SPACE-BASED POSITIONING
NAVIGATION & TIMING

NATIONAL ADVISORY BOARD

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

Fifteenth Meeting

June 11-12, 2015

Annapolis Marriott Hotel

80 Compromise Street
Annapolis, Maryland 21401

Bradford Parkinson

Bradford W. Parkinson
Acting Chair

James J. Miller
Executive Director

SPACE-BASED POSITIONING NAVIGATION & TIMING

NATIONAL ADVISORY BOARD

National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board
Fifteenth Meeting Agenda
June 11-12, 2015

Annapolis Marriott Hotel, Ballroom North/Center
80 Compromise Street, Annapolis, MD 21401

Thursday, June 11, 2015

10:00 – 10:05	**BOARD CONVENES** *Call to Order & Announcements*	Mr. James J. Miller, *PNT Advisory Board Executive Director, NASA Headquarters*
10:05 – 10:45	Opening Remarks & Introductions *Welcome New Members, Board Overview & Criticality of GPS*	Dr. Bradford Parkinson *(1st Vice-Chair)* &Mr. Marty Faga (*PNT Board Steering Group*)
10:45 – 11:05	Role of the Department of Transportation (DOT) as PNT Executive Committee (EXCOM) Co-Chair: *Enabling & Preserving Critical National Equities*	The Honorable Gregory D. Winfree, *Assistant Secretary for Research and Technology, U.S. DOT*
11:05 – 11:25	National Coordination Office (NCO) Policy Update: *PNT EXCOM Interagency Priorities& Initial Taskings*	Mr. Harold "Stormy" Martin, *Director, National Coordination Office for Space-Based PNT*
11:25 – 12:05	Global Positioning System Modernization & Program Plan Update *Schedule & Funding for Satellites, Ground Segment & Services*	Colonel Steve Whitney, *GPS User Equipment, GPS Directorate, U.S. Air Force*
12:05–12:35	U.S. DOT Civil GPS/PNT Update: *Adjacent L-Band Compatibility & Complementary PNT (CPNT) Studies*	Ms. Karen Van Dyke, *Director for PNT, DOT Office of the Secretary, Research and Technology*
12:35 – 1:00	Collaboration & Use of Global Navigation Satellite System Services – *Bilaterals &United Nations International Committee on GNSS (ICG)*	Mr. Ray Clore, *Senior Advisor, Office of Space & Advanced Technology, U.S. Department of State*
1:00 – 2:00	**LUNCH** – *Annual Ethics Training for Special Government Employees*	Mr. Adam Greenstone, *Designated Agency Ethics Official, Office of General Counsel, NASA*
2:00 – 2:30	International GNSS Service Multi-GNSS Experiment (IGS-MGEX): *Preparing for a Multi-GNSS World*	Dr. Oliver Montenbruck, *GNSS Technology & Nav., DLR German Space Operations Center*
2:30 – 3:00	Toughening Techniques for GPS Receiver Operations: *Navigation Message Authentication*	Dr. Todd Humphreys, *Assistant Professor, Aerospace Engineering, Univ. of Texas at Austin*
3:00 – 3:20	Automated/Autonomous Trucking: *Emerging Users -- Terrestrial*	Mr. Russell Shields, *PNT Board Member*
3:20 – 3:40	Unmanned Aerial Vehicles (UAV): *Emerging Users -- Aviation*	Captain Joe Burns, *PNT Board Member*
3:40 – 4:00	Enhanced 911 (E911) GNSS Geolocation: *Emerging Users -- Terrestrial*	Mr. Dean Brenner, *PNT Board Member*
4:15 – 4:45	GPS Space Service Volume (SSV): *Emerging Users -- Space*	Mr. Frank Bauer, *FBauer Aerospace Consulting*
4:45 – 5:10	Raw Data to Improve Accuracy, Integrity, & Availability of SatNav	Dr. James L. Farrell, *VIGIL, Inc.*
5:10 – 5:50	The Economic Value of GPS: *Preliminary Assessment*	Dr. Irving Leveson, *Founder, Leveson Consulting*
5:50 – 6:00	PNT Board Member Roundtable Observations & Recap	All PNT Board Members

Friday, June 12, 2015

10:00 – 10:05	**BOARD CONVENES** *Call to Order*	Mr. James J. Miller, *PNT Advisory Board Executive Director, NASA Headquarters*
10:05 – 10:15	Announcements & Agenda: *Quick Thoughts &Feedback from June 11Discussions*	Dr. Bradford Parkinson (*1st Vice-Chair),* Mr. Marty Faga (*PNT Board Steering Group*)
10:15 – 11:15	International PNT Board Member Regional Updates & Perspectives • Dr. Gerhard Beutler • Mr. Arve Dimmen • Mr. Matt Higgins • Dr. Refaat Rashad • Dr. Sergio Camacho-Lara	(*at members' discretion*) *Switzerland* *Norway* *Australia* *Egypt* *Mexico*
11:15 – 12:45	Roundtable Discussion: Recommendations for PNT EXCOM *Proposed Issues & Topics to work for 2015-2017 Charter Period*	All PNT Board Members

