018

The Thursday, May 17, 2018 session was convened at 9:00 a.m.

Member Concise Observations on May 16, 2018 session
All Members

Dr. Parkinson, 1st co-chair, requested each member to comment briefly on what from the previous day's discussion seemed to them most important.

Mr. McGurn wondered how many problems associated with timing would go away if the use of optical fiber were looked at more seriously.

Dr. Parkinson said he welcomes a talk on that subject, particularly one that presents quantifiable data.

Mr. McGurn said he believes considerable testing of this is being done in Europe.

Dr. Parkinson said he believes there are unresolved operational difficulties. It would be wise to have an expert address the subject.

Mr. McGurn said that while optical cables are subject to movement, the movement is not great.

Dr. Parkinson said movement would be reduced in buried cables.

Dr. Axelrad endorsed having such a presentation.

Dr. Camacho-Lara noted that mention was made of using multi-GNSS, both in scientific research and as an alternative for resilience. The Advisory Board should address this subject; if not at the upcoming meeting, then at its next meeting thereafter.

Dr. Parkinson endorsed addressing it at the next meeting. He asked if members have other topics to propose.

Mr. Dimmen noted it remained a mystery why the FCC has not approved use of the Galileo signal in the U.S.

Dr. Rashad said that in forthcoming meetings the Advisory Board should look at alternatives for PNT, both present and future.

Mr. Shields said that, having been on the Advisory Board for three years, he is surprised by the lack of substantive advice forthcoming. On other committees on which he's served, the general sessions are reserved for gathering information; then, in the time between meetings, one or two WebEx or telephone meetings are held to draft specific advice. Given that the Advisory Board has six months between meetings, most members should be able to find five or six hours for telephone conferences to come up with the advice that is really needed. Such advice needs to come more rapidly.

Dr. Parkinson endorsed Mr. Shields' proposal. He noted that the Advisory Board has submitted six to eight recommendations without receiving a response. Follow-up is needed. Each meeting should begin by reviewing what recommendations are on the table. Some recommendations have not received public response due to boundary conditions. He remains frustrated with this. He said he will work with Mr. Miller and, also, with Mr. Martin, as the NCO is the channel through which things need to move.

Ms. Van Dyke fully supported this suggestion. Given the time taken to delve into topics, it is entirely appropriate to focus on recommendations that have already been made.

Mr. Martin noted that the Advisory Board's creation of receiver testing criteria has been very useful as it became the basis of the testing regimen undertook by DOT. One year after the recommendation was made the EXCOM met, so it should be easier to get a response.

Dr. Parkinson said a more concrete approach is needed. The Advisory Board's records should be reviewed to ensure that no recommendations are left dangling.

Mr. Burns said he sees value in being forward looking. Given rapid developments, including that of driverless vehicles, he hopes the group could focus on on-board autonomy.

Dr. Parkinson asked if cybersecurity should be a fourth focus area.

Gov. Geringer noted that cybersecurity means so many things to so many people that there is a need to define boundaries on what it means relative to PNT. "Cyber" is an often-misunderstood concept.

Mr. Goward commented that disruption of PNT is a subset of the cyber threat. Perhaps, rather than viewing spoofing, etc., as a threat to PNT, it would be better to examine it as another phase of cyber security.

Dr. Parkinson said he agrees that "cyber" is both looming and somewhat amorphous. The first step is to decide what aspect of cyber the Advisory Board can usefully address. He recommends creating a subgroup to study this question and inform the full Advisory Board.

Mr. Shields said that saying the focus is "cyber" will help make it broader and get more useful attention than saying the focus is "spoofing and jamming." This is a serious issue we need to address.

Mr. Hatch said one could term jamming as "a denial of service." Yesterday's briefings were very useful in getting insight into breakthrough technology.

Ms. Ciganer commented she was impressed by the international Strike3 monitoring network. Global markets support the "G" in GNSS.

Mr. Marquez thanked Mr. Miller and others for their efforts in putting together so substantive an agenda. The Advisory Board has been discussing the issue of "backup" for a considerable time. It is time to put some teeth into communicating with people that are not presidential guidance.

Dr. Beutler had no comment.

Mr. Higgins had no comment.

Mr. Powell also expressed thanks to Mr. Miller for composing the agenda. He suggested that the GPS "rollover week," in April 2019 should be a topic at the next Advisory Board. Further, much of alternate PNT ties to open systems architecture, and this could also be a topic for the next Advisory Board.

* * *

Department of Homeland Security Update
Findings from JamX17 Exercise
Dr. John Merrill
Director for the Office on Interoperability and Compatibility
Department of Homeland Security

Dr. John Merrill noted that his initial slides on interface requirements may seem elementary, but that's because they are intended for an audience of First Responders who may lack a clear idea of jamming and spoofing. Tests conducted in 2016-2017 established that these problems are horrendous. From an FCC perspective, jammers are illegal to manufacture, import, market, sell or use.

Dr. Parkinson asked why it is not illegal to possess a jammer.

Mr. Merrill said the FCC focus is on interference with signals.

On the topic of "Threats and Motives," these are quite varied. Anecdotally, there has even been a case of a priest who used a jammer to silence the cell phones of his parishioners.

Regarding "Mission Impacts," Mr. Merrill said his principal concern is the First Responder community and consequent effects on public safety. First Responders who lose communications do not, in general, know if the problem is in their equipment or if it is caused by signal interference. It is difficult to know if one is being "spoofed" unless one knows what to look for.