Potential Issue Areas for further PNT Board Consideration:

- GPS as Critical Infrastructure
- GPS Threat Assessment
- Pseudolite Licensing in Radio Navigation Satellite Service (RNSS) Bands
- GPS Jammer Proliferation
- Federal Communications Commission Licensing of non-U.S. GNSS Services
- Criteria for U.S. use of other GNSS systems
- GPS Back-Up – CPNT Options
- GPS vs. Inertial Platforms – Capabilities vs. Constraints
- "Toughening" Techniques for Commercial Receivers – Pros and Cons of imposing "Standards"
- Anti-Spoofing Authentication Codes
- Reducing Costs of GPS Acquisition and Operations
- Ensuring Backwards Compatibility / Do No Harm – L1 C/A, SSV
- GPS Economic Assessment (Phase II) – Loss of Service Impacts by Sector &International Benefits by Region
- Strategies for International Engagement – Reciprocal Effects

Working Group-1: Assured Availability	(*at members' discretion*)
• ***Protect*** the Clear and Truthful Reception 1.1 Spectrum Allocation Assurance (Spectrum Subgroup)	• Ms. Ann Ciganer & Mr. Ron Hatch
• ***Toughen*** Users' Receivers 1.2 All GNSS Signal Receivers (International Subgroup)	• Dr. John Betz & Dr. Per Enge
• ***Augment*** or Substitute PNT Sources 1.3 Non-GPS PNT (International Subgroup)	• Mr. Matt Higgins & Mr. Terry McGurn
Working Group-2: Economic Value of PNT 2.1 Spectrum Denial – Economic Impact (Spectrum Subgroup)	• Gov. Jim Geringer *(2nd Vice-Chair)*

12:45 – 1:00	Preparation &Next Steps for July/Aug.PNT EXCOM& Oct. 30-31, 2015 16th PNT Advisory Board in conjunction with 10th ICG Meeting in Boulder, CO	All PNT Board Members
1:00 – 2:00	**WORKING LUNCH**	
2:00	**ADJOURNMENT**	

Meeting Minutes: Mark Bernstein, ARSCMS

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The 15th Space-Based Positioning, Navigation & Timing Advisory Board meeting convened Thursday, May 25, 2015 at 10 a.m.

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

Mr. James J. Miller welcomed all present. The National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board has been meeting since 2007, and NASA Administrator Charles Bolden recently renewed the Charter for 2015-2017. The renewal brings in new tasks and new members. The board consists of subject matter experts including Special Government Employees (SGEs) and Representatives who are by statute required to collectively represent a fair balance of viewpoints and interests. This requirement has been met as board members are nominated by federal agencies represented on the PNT Executive Committee (EXCOM), reviewed by the PNT Executive Steering Group (ESG), and finally approved by the NASA Administrator. This is a Federal Advisory Committee Act, 1973 body and, therefore, conflicts of interest must be avoided. Therefore, discussions focus on high national policy questions rather than narrower matters that could pose such conflicts of interest. Should a board member feel there is a conflict of interest on any issue at hand, they must recuse themselves.

Mr. Miller welcomed a special guest, the Honorable Gregory D. Winfree, Assistant Secretary for Research and Technology, U.S. Department of Transportation (DOT). Mr. Winfree, along with Ms. Karen Van Dyke and others in his staff had been crucial to the operation of the Global Positioning System (GPS). Mr. Miller also welcomed Col Steve Whitney, a key member of the GPS leadership team within the U. S. Air Force.

All discussions are on the record. Presentations and formal meeting meetings are posted at: www.gps.gov (under: www.gps.gov/governance/advisory/meetings/2015-06/).

The main task of the 15th session is to develop work plans and preliminary recommendations for the next PNT EXCOM meeting (September 3, 2015).

Finally, it is not customary to take questions from the audience, however, members in the audience can approach board members during breaks.

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Opening Remarks and Introductions
Welcome New Members, Board Overview & Criticality of GPS
Dr. Bradford Parkinson, *1st Vice-Chair*
Mr. Martin Faga, *PNT Board Steering Group*

Dr. Parkinson noted the board's role is to oversee PNT, and improve GPS and its backups. There are two key aspects to the board: first, it reports to the EXCOM; second, it includes international experts, which is unusual for this type of board. The board is also fortunate in having strong support from the NASA Administrator. The Advisory Board's 16th meeting is scheduled for Boulder, Colorado, October 30-31, 2015. This session will immediately precede the 10th meeting of the International Committee on GNSS (ICG-10) thereby facilitating interactions between the two bodies.