DHS has three goals for Resilient Communications:

- First, increase the capability to recognize, respond to, report and resolve interference
- Second, improve understanding of spectrum-threat environment.
- Third, improve jammer interdiction and enforcement.

DHS has been working on the following projects:

- 2016 First Responder Electronic Jamming Exercise, July 2016
- 2017 First Responder Electronic Jamming Exercise (JamX 17), July 2017
- GPS Equipment Testing for Critical Infrastructure. Due to some associated sensitivities, at this time Dr. Merrill is not able to share the data in a public setting, but he can supply it directly to interested Advisory Board members.

Some of the test results are pretty astounding. JAMX17 involved 200 participants and 108 organizations. The test protocol involved depriving First Responders of their communications capabilities and then seeing how often they follow protocols. A variety of scenarios were used: jammers on vehicles, jammers on long roadways, multiple jammers, etc. The central question is

whether First Responders can detect a jammer and maintain communications. A tool kit is being prepared to inform First Responders of responses to spoofing and jamming. Receiver equipment is becoming more resilient with time. There are certain special events intended to mitigate jamming, including PACE (Primary, Alternate, Contingency, Emergency) plans for communications. The initial version of this guidebook is targeted for release this fall.

Dr. Betz said he had hoped to see more emphasis on creating receivers that have a "red light" indicating that jamming or spoofing is occurring. Are manufacturers being prodded in this direction?

Mr. Merrill noted that such efforts are complicated by the volume of legacy equipment. Nonetheless, the matter is being pursued with manufacturers of new equipment.

Gov. Geringer said he was present for several First Responder events. Even though those involved knew it was a jamming exercise, their common first response was to contact their Information Technology (IT) representatives on whether the issue was with the equipment. This shows they are not sensitized to the possibility that perhaps it is not their equipment that is at fault. Manufacturers should be offering built-in awareness of equipment failure.

Dr. Merrill said he hopes under the Small Business Innovation Research (SBIR) program, a device could be developed to indicate if a receiver is in a potential jamming environment.

Mr. Faga asked what mitigation steps are available to users.

Dr. Merrill said there were some very inventive participants – for example, some put up a mylar shield to block interference.

Mr. Goward noted that DHS has just released its cyber-security policy statement. In the document, he did not see any mention of PNT or GPS. Are they going to be included in the cyber strategy?

Mr. Merrill said PNT was not part of this exercise. A two-pronged approach was taken. First, the application side; second, an end-to-end approach to see where system protections need to be injected. The latter is a difficult challenge, in part because end-to-end cybersecurity is quite expensive. He does not anticipate resolution within the next year or two.

Mr. McGurn said a list of prohibitions regarding jammers should put "owning, having or possessing" at the top. Why is this not being done?

Mr. Goward said the FCC position is that, under the Communications Act of 1934 (as amended), just because a transmitter can broadcast on a protected frequency, is not a reason for it to be declared illegal. The problem is that not enough negative events have occurred for the FCC to reconsider its position concerning purpose-built jammers and spoofers.

Dr. Parkinson said the problem stems from indifference. Certainly, devices specifically manufactured as jammers could be readily singled out as illegal.

Mr. Goward said the PNT Resilience Foundation has long advocated steps to make possession of jammers illegal. Further, state and local law officials should be empowered and enabled to enforce this restriction.

Dr. Parkinson said he hoped that DHS would advocate to Congress that mere possession of anything specifically designed to be a jammer is illegal.

Mr. Merrill said that as jammers became more prevalent, his goal is to work with the FCC to see that the law is changed.

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Representatives / International Reports & Perspectives

(Top Items – 10 minutes or less, at member's discretion)

1) Interface Requirements for SAE-Compliant GPS Receivers
Dr. James L. Farrell, *VIGIL, Inc.*
(Special Topic Speaker)

New interface requirements are being developed for SAE-compliant receivers. Compared to only three years ago, the effect of having access to specific satellite measurements is profound. There are new capabilities in using GPS to measure velocity and horizontal direction that are clearly worth exploiting. However, the opportunity for major improvement has been delayed by the influence of ingrained habits which have held things back for decades. Stunning advances have been achieved in receivers, hardware, software and other areas. The weak link is the

manner integration is undertaken. Economy and flexibility are prerequisites for industry to adopt a new approach. Mr. William Woodward, Chair, SAE International Aerospace Avionics Systems Division, is assisting Dr. Farrell in creating the new requirements. SAE is extendable beyond in-air applications to include aircraft on the ground, maritime operation, UAVs, driverless vehicles and others.

Dr. Parkinson noted that while the topic may sound esoteric, an enormous improvement is available in fact.

2) Sustained Open GNSS Markets
Ms. Ann Ciganer
GPS Innovation Alliance

Ms. Ann Ciganer said she would address potential barriers to sustaining open GNSS markets in the EU. At present it appears progress is being made, but there are a number of potential issues: (1) Lack of timely access to Galileo service offerings/markets; and (2) EC RED implementation of the EU Radio Equipment Directive (RED).