Newly appointed board members include:

- Mr. John Stenbit as the board's new chair. Mr. Stenbit had been associated with the field of GPS since 1974, when he worked at TRW on a user-equipment proposal for GPS.
- Mr. Scott Burnett, Director of Global Navigation Satellite Systems (GNSS) for Garmin International.
- Mr. Dana Goward, Founder, President and Executive Director of the Resilient Navigation and Timing Foundation, a non-profit organization.
- Mr. Larry James, Deputy Director of the Jet Propulsion Laboratory and retired U.S. Air Force Lt General.
- Dr. Sergio Camacho-Lara, international member and Secretary General of the United Nations Center for Regional Education of Science and Space Technology for the Caribbean (CRECTEALC).

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Assured PNT Strengths and Synergies
Dr. Bradford Parkinson, *1st Vice-Chair*

There is no practical alternative to GPS capable of providing similar levels of accuracy. This may seem a bold statement, but it is supported by facts. Signals broadcast from space are weak and this has prompted some government officials to suggest GPS is inherently vulnerable and should be replaced with other technologies such as new inertial navigation systems for positioning and Chip-Scale Atomic Clocks for timing. The Advisory Board's actions to *protect* the signal, *toughen* receivers, and *augment* GPS is, in his view, a far better approach. The board has urged GPS to be declared a critical national infrastructure, and a national threat model established as a basis for assessment and response. Further, the Board has strongly opposed permitting commercial emitters, including pseudolites, to operate in GPS bandwidth. Finally, the board believes Enhanced Loran (eLoran) is needed as backup to GPS. In the near term, the board will continue studies on the economic benefit of GPS and anti-spoofing techniques, and participate in international fora related to GPS. Other tasks may emerge from the board's discussions these two days.

The combined use of inertial systems, wider spreading beam forming antennas, aircraft shading, and vector receivers can reduce the impact of a jammer to 1/60,000th. There are cost issues with this approach, and it would not make GPS impervious to jamming, but it would greatly raise system resistance.

Inertial navigation systems are invulnerable to jamming, but there are also important limitations. If one doubles integrated vector acceleration, one has a three dimensional vector position. Therefore, in principle, a perfect "accelerometer" provides perfect position. However, this requires users know the initial position and velocity. The current position cannot be known better than the initial position, and the error increases with time if the initial velocity is not known. An accelerometer measures force minus gravity (which is assumed to point 'down'), but since Earth is not a perfect sphere gravity is not a constant nor is 'down' always pointing directly towards Earth's center. Therefore, even a "perfect" accelerator would be influenced by the inexact knowledge of local gravity. In consequence, traditional inertial navigation systems have a horizontal inaccuracy that can grow by 200 meters over one hour. High performance inertial navigation systems can reduce the error growth to approximately 20 meters over one hour. In either case the overall performance is not anywhere near what is provided by GPS. Newer inertial technologies currently under development are unlikely to mature for at least 20 years.

Enhanced Loran provides two-dimensional horizontal positioning (it cannot provide vertical positioning) generally with 10-meter accuracy. The signal is powerful and difficult to jam. Because transmissions are synchronized, one can listen to any combination of transmitters. This provides something that looks like a GPS ranging equation. The difficulty is that because eLoran uses a low frequency signal it is subject to delay. The atmosphere can delay the entire wave front and, depending on terrain conductivity, there is also a lag near the surface. As a consequence of variables in the basic eLoran equation, when operating over land there can be substantial variability over a 100 km range. Over mountainous terrain, eLoran beyond a 60 km range produces "wiggles." Various studies have shown an eLoran error rate of 10 to 90 meters per mile traveled by the signal. In consequence, for example, ships entering the River Thames' estuary must make adjustments of up to 550 meters. However, GPS and eLoran can be combined so that direct measurement is made of the correction. With such GPS correction, the net effect of all eLoran variables can, in theory, be reduced to zero. In summary, eLoran offers "good news', 'less good news', and 'good news': (1) differential techniques can improve accuracy to 20 meters or better; (2) corrections are typically useful only in small areas, such as harbors; and (3) when used in combination with GPS it can "flywheel" through brief GPS outages.

When GPS is 'toughened' it remains unmatched. There are costs to 'toughening' GPS, but they are dropping significantly some of these alternatives.

> Mr. Faga asked if Dr. Parkinson will be presenting this information to high-ranking government officials.
>
> Dr. Parkinson replied that he was going to look to Mr. Stenbit, as the Advisory Board's new chair, for assistance on that matter.
>
> Ms. Neilan asked whether the 'toughening' approach is practical.
>
> Dr. Parkinson replied that all the separate pieces have been built. This approach offered remarkable capabilities, in particular to 'safety-of-life' users
>
> Mr. Matt Higgins said a big issue is that eLoran does not provide wide coverage. The whole point of satellites is that they provide wide-area, and global, coverage.
>
> Dr. Parkinson agreed, and noted it is possible to also use Additional Safety Factor (ASF) corrections.
>
> Mr. Goward said ASF units have a typical radius of 60 miles and, within the area, can serve multiple points, e.g. an airport; a railway network, and a port. Such units are neither complex nor expensive.

Mr. Higgins said this approach only deals with the "N" in PNT, and does not help the many users who relied on the ubiquity of PNT.

Dr. Parkinson agreed, and noted that the key point being made is that while there is no foreseeable replacement for GPS- and GNSS-based PNT, its vulnerabilities can be mitigated with these techniques.

Mr. Goward noted that the Department of Homeland Security (DHS) has recently signed a cooperative agreement to put the eLoran signal on the air within 10 days with the intention to gauge its potential for time dissemination.

Dr. Parkinson added that Dr. Penina Axelrad has informed him that advocates of new inertial navigation devices are claiming a reduction in drift rate down to 5 meters per hour, but in his view their calculation is not addressing the full eLoran equation.

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Role of the Department of Transportation (DOT) as PNT EXCOM Co-Chair
Enabling and Preserving Critical National Equities
The Honorable Gregory D. Winfree, *Assistant Secretary for Research and Technology, DOT*

The Honorable Gregory D. Winfree explained the DOT has been reorganized to elevate the former role of Research and Innovative Technology Administration (RITA) into the office of the Secretary of Transportation with the objective to provide better access and encouraging collaborative work across DOT. This office also has the responsibility for protecting the Radio Navigation Satellite System (RNSS) spectrum. Under Presidential Policy Directive (PPD) 39, the Secretary of Transportation exercises civilian leadership responsibility for PNT in close partnership with the Department of Defense (DoD). DOT has many equities to protect when representing the civilian side.

The nation has grown to be "ignorantly reliant" on GPS and, thus, the Advisory Board must keep working to make its importance known. PPD 21 mentions sixteen critical infrastructures, and GPS plays a vital role in each. All EXCOM member agencies are committed to ensuring GPS remains the world's "Gold Standard" and that it continues to grow and prosper. There is "nothing down the road" that can substitute for GPS.

Mr. Faga said he appreciated Mr. Winfree's strong and thoughtful comments.

Dr. Parkinson seconded this, added that Mr. Winfree is "an essential lynchpin" in protecting GPS.

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

The Honorable Gregory D. Winfree noted that Mr. Harold Martin is a recent, highly experienced and extremely welcomed addition to the PNT team at DOT.

Mr. Harold Martin explained that his briefing highlights U.S. policy and recent EXCOM activities. All sixteen critical infrastructures are heavily dependent on at least one aspect of PNT. The essential policy point is to maintain U.S. leadership in GNSS. This has become more difficult due to increasing international competition. What has made GPS the best is its continuous free availability to users worldwide. Though free to users, GPS needs public funds to operate. GPS policy encourages compatibility and interoperability with foreign GNSS systems. This helps ensure a level playing field, giving U.S. manufacturers equal access to the growing GNSS market. Because GPS signals are weak and susceptible to jamming, U.S. policy calls for detection, mitigation, and increased resistance to interference. GPS policy is overseen by the EXCOM, co-chaired by the Deputy Secretaries of Defense and Transportation and with equivalent-level participation from seven other federal agencies. The NCO serves as the Executive Secretariat of the EXCOM and undertakes a variety of outreach projects. Various working groups within the NCO address specific issues.

PNT also includes government-provided GPS augmentation systems. These augmentations relate to user groups, e.g., aviation. Some sectors, such as precision agriculture, are more reliant on commercial augmentations. Collectively augmentation systems are not afterthoughts, but involve many moving parts with many timing and budgetary implications as demonstrated by the implementation of the L2C and L5 civilian signals. In addition, augmentations such as the Federal Aviation Administration (FAA) Wide Area Augmentation System (WAAS) are critically dependent on GPS, and if one were to eliminate GPS then WAAS would also be eliminated.

The EXCOM is currently focused on a number of issues:

- GPS Sustainment and Modernization.
- International Cooperation.
- Spectrum Management, which is now an issue of high concern due to the drive for broadband in frequency bands near GPS spectrum.
- Outreach, where the NCO has been involved in efforts to educate on GPS newly-hired Congressional staffers.
- Critical Infrastructure PNT Resilience.