Regarding access to Galileo service offering(s): ICDs are not yet public that provide technical specifications to build GNSS products with this Galileo service offering capability in order to address the European market. Also, regarding EU Radio Equipment Directive (RED), the 'popular' RED GNSS receiver standard, EN 303 413, was cited in the Official Journal of the European Union (OJEU) in December 2017. This means that a manufacturer can place GNSS products on the European market with self-declared conformity with the EN 303 413 harmonized standard for presumption of conformity with RED Article 3.2 essential requirements (on spectrum use): radio equipment shall be so constructed as to both effectively use and support the efficient use of radio spectrum for the avoidance of harmful interference. When the EC Unit COM/3 RED Desk Officer reviewed this Red GNSS receiver standard last year, he used an ETSI technical guide (EG 203 336) that did not include the technical parameters for Radiodetermination, a Category newly explicit in RED. He said he would cite it in the OJEU provided that the ETSI Technical Committee (SES SCN) that developed EN 303 413 agreed to open a new work item to revise it to include "classical" radiocommunication receiver parameters applied to GNSS radionavigation receivers. This is cause for concern because if the Desk Officer insists that radionavigation parameters be altered, then it amounts to a unilateral reinterpretation of an internationally developed and adopted standard (1 dB decrease in C/No IPC). This will lead to increased spectrum interference.

Ms. Ciganer said she will urge Working Group B to seek the timely release of technical information on Galileo service offerings. As a further concern, European industry, participating in European GNSS Agency Galileo projects, has access to unpublished Galileo technical information to build product for the European Galileo markets. If Galileo holds to its announced launch schedule, it could declare full service by 2020-2021.

A clear understanding is required of the difference between radionavigation and radiocommunications. She will further urge Working Group B to seek coordination within the European Commission (EC) Directorate-General GROW, where the Galileo GNSS program is located, to facilitate understanding of the distinction between the two and to seek agreement on sustaining EN 303 413 cited in the OJEU (12/2017) for presumption of Radiodetermination/GNSS receiver conformity with RED 3.2.

Dr. Parkinson said he believes a ruling will be made that fails to provide specifications and introduces a receiver performance standard that fetters innovation.

Dr. Kurt Zimmerman said this is the case. In his view this is tied to Working Group B and urges that body to seek coordination within the EC on the specifics in the Radio Equipment Directive and how application of a template (e.g.,EG 203 336) would include Radiodetermination/radionavigation receiver parameters appropriate to GNSS receivers.

Dr. Parkinson asked what role the Advisory Board can play in this.

Ms. Ciganer said the Departments of State and Commerce are playing the lead role. She hopes that Working Group B will hold more meetings to address these concerns.

Dr. Parkinson asked Ms. Ciganer to draft a statement of support for the Advisory Board to consider.

Dr. Axelrad asked if FCC approval of Galileo signal use would be of assistance.

Dr. Parkinson said this means, in effect, that there is a quid pro quo involved. This calls for a response from the Department of State.

3) Protect, Toughen, Augment Initiatives

Mr. Dana Goward
Resilient Navigation & Timing Foundation

While the U.S. is committed to maintaining GPS as the "Gold Standard" of world GNSS, Russia may be committed to the opposite. It appears Russia may have initiated aggressive actions beyond its borders, including active disruption in Norway and in the Baltic Sea, specifically directed against GPS. Also, currently the most aggressive jamming environment is in the Eastern Mediterranean. This is difficult to overlook. Since 2015 multiple Russian press outlets have stated that 25,000 Russian cell towers would include GPS jammers to thwart potential U.S. cruise missiles. There are four possible Russian goals for this behavior:

- Frustrate Western military and peacekeeping operations
- Protect high-value assets from drones
- Encourage adoption and use of GLONASS instead of GPS
- Intimidate neighboring nations to cause them to question their relationship with, and reliance upon, the U.S. and U.S. technology

What might be done about this? A February 2018 statement from the National Space Council (NSpC) panel noted the "need for a holistic approach to space security with ground systems like eLoran." The PNT Advisory Board in its June 2017 meeting heard the statement that "GPS and encrypted high power eLoran time signal is bullet proof." Multiple U.S. government studies have concluded that "eLoran is the only practical augmentation." In his view, if the U.S. and other nations focus more strongly on a resilience architecture, including many sources of PNT, the combination would be virtually impossible to interrupt, provide more credibility to the U.S. and further U.S. goals.

4) Signal-in-Space Error Assessment based on the International GNSS Service (IGS) Multi-GNSS Experiment (MGEX)

Dr. Gerhard Beutler
International Association of Geodesy

Dr. Gerhard Beutler said he would address four items: assessment of the signal in space range error (SISRE); status of multi-GNSS; the Gravity Recovery and Climate Experiment Follow-On (GRACE FO) mission for launch on May 22, 2018; and a tribute to Ms. Ruth Neilan who just retired.

The substance of the first item is covered in the report, "Multi-GNSS Signal-in-Space Range Error Assessment – Methodology and Results," published in *Advances in Space Research* and available online.

The SISRE assessments for GPS, GLONASS, BeiDou, and Galileo are as follows: (1) for GPS, the error is about one-half meter; (2) the margin of error for GLONASS is about four times that of GPS; (3) Galileo has fairly good performance and only made a small contribution to the clock error. Based on 2017 monthly assessments of global averages, the signal in space ranging errors was 20 cm for Galileo (compared to 60 cm for GPS); and (4) one meter for BeiDou and 2 meters for GLONASS.

Regarding Multi-GNSS status, in May 2018, there were 81 satellites in orbit, soon to be raised to 84 by upcoming Galileo launches. All of these satellites are analyzed at the Center for Orbit Determination in Europe (CODE).

GRACE FO is the successor of the GRACE mission and will measure earth gravity over a decade.

Finally, Dr. Beutler said he wished to pay tribute to Ms. Ruth Neilan, who recently stepped down from the directorship of the IGS Central Bureau and as a member of the Advisory Board. Ms. Neilan served as director of the IGS Central Bureau since 1993. The international representatives and members of the science subcommittee of the PNTAB are most grateful to Ruth for a very long, fruitful cooperation and for her vision and friendship.