Critical infrastructure and PNT resilience is a very important issue since over 99% of critical infrastructure is privately-owned. We need to understand what steps they are prepared to take in the event of a GPS outage. The EXCOM has established a team to determine how best to provide backup to GPS in the United States. Multiple technologies have been reviewed. The EXCOM has engaged the private sector and asked questions such as: How do you use GPS now? What kind of backup do you require? Would you purchase an eLoran system if that option were available? Given that the EXCOM is a consensus-based organization a decision may take some time.

> Dr. Parkinson noted the importance of stakeholder outreach. Had the question, "Does the world want GPS?" been posed back in 1973, the answer would have been 'no'. Therefore, he hopes any final decision reflects a broad perspective and not just a simple consensus.
>
> Mr. Faga noted that U.S. policy permits the use of foreign GNSS systems to complement GPS operation; do any U.S. government systems or receivers currently use foreign GNSS for this purpose?
>
> Mr. Martin said that discussions are continuing in this area. Regarding multi-GNSS he believes, "the more the merrier." Government agencies are free to approach private manufacturers to secure multi-GNSS receivers. Therefore, the term "government receivers" is as broad as the market. In fact, his own government-issue smartphone contains a GPS/GLONASS chip.
>
> Dr. Parkinson noted that the Federal Communications Commission (FCC) requires waivers for use of foreign signals.
>
> Mr. Martin said that question has not yet been resolved.
>
> Ms. Neilan said she believes many NASA space missions carry multi-GNSS systems.
>
> Mr. Martin noted the pending presentation from the International GNSS Service (IGS), where the 'G' once stood for GPS.
>
> Mr. Higgins said many multi-user receivers are already in use.
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> Mr. Goward noted that the International Maritime Organization (IMO) will soon provide specifications for multi-GNSS receivers contained in one box.

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Global Positioning System (GPS) Modernization and Program Plan Update
Schedule & Funding for Satellites, Ground Segment & Services
Colonel Steve Whitney, *GPS User Equipment*
GPS Directorate, U.S. Air Force

Col Whitney explained the GPS Directorate (GPS-D) is tasked with acquiring, sustaining and delivering GPS capabilities for military and civilian users. Currently there are 38 GPS satellites in operation, of which 31 are "set to healthy," with a baseline constellation of 24 satellites. The oldest operating satellite is one of three remaining Block IIA that is now 24.4 years old. Block IIR has 12 satellites; Block IIR-M has seven, and Block IIF has nine.

The accuracy of GPS is at a best-ever of 0.7 meters. This is an average figure, and would be even better by removing a few satellites that performed poorly. The central point is that the GPS-D remains committed to deliver precise capabilities to the world. The performance of military and civil signals are virtually identical. Regarding civil signals, the Civilian Navigation Message (CNAV) broadcast on L2C and L5 began on April 28, 2014, with daily uploads commencing December 31, 2014. L2C and L5 signal accuracy equals that of the previously existing signal. The GPS-D is also working with receiver manufacturers to encourage them to build equipment that makes use of this expanded capability. Regarding military signals, there are currently 16 satellites broadcasting M-Code. M-Code is real, it is working today, and efforts are underway to build receivers to use it. Upcoming GPS scheduled launches included the 10th IIF satellite on July 15, 2015; the 11th IIF on October 30, 2015, and the 12th IIF in February 2016. The 11th IIF launch conflicts with the next scheduled Advisory Board meeting.

Dr. Parkinson asked if the Advisory Board could view the actual launch.

Col Whitney said he believes this could be arranged.

The GPS III satellites are under development with Lockheed-Martin. These will have all the capabilities of IIF, with higher power to support the GPS modernized signals. The first eight are under contract and two more have been approved. The first Block III satellite should be available for launch in August 2016.

The Modernized GPS Control Segment (OCX) continues its development. It will offer improved cyber security, modern civil signals, and improved PNT performance. Its development has presented many challenges, but while no one is fully happy with the rate of progress "we will roll up our sleeves and deliver this modernized capability."

Regarding Modernized User Equipment (MGUE) there have been significant changes over the past 18 months. Following discussions within the DoD, the effort has been re-directed to a market-driven approach. The original intention was to down-select from three chosen vendors, but it was decided to instead have a three-way competition between those vendors. It is believed this will produce superior results. The first delivery of M-Code cards for testing is anticipated on July 1, 2015.

In conclusion, the GPS-D remains focused on delivering new signals to military and civilian users, accelerating development of MGUE, pursuing GPS III production, and resolving challenges in OCX.

Dr. Parkinson said that, historically, users are reluctant to purchase equipment until a signal is fully operational, that is, there being enough satellites broadcasting the signal to enable its operational use.

Mr. Faga asked about volume production of user equipment: once systems are created, from whom can they be purchased?

Col Whitney said the government builds the prototypes and establishes requirements. From there, users can choose among suppliers.

Dr. Axelrad asked what will follow GPS III satellites vehicles (SVs) 1-8.

Col Whitney noted that SVs 9 and 10 have been approved. The government is discussing how to proceed thereafter. Comments are being sought from industry on how best to proceed.

Ms. Neilan asked when laser retro-reflector arrays (LRAs) will be introduced on GPS III.

Col Whitney said the first LRA is contracted for GPS-III SV9.

Ms. Neilan noted that all other GNSS systems carry LRAs thus enabling GPS to be tracked both by radiometric and optical means.

Mr. Miller added that considerable interest also exists with the GPS Search and Rescue (GPS SAR) payload on GPS-III Originally, this was to be introduced on GPS-III SV 9, but schedule slippages have occurred. In the interim, a substitute solution has been developed so this function can also be performed on GPS-III SVs 1-8. Some interagency colleagues would like to activate those signals on the first block of GPS III, but the determination should be made by the GPS-D.

Col Whitney said that at this time he is not in a position to comment on that issue.

Dr. Parkinson said questions have repeatedly been raised over which signals military receivers should process. The Independent Review Team (IRT) believes all signals should be used. The military has expressed concerns on whether non-U.S. signals are dependable. The IRT believes reliability can always be determined. Dr. Parkinson asked whether progress has been made in developing integrated user equipment.

Col Whitney said the subject is still being investigated. However, the next "user cards" due out in July will not have multi-GNSS capability.

Dr. Parkinson said that, as shown by cell phones, multi-GNSS capability is neither expensive nor power demanding. Also, their use would assist the military to resolve the question of signal integrity.

Col Whitney noted that "the devil is always in the details."

Dr. Betz commented that standard cell phones do not draw signals from all operating GNSS systems, as that would be prohibitively expensive.

Dr. Parkinson said that's a good point. However, multi-GNSS capability, if approved, may be used in varying degrees depending on the type of equipment available.

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US DOT Civil GPS/PNT Update
Adjacent L-Band Compatibility & Complementary PNT (CPNT) Studies
Ms. Karen Van Dyke, *Director for PNT*
DOT Office of the Secretary, Research and Technology

Dr. Parkinson introduced Ms. Karen Van Dyke as one of the longest-serving of government officials working on GPS. Dr. Parkinson then recused himself, turning meeting chairmanship over to Mr. Faga. Four additional PNT Advisory Board members also recused themselves: Thad Allen, Dean Brenner, Joseph Burns, and Tim Murphy.

Ms. Van Dyke said she would address the 2014 Federal Radionavigation Plan (FRP); CPNT; Nationwide Differential GPS (NDGPS), and the GPS Adjacent Band Compatibility Assessment. The issuance of the 2014 FRP has been delayed due to the requirement that three separate cabinet secretaries sign it. The FRP emphasizes planning, civilian PNT requirements, incorporation of the National PNT Architecture concepts, and PNT Architecture Assessment and Evolution.

The 2014 FRP includes revised language on the discontinuation of codeless and semi-codeless GPS access. The previous plan was to discontinue service guarantees as of December 31, 2020, but the revised language states that codeless and semi-codeless access will be maintained until two years after 24 operational satellites are broadcasting L5, which is estimated to occur in 2024.

The CPNT effort includes circulating a request for users to provide feedback on their requirements for backup to GPS. Feedback has already been obtained for many users. For example, if one just took eLoran it would be possible to design a system that predominantly serves users that require timing. Users were asked for their contingency plans in the event of a GPS disruption for a full day. Over 200 comments were received on this questions and are currently being assessed (comments can be viewed at: www.regulations.com by entering DOT-OST-2015-0053 in the search box).

On the issue of whether to discontinue NDGPS, the current focus is on making an investment decision, either to maintain the current system; decommission the system, or something in between. A decision is expected in the near-term. NDGPS has 84 remote broadcast sites in the U.S. and territories, with 92% signal coverage nationwide. Anecdotally, until recently there were 85 stations in operation but one in Hawaii has been covered in lava. Overall NDGPS provides 10 meter position accuracy, with 10 second integrity alarm to the user. The number of NDGPS users has been declining for some time because other more accurate alternatives are available. Furthermore, the U.S. Coast Guard has dropped its requirement that vessels carry NDGPS. In consequence, the number of NDGPS receivers being built has declined. The Federal Railroad Administration (FRA) no longer requires NDGPS for Positive Train Control, and the agriculture sector is now largely using commercial alternatives.