Dr. Parkinson noted that the Advisory Board will draft a letter of appreciation to be presented to Ms. Neilan in recognition of her contributions.

Dr. Beutler urged that the letter be presented at the December 2018 PNTAB meeting in Redondo Beach, CA, which is not far from Ms. Neilan's residence.

5) Possible Arctic Space-Based Augmentation Systems (SBAS) Coverage by Using High-Elliptic Orbit Satellites
Mr. Arve Dimmen
Norwegian Coastal Authority

Activity, including ship traffic, is increasing at high latitudes. To increase the communications capability in this region, "Space Norway" plans to launch two satellites to provide space-related support of national needs. The satellites will be put in a High Elliptical Orbit (HEO) with a 63.4° degree inclination and should be operational by 2022. There is now a short window where it could be possible to add navigational payloads to the satellites, subjects currently under discussion. This option could potentially make Space Based Augmentation Systems (SBAS) available at the higher latitudes. The satellites will provide service to maritime users from 70°N, and aviation users from 55°N.

6) Update on GNSS activities in Australia
Mr. Matt Higgins, Manager
Department of Natural Resources, Mines and Energy

Mr. Matt Higgins said he would address the National Positioning Infrastructure and the Australian Space Agency. Last week the Australian government issued its annual budget which allocates $170 million over four years, along with $30 million to support the Australian space industry. In the past, it was difficult to fund an SBAS based solely on aviation needs so benefits to other activities were included to help the business case." Regarding the space industry, funds have been allocated, again over four years, to establish a national space agency and coordinate domestic activities. The funding for industry will take the form of a program that makes grants for space-related activities that create employment opportunities for Australians.

Dr. Parkinson commended the action of the Australian government as foresighted.

7) Update on GNSS Issues at the United Nations
Dr. Sergio Camacho-Lara
U.N. Regional Centre for Space Science and Technology Education

Dr. Sergio Camacho-Lara said his foremost message is that the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) continues to move forward on issues related to the protection of the GNSS spectrum. The major current focus is statements under a regular agenda item on GNSS made by ten countries on the use of GNSS and reports of Interference Detection and Mitigation actions taken in defense of the spectrum. One important thing that came out of the Scientific and Technical Subcommittee is that international cooperation exists as reflected in what was said by member States or organizations. For example, China is considering joining and contributing to the International Satellite System for Search and Rescue (COSPAS-SARSAT) system that has been using upgraded GPS, GLONASS and Galileo satellites and the Russian Federation aimed at making GLONASS an essential element of the international GNSS infrastructure.

While it has not yet been included in its agenda, the report of the International Committee on GNSS (ICG) has stated that when one looks at SSV, it is only through the contributions of the four GNSS systems that it becomes possible to provide PNT services to satellites in the geostationary orbit and reliable internet connectivity beyond that orbit.

Regarding spectrum protection and IDM, the number of countries reporting has risen in one year from two to ten: China, Egypt, India, Indonesia, Japan, Pakistan, South Korea, Russia, Spain and the United States. The Scientific and Technical Committee continues to emphasize the need to ensure continuous reception of GNSS signals.

Dr. Camacho-Lara also presented a map of the "Belt and Road Spatial Corridor," which intends to synergize economic and social development across 65 nations and will be provided with PNT services by China´s BeiDou-3 system.

Dr. Parkinson suggested that, relative to the concern expressed by Ms. Ciganer, there may be a route through the ICG back to the governments involved.

Ms. Ciganer commented that her group will work with Dr. Camacho-Lara. She called attention to the statement about receiver sensitivity, suggesting this might be a point of focus.

Dr. Camacho said he would endeavor to assist.

8) Mideast Regional GNSS Updates
Dr. Refaat Rashad
Arab Institute of Navigation

Dr. Refaat Rashad noted completion of the Beyond Project to heighten the use of the European Geostationary Navigation Overlay Service (EGNOS) and Galileo, particularly in Eastern Europe and the Mediterranean. Beyond is a subproject of a $2 billion undertaking known as Horizon. The overall purpose of Horizon is to build capacity and promote development of multi-model applications, especially for aviation. Its major purpose is to stimulate related investments outside the EU and support networking with EU border countries by creating the basis for future business opportunities. The project partners include France, Spain, Italy, U.K., Montenegro, Hungary, Kosovo, Turkey, Egypt, Israel and Morocco.

Dr. Rashad then reported on the MEDA project. It began in 2009 with agreements between the EU and four Mediterranean countries to build EGNOS Ranging & Integrity Monitoring Stations (RIMS). Two of these were built in Egypt.

Furthermore, China has opened in Tunisia the first overseas center for the BeiDou navigation system. The intention is to expand BeiDou services in the region. Since 2014, there has been regular contact been China and Arab nations, such as Saudi Arabia, Egypt, Tunisia and Algeria to promote joint research and development. A second Chinese BeiDou Center for Excellence is scheduled to open October 2018 in Egypt. Morocco will also be opening a GNSS training center.

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Advisory Board Discussion

All Members

Dr. Parkinson noted that since the previous day, efforts have been made to find quotes in various documents on the issue of adjacent band compatibility. He asked Mr. Miller to present a plan on how to proceed.

Mr. Miller said it is his understanding that various Advisory Board members have worked on issues during the Tuesday prep day. He does not believe the issue has been resolved. Also, regarding the Topic Paper, work remains to be done by each subgroup. He suggested posting the draft Topic Paper, with the expectation that a WebEx conference on the subject will be held prior to the Advisory Board's scheduled December 2018 session.