The GPS Adjacent Band Compatibility Assessment has been divided in two parts: one led by the FAA for aviation users, and the other led by the DOT/OST-R Volpe Center for remaining users. In addition, DOT has partnered with civil agencies and other entities, including MITRE, Stansell Consulting, and Zeta Associates. The effort has included outreach activities, with participation by receiver manufacturers being of high importance. Three workshops have been held, September 18 and December 4, 2014 and March 12, 2015. The latter workshop focused on the test criteria for compatibility assessment and receiver models to be tested. Currently, seven receiver models are under consideration. The selection process must be such that all users groups are comfortable that the study is addressing their particular requirements. This is a complex issue. Among other things, it is necessary to determine: (1) the interference protection criteria that must be applied to receivers; (2) how to balance the desire for open systems vs. commercial proprietary issues; (3) how to handle the aggregation of interference at different frequencies; and (4) how to address spectrum protection for both GPS (and its augmentations) and for multi-GNSS systems. This is necessary because some GNSS signals are close to the GPS frequency band and could be similarly affected. This requires a balancing of what DOT may wish to do vs. the realities of time and budget constraints.

Mr. Miller thanked Ms. Van Dyke for returning from Vienna, Austria, on a "red eye" flight in order to make it in time for this presentation. NASA fully supports the effort Ms. Van Dyke has described, and views the study as authoritative and comprehensive. Mr. Miller also noted that the Advisory Board members who had recused themselves had done so because they had been contacted by a third party that wished to undertake such a study independently and, thus, they wished to avoid any perception of a potential conflict of interest.

Mr. Faga asked whether public statements have been made on CPNT.

Ms. Van Dyke said that comments are still being reviewed. Interested members could view these comments on the web. A decision is expected this summer.

Mr. Faga asked who would run the actual adjacent band tests.

Ms. Van Dyke responded that DOT is leading the effort. In her view a "dream team" has been assembled and the GPS-D has been very helpful in identifying appropriate facilities. The effort is proceeding with a strong partnership with the U.S. Air Force.

Mr. Goward asked whether a new purpose could be found for NDGPS infrastructure in the event of its decommissioning.

Ms. Van Dyke said re-purposing is preferable to bearing the environmental costs of cleanup associated with decommissioning.

Mr. Higgins noted the Australian Maritime Association raised the issue of an internationally harmonized approach, such as eLoran.

Ms. Van Dyke said harmonization will certainly be sought.

Mr. Higgins asked how multi-GNSS capable receivers can be addressed.

Ms. Van Dyke said the plan includes multi-GNSS in a two-stage approach: the first stage looks at existing equipment and what may be needed to protect it, and the second stage will consider future receivers and what increased protection they may require. The first stage focuses on equipment that predominantly uses the GPS L1 frequency band, and the second stage will extend the analysis to other frequency bands.

Dr. Betz raised a concern about the CPNT effort's emphasis of first level effects on loss of GPS, and asked the approach should be modified to include second and third level effects. Many timing and communications devices have a somewhat hidden reliance on GPS, and it would be a shame to invest considerable time and money to end up with something that is still dependent in GPS.

Mr. Dimmen noted that consideration is being given to allowing maritime use of WAAS. This makes sense from an accuracy standpoint, but not from an integrity standpoint. How does Ms. Van Dyke view WAAS as a possible replacement to NDGPS?

Ms. Van Dyke noted there have been discussions on maritime standards for WAAS equipment. There has also been interest in Receiver Autonomous Integrity Monitoring (RAIM) to meet integrity requirements.

Ms. Neilan asked if any additional Adjacent Band Compatibility workshops are planned and, if so, whether international participation is sought.

Ms. Van Dyke said efforts are currently focused on developing the test plan. Once it is complete, further workshops will be held, and these are open to all.

Ms. Neilan said the scientific community is concerned with maintaining service quality with global networks in well over 100 nations.

Dr. Camacho-Lara asked if the ICG has been asked to participate. He noted that this group has produced a body of work and asked if it will be included in the draft report?

Ms. Van Dyke said the Adjacent Band Compatibility effort was presented at the ICG-9 meeting in Prague, and international participation has been encouraged. There will be opportunity for international representatives to provide input once the test plan is established.

The Honorable Gregory Winfree praised Ms. Van Dyke's efforts, calling her a "paragon of the civil service and a credit to the U.S."

Ms. Van Dyke observed that a team effort was involved.

Mr. Shields seconded Mr. Winfree's comment.

With the conclusion of Ms. Van Dyke's presentation, Mr. Faga returned the gavel to Dr. Parkinson.

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Collaboration & Use of Global Navigation Satellite System Services
Bilaterals & United Nations International Committee on GNSS
Mr. Ray Clore, *Senior Advisor*
Office of Space & Advanced Technology, U.S. Department of State

Mr. Ray Clore, echoing earlier comments from Mr. Harold Martin, said that U.S. policy stresses provision of civil GPS signals, free of direct user charges; encourages compatibility and interoperability with foreign systems; promotes transparency and equal market access, and supports efforts to detect and mitigate interference. These ideas are constantly repeated in international dealings. Due to an aggressive launch schedule, Galileo should have 15 satellites in orbit by the close of 2016. The ICG-9 conference was held in Prague, Czech Republic, in November 2014 and a Providers' Forum currently meeting in Vienna is developing the ICG-10 agenda in Boulder, Colorado, November 1-6, 2015. Everyone is encouraged to attend, and a variety of tours and exhibits are planned for this event.