Dr. Parkinson agreed with this approach.

Gov. Geringer called attention to the statements in the public domain from a recent Op Ed article on Ligado (see Appendix E: Briefing by Gov. Geringer). These statements are, in his view, misleading:

1. The Op-Ed claims it is a "complete fallacy" that Ligado would harm GPS. In response, the Advisory Board has gathered reports to refute this claim, including extensive work done by the DOT assessment that clearly shows non-compliance with internationally accepted standards. These reports also clearly show that General Aviation receivers are impacted at considerable distance and the most harmful effects are on high precision receivers which, in turn, happen to make the greatest economic contribution.
2. Another claim is that "five of the large GPS manufacturers have said they are not opposed to Ligado's spectrum proposal." In fact, four of the five equipment manufacturers said that while they would not publicly oppose the proposal, they still support the 1 dB noise floor standard (which Ligado does not meet), while the fifth manufacturer declined to take a public position. In fact, Garmin has stated that Ligado "should not come at the expense or harm to the nation's well-functioning and economically important existing GPS system."
3. It has also been claimed that testing done by the National Advanced Spectrum and Communications Test Network (NASTCN) was "developed by the nation's top scientists and engineers." However, such individuals are yet to be publicly identified; indeed, the nation's top scientists and engineers are members of the Advisory Board. The Advisory Board put forth 14 recommendations related to the NASTCN testing, but NASTCN declined to respond to these recommendations by dismissing them as outside the scope of their obligation. Such scope is, in fact, determined by Ligado, who funded those tests, and the success criteria was also set by Ligado. For example, NASTCN did not test critical modes of operation, nor did they test wideband GPS.
4. Another claim is that "Ligado is not planning to become a national telecommunications provider with 40,000 towers…" In fact, Ligado has not provided a business plan to the Advisory Board, so the board does not have a basis knowing what Ligado's plans are, or what their overall impact will be.

5. The Op Ed stated that the Advisory Board has "ignored volumes of data and thousands of hours of testing." However, if one conducts 2,000 hours of testing that should have taken 83 days even if operating 24/7. The board is not aware of any such thing having occurred.
6. Finally, Ligado's purported coordination with industry has been only with manufacturers; none with industry or representatives of the billions of users in the GPS community.

In summary, Gov. Geringer said he is at a loss to explain how anyone could have come up with such generalized statements in the Op-Ed.

Dr. Parkinson queried the Advisory Board as to whether there is broad consensus that the statement made by Gov. Geringer was fair? Does anyone feel the matter is being overstated? Dr. Parkinson noted there appears to be a unanimous view among the non-recused members that Gov. Geringer's statement should stand. He added that if any Advisory Board member should find themselves interacting with Congress, the statement would prove useful.

Dr. Parkinson then turned to the subject of planning. He noted that the Advisory Board should start holding occasional WebEx meetings between its regularly scheduled sessions. A published agenda will be needed for such meetings.

Dr. Parkinson noted, regarding other items on the agenda, that:

- First, there is a need to close out work on the Topic Paper. A decision is needed on how to approach the issue of eLoran. The Advisory Board unanimously supported eLoran in the past, but this may no longer be the case. This has been a sticking point in trying to get the Topic Paper out. He suggested drafting two statements and at the WebEx meeting make a decision. There is no provision for the Advisory Board to submit a minority report, but there is an allowance to include alternative wording to express disagreement.
- Second, there is the issue of the Advisory Board's attempts to get a letter to the EXCOM with its recommendations on Ligado. There is a need to have a formal discussion on what the letter will say and that discussion needs to be part of an agenda item that has been published. The most recent letter from the Advisory Board was good, but ended up not being submitted. In his view, the PNT EXCOM representatives, while highly intelligent, are not necessarily well informed on matters pertaining to GPS.

Dr. Parkinson noted that the proposed WebEx meeting should be scheduled in the relative near future, perhaps in one or two months.

Dr. Camacho-Lara noted that, regarding the Topic Paper, draft text for the issues discussed on the prep day should be given to Mr. Miller for distribution to the Advisory Board members and ensure general consent.

Dr. Parkinson endorsed this approach. He added that he hopes to focus the WebEx on substantive rather than grammatical issues.

Mr. Miller said he will see that the appropriate Federal Register Notice (FRN) be sent out.

Mr. Goward said that if members have original text, or suggested text, it would make it easier for others to review and modify.

Mr. Miller suggested to attempt completing as much work as possible by email before the WebEx meeting.

Dr. Parkinson asked which Advisory Board members wish to serve on the cyber-security task force. The following board members expressed interest: Mr. Goward, Mr. Shields, Capt Murphy, Mr. Marquez, Mr. Higgins and Mr. Burns.

Mr. Miller concluded by thanking the meeting support staff for its efforts.

Dr. Parkinson adjourned the 21st session of the National Space-Based PNT Advisory Board at 11:48 a.m.

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Appendix A: PNT Advisory Board Membership

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

Special Government Employees

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

- **John Stenbit** (Chair), former Assistant Secretary of Defense
- **Bradford Parkinson** (Vice Chair), Stanford University
- **James E. Geringer** (Second Vice Chair), Environmental Systems Research Institute (ESRI), former Governor of Wyoming
- **Thad Allen**, Booz Allen Hamilton
- **Penina Axelrad**, University of Colorado Boulder
- **John Betz**, MITRE
- **Dean Brenner**, Qualcomm
- **Scott Burgett**, Garmin International
- **Joseph D. Burns**, Sensurion Aerospace
- **Martin C. Faga**, private consultant (retired MITRE)
- **Ronald R. Hatch**, private consultant (retired John Deere)
- **Larry James**, Jet Propulsion Laboratory
- **Peter Marquez**, Andart Global
- **Terence J. McGurn**, private consultant (retired CIA)
- **Timothy A. Murphy**, The Boeing Company
- **T. Russell Shields**, Ygomi

Representatives

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 (U.S.)
- **Arve Dimmen**, Norwegian Coastal Administration (Norway)
- **Dana Goward**, Resilient Navigation and Timing Foundation (U.S.)
- **Matt Higgins**, International GNSS Society (Australia)
- **Refaat M. Rashad**, Arab Institute of Navigation (Egypt)

Executive Director

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

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

Special Counselors

- **Mr. Kirk Lewis**, Institute for Defense Analyses (IDA)
- **Dr. Tom Powell**, The Aerospace Corporation

Appendix B: List of Presentations

Presentations are available at: https://www.gps.gov/governance/advisory/meetings/2018-05/

1. National Coordination Office Perspective / Mr. Harold Martin
2. GPS Program Status & Modernization Milestones / Lt Col Andy Menschner
3. U.S. Department of Transportation (DOT) Update / Ms. Karen Van Dyke
4. Federal Aviation Administration (FAA) Update / Ms. Deborah Lawrence
5. Connectivity Connected Aviation: Enabling Innovations in the Internet of Things – That Fly / Dr. Bruce Holmes
6. Annual Ethics Training for Special Government Employees (SGEs) / Mr. Adam F. Greenstone
7. U.S. Department of State (DOS) Update / Mr. Jeff Auerbach
8. United Kingdom (UK) Progress on Resilient PNT / Prof. David Last
9. Initial Findings from the STRIKE3 GNSS Interference Monitoring Network / Dr. Mark Dumville
10. Report from the Workshop on Time Receiver Resilience / Dr. Marc Weiss
11. Superior Beamforming GPS Anti-Jamming for Airborne Platforms / Dr. Alex Stratton
12. Current Operational Status of Low Earth Orbit (LEO) satellite-based Time & Location / Dr. Gregory Gutt
13. Feasibility of a Nationwide Fiber-Optic Sub-nanosecond Timing Infrastructure for Terrestrial PNT & GPS Back-Up / Dr. Jeroen Koelemeij
14. GPS Radio Occultation: The Real Forecast / Mr. Keith E. Johnson
15. Department of Homeland Security (DHS) Update / Mr. John Merrill
16. Interface Requirements for SAE-Compliant GPS Receivers / Dr. James L. Farrell
17. Sustaining Open GNSS Markets / Ms. Ann Ciganer
18. Protect, Toughen, Augment Initiatives / Mr. Dana Goward
19. Signal-in-Space Error Assessment based on the International GNSS Service (IGS) Multi-GNSS Experiment (MGEX) / Dr. Gerhard Beutler
20. Possible Arctic Space-based Augmentation System (SBAS) Coverage by Using High Elliptic Orbit Satellites / Mr. Arve Dimmen
21. Update on GNSS Activities in Australia / Mr. Matt Higgins
22. Update on GNSS Issues at the United Nations (U.N.) / Dr, Sergio Camacho-Lara
23. Middle East Regional GNSS Cooperation Updates / Dr. Refaat Rashad

Appendix C: Sign-in List

Wednesday, May 16, 2018

PNT Advisory Board Members

- Brad Parkinson, Stanford University
- Jim Geringer, ESRI
- Penina Axelrad, Colorado University
- Gerhard Beutler, IAG
- Sergio Camacho-Lara, CRECTEALC
- Ann Ciganer, Trimble/GPSIA
- Arve Dimmen, Norwegian Coastal Authority
- Martin Faga, MITRE
- Ron Hatch, Deere [retired]
- Matt Higgins, IGNSS
- Russ Shields, Ygomi

NASA Personnel

- Barbara Adde, NASA
- Frank Bauer, NASA
- Catherine Barclay, NASA
- Don Cornwell, NASA
- Jennifer Donaldson, NASA
- Jimmy Durden, NASA
- Paul Kim, NASA
- William Notley, NASA
- A. J. Oria, NASA/Overlook

Other Attendees

- Ken Alexander, National Coordination Office
- Ryan Arbuckle, Department of Transportation
- Jeff Auerbach, Department of State
- Jean-Luc Bald, EU Delegation
- Elliott Baskerville, Department of Transportation
- Davis Besson, U.S. Air Force
- Laila El Bahej
- Edith Bradley, NOAA/NOS/NGS
- Guy Buesnel, Spirent
- Jim Burton, National Coordination Office
- Kevin Collins, Booz Allen
- Ben Corbin, STPI

Robert Crane, National Coordination Office

DeeAnn Davis, *Inside GNSS*

Jim Doherty, IDA

Mark Dumville, NSL

Neil Ferguson, Harris

John Fischer, Orolia

Richard Foster, Microsemi

Valerie Green, Ligado

Rick Hamilton, U.S. Coast Guard

John Hardin, NIST

Russ Holmes, U.S. Coast Guard

Keith John, Spire

Monty Johnson, OPNT

Matt Jones, Boeing

Therese Jones, SIA

Jason Kim, National Coordination Office

David Kunkee, Aerospace

David Last, UK GLA

Deborah Lawrence, FAA

Rich Lee, Iposi

David Lubar, Aerospace for GOES-R

Stephen Malys, NGA

Andy Menschner, U.S. Air Force

Chris Mindnich, National Coordination Office

Luis Munoz, U.S. Air Force

Richard Nordberg, Century Link

Ted Okade, FEMA

Ciaran O'Malley, DHS

Richard Popp, COGO

Ed Powers, U.S. Naval Observatory

Ben Reed, OSTP

Carlos Rodriquez, FAA

Joe Rolli, Harris

Mike Rosso, Continental

Mark Settle, WBK

Nancy Smith, Harris

Alex Stratton, Rockwell Collins

Doug Taggart, Overlook

Karen Van Dyke, Department of Transportation

Frank van Graas, Ohio University

Marc Weiss, Spirent

Greg Wolff,

Kurt Zimmerman, Trimble

Thursday, May 17, 2018

PNT Advisory Board Members

Penina Axelrad, Colorado University/Boulder

Gerhard Beutler, AUIB

Betz, PNTAB

Peter Marquez

Terry McGurn

NASA Personnel

Paul Kim, NASA

A. J. Oria, NASA/Overlook

Other Attendees

Ken Alexander, National Coordination Office

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Jim Burton, National Coordination Office

Guy Buesnel, Spirent

Mark Dumville, NSL

Neil Ferguson, Harris

Rick Hamilton, U.S. Coast Guard

Russell Holmes, U.S. Coast Guard

David Kunkee, Aerospace

Deborah Lawrence, FAA

David Lubar, Aerospace for GOES-R

Stephen Malys, NGA

Andy Menschner, U.S. Air Force

John Merrill, DHS

Luis Munoz, U.S. Air Force

Ciaran O'Malley, DHS

James Platt, DHS

Joe Rolli, Harris

Appendix D: Acronyms & Definitions

$	U.S. Dollar Currency
4G	4th Generation Mobile Communications Standard
5G	5th Generation Mobile Communications Standard
ABC	DOT GPS Adjacent Band Compatibility Study
ADS-B	Automatic Dependent Surveillance-Broadcast
AFSPC	Air Force Space Command
AIAA	American Institute of Aeronautics and Astronautics
AIS	Automated Identification Systems
AMS	Acquisition Management System
ANSP	Air Navigation Service Provider
APNT	Advanced Position, Navigation, and Timing
ARAIM	Advanced Receiver Autonomous Integrity Monitoring
BeiDou	China's GNSS
Cat 1	Category 1
Cat 2	Category 2
Cat 3	Category 3
CDMA	Code Division Multiple Access
Chirp	A signal in which the frequency increases (up-chirp) or decreases (down-chirp) with time
cm	centimeter
CNI	Critical National Infrastructure (UK)
CODE	Center for Orbit Determination in Europe
COPUOS	UN Committee on the Peaceful Uses of Outer Space
CRECTEALC	Regional Center for Space Science and Technology Education for Latin America and Caribbean, affiliated to the United Nations
COps	GPS Contingency Operations
COPUOS	UN Committee on the Peaceful Uses of Outer Space
dB	decibel
DHS	Department of Homeland Security
DME	Distance Measuring Equipment
DoD	Department of Defense
DOT	Department of Transportation
EC	European Commission
EFVS	Enhance Flight Vision Systems
EGNOS	European Geostationary Navigation Overlay Service
eLoran	Enhanced Loran
EU	European Union
ERTL	GPS Enterprise Road to Launch

ETSI	European Telecommunications Standards Institute
EXCOM	Executive Committee
FAA	Federal Aviation Administration
FACA	Federal Advisory Committee Act
FCC	Federal Communications Commission
FOC	Full Operational Capability
FRN	Federal Register Notice
Galileo	European GNSS
GBAS	Ground Based Augmentation System
GEO	Geosynchronous Equatorial Orbit
GLONASS	Russian GNSS
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPS-D	GPS Directorate
GPS III	GPS Block III SVs 1-10
GPS IIIF	GPS Block III SVs 11-32
GPS Week Rollover	To limit the size of the numbers used in the data and calculations the GPS Week Number is a ten-bit count in the range 0-1023, repeating every 1024 weeks. There are potential issues with some GPS-based equipment or software that could be confused by the rollover event, which is akin to Y2K issue. The next rollover will occur at 0000 GPS Time on April 7, 2019, when the GPS week number broadcast by satellites will change from '1023' to '0'. It is the responsibility of the user (i.e., user equipment or software) to account for the previous 1024 weeks.
GPSIA	U.S. GPS Innovation Alliance
GRACE FO	Gravity Recovery and Climate Experiment Follow-On mission
Hz	Hertz
ICAO	International Civil Aviation Organization
ICG	International Committee on GNSS
IDM	Interference Detection and Mitigation
IGMA	International GNSS Monitoring and Assessment
IGS	International GNSS Service
ILS	Instrument Landing System
IOC	Initial Operating Capability
ION	Institute of Navigation
IP	Internet Protocol
IPC	Interference Protection Criteria
ITAR	U.S. International Traffic in Arms Regulations
IT	Information Technology
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)
LEO	Low Earth Orbit
Ligado	Ligado Networks is an American satellite communications company developing a satellite-terrestrial network to support 5th Generation (5G) and IoT applications in North America.
Loran	Long-Range Aid to Navigation (typical refers to the system up through Loran-C, now decommissioned in the U.S)
LPV	Localizer-performance with vertical guidance
M-Code	GPS encrypted signal
MEO	Medium Earth Orbit
MGEX	Multi-GNSS Experiment
MHz	Megahertz
MON	Minimum Operational Network
MOPS	FAA Minimum Operational Performance Standards
NASCTN	National Advanced Spectrum and Communications Test Network
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NavAids	Navigation Aids
NCO	National Coordination Office (located at the Department of Commerce in Washington, D.C.)
NDB	Nondirectional Beacon
NDGPS	Nationwide Differential GPS
NESS	NAS Efficient, Streamlined Services
NextGen	Next Generation Air Transportation System
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NSpC	National Space Council
NTIA	National Telecommunications and Information Administration
OCS	GPS Operational Control Segment
ODM	On-Demand Mobility
OJEU	Official Journal of the European Union
OCX	Modernized GPS Operational Control System
P(Y)	GPS encrypted signal
PACE	Primary, Alternate, Contingency, Emergency
PBN	Performance Based Navigation
PNT	Positioning, Navigation, and Timing
PNTAB	National Space-Based PNT Advisory Board
PTA	Protect, Toughen, and Augment
PTC	Positive Train Control
RF	Radio Frequency
RNSS	Radio Navigation Satellite Service

RTCA	Formerly known as Radio Technical Commission for Aeronautics, now RTCA, Inc.
RO	Radio Occultation
SBAS	Satellite-Based Augmentation System
SBIR	Small Business Innovation Research
SISRE	Signal in Space Range Error
SMC	Space & Missile Systems Center
SSV	Space Service Volume
SV	GPS satellite vehicle
TACAN	Tactical Air Navigation System
TDM	Time Division Multiplexing
TEC	Total Electron Count
U.S.	United States
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
UN	United Nations
U.S.	United States of America
USAF	U.S. Air Force
USB	Universal Serial Bus
USGC	U.S. Coast Guard
UTC	Universal Time Coordinated
VOR	Very-High Frequency Omnidirectional Receiver
WAAS	FAA Wide Area Augmentation System

Appendix E: Briefing by Gov. Geringer

Major Myths in recent Op Ed that are in the public domain

Claim: "… the suggestion that Ligado's proposal would harm GPS is a complete fallacy."

- Validated Dept. of Transportation Interference tests clearly show violation of International Standard at Power Levels less than .0.1% of the latest Ligado Proposal of 20 watts
- Most affected are the High Precision receivers that deliver over 30B$ in productivity etc.
- Concern over safety and security:
  - General Aviation receivers (e.g., UAS) impacted at significant distances according to DOT ABC Assessment;
  - Current proposal exceeds certified aviation standard

"Five of the largest GPS manufacturers have said they are not opposed to Ligado's spectrum proposal."

- Settlement agreements for 3 of the 5 –not blanket approvals
- Manufacturers conditioned their support not-opposed, and for Trimble, with proviso that the DOT testing would inform base station transmit power levels
- Filings by Garmin and Deere clarified the bounds of what was covered ion their agreements.
- 4 of the 5 support the 1 dB standard, with TopCon neither supporting or opposing the 1 dB standard.

"Garmin stated it 'doesn't anticipate any performance-degradation issues.' "

- But reserved its position and ability to comment on certified aviation receivers;
- Strongly supportive of the 1 dB IPC;
- Ex Parte filing indicated that, consistent with agreement between Ligado and Garmin, Garmin's agreement with Ligado did not constitute an endorsement of the Ligado proposal.

> Garmin has long supported the domestic development of new broadband service; it believes, however, that broadband development generally should not come at the expense or harm to the nation's well-functioning, innovative, and economically important Global Positioning Service ("GPS");
>
> Ex Parte[illegible]

"This testing [NASTCN} was developed and executed by our nation's top scientists and engineers and shows that GPS devices of all kinds can co-exist with Ligado's services"

- PNTAB reviewed and made 14 recommendations to the NASCTN test plan, many of which were dismissed as outside the scope of the Cooperative Research and Development Agreement (CRADA), which has never been made publicly available
- Did not test critical modes of operation
- Did not test latest wide-band GPS signals
- Was an effort to develop a methodology and specifically NOT a test for compatibility.

"Ligado is not planning to become a national telecommunications provider with 40,000 towers. Instead, the company has asked the FCC to use the spectrum for new, targeted networks that will help America's industrial sector take advantage of 5G and the "internet of things" —"

- Relevant signals interfere with Safety and Security
- IOT needs GPS
- Basic underlying license request still has a maximum EIRP of 32 dBW
- Statements at the PNTAB meeting in Nov 2017- Ligado still remains less than clear about its business plans and network laydown.

"Ignored volumes of data and thousands of hours of testing collected and analyzed in 2016 at government labs in Colorado"

- Testing was done under a CRADA that has not been made public and using a process that was not fully transparent;
- Ignored most of the PNTAB recommendations;
- Found by the NPEF Gap Analysis to not meet the majority of criteria as specified by the PNTAB and subsequently endorsed by the PNT EXCOM via the NPEF tasking.

They have dramatically reduced operating power levels, relinquished spectrum to create a wide guard band for GPS, and coordinated with the industry to show that these technologies can readily coexist.

- Reduced power levels still cause interference to majority of GPS receiver categories according to the DOT ABC Assessment;
- Upper 10 MHz of spectrum from 1545-1555 MHz relinquished in 2011 had already been tested during 2011-2012 timeframe...nothing new.
- Coordination with industry was primarily via GPS company agreements (not to oppose) and don't represent the whole of the GPS community.
- RTCA proposal for certified aviation did not achieve consensus and has not been agreed by FAA.