Regarding bilateral matters:

The U.S. enjoys very good bilateral relations with Europe. The third plenary meeting was held in Torrejon, Spain on July 2014. A variety of working groups were established – on compatibility and interoperability; on GPS-Galileo time offset, and others. The time offset group held its first meeting this month (June 2015).

Regarding China, progress has been slow, although we are encouraged by the opening of a dialogue with China on space-based PNT issues. A meeting held last year in Beijing led to an agreement to meet again on June 4-5, 2015, in Washington, D.C. Topics addressed included aviation, spectrum compatibility, and civil performance standards.

Japan has been a very good partner. The U.S. hosts monitoring stations in Hawaii and Guam for the Quasi Zenith Satellite System (QZSS). Japan plans a seven-satellite system. The U.S. has completed its collaboration requirements with the first four QZSS satellites. GNSS conversations have been rolled into the 3rd U.S.-Japan Comprehensive Dialogue on Space in Tokyo, September 11, 2015.

There have been "off and on" conversations with India.

A very good meeting with Canada was held in Ottawa in May 2015 and, among other things, cooperation has expanded on detection, mitigation, and jammer enforcement.

The U.S. held its first bilateral civil space dialogue with South Korea in July 2014, who expressed interest in developing a Space-Based Augmentation System (SBAS).

The U.S. and Australia have reached a joint State of Cooperation in the Civil Use of GPS in 2007.

Finally, the U.S. has pursued discussions with the Russians regarding GLONASS since 1996. Several working groups have been established, but these are currently on hold.

> Dr. Parkinson noted considerable discussion is happening on the legality of receiving signals from other GNSS systems. Could Mr. Clore comment?
>
> Mr. Clore noted that the FCC is the guardian of U.S. spectrum use. Receivers must have licenses for receiving non-U.S. signals. Provisions exist for seeking such waivers, and individuals can apply for licenses. The U.S. State Department, in an FCC Public Notice published in 2011, said any foreign GNSS service applying for a waiver would be assisted by the State Department.
>
> Dr. Parkinson commented it is not that "a horse has left the barn; the whole herd has gone." Virtually all mining and agricultural users, among others, are using receivers with other GNSS systems integrated into the chip. This is why there is international interest in how the U.S. reacts. Other nations could, for example, seek a quid pro quo by excluding GPS themselves.
>
> Mr. Clore said the argument should be made to the FCC. Obviously, the Dept. of State would oppose actions leading to tariff barriers on U.S. firms. It is the task of the FCC to explain why it does not enforce its own rules.

Dr. John Betz asked if the State Department sees international implications to these rules and what will it do if other countries establish similar rules?

Mr. Clore said the issue would likely be approached from a world trade perspective. The focus, would be on maintaining market access on a fair basis for all manufacturers.

Mr. Winfree offered a clarification. The FCC's principal concern is with licensing transmitters; e.g. the possibility of "off shore" radio stations broadcasting into U.S. territory. The original rules did not anticipate global transmitting ability. The FCC is much less concerned with receivers than transmitters.

Dr. Parkinson acknowledged this, but said a quandary remains. In his view, U.S. leadership should pressure the FCC to waive this requirement, whether or not it is being enforced.

Mr. Brenner recalled an issue with Russia, where for a time President Putin asserted that vehicles not equipped with GLONASS could not be equipped with GPS. That issue disappeared when Apple introduced a dual-use chip.

Dr. Camacho-Lara said that part of this work is being done within the ICG, which is a good arena for international collaboration.

Dr. Parkinson said his concerns remain. For example, the FAA would ideally want to use all signals with demonstrated integrity, particularly for landing airplanes and other safety-of-life applications. Dr. Parkinson asked Mr. Tim Murphy if activities are underway within RTCA on what a combined receiver would look like.

Mr. Murphy said progress is slow.

Dr. Parkinson reiterated he hopes the Department of State will raise this issue with the FCC.

Mr. Higgins said the next day (June 12) he will brief on Australia's equivalent to the FCC. A proposal has been made to separate RNSS from all other operating systems and then place it under a different licensing regime.

Mr. Goward said the board strongly favors a declaration of GPS recognition as a critical infrastructure. The current position is that GPS is an enabler of critical infrastructure. Would the U.S. oppose other nations proclaiming GNSS to be a critical infrastructure?

Mr. Clore said that the issue is not clear at this point, so any comment would be premature.

Dr. Rashad noted that U.S. bilateral efforts do not appeared to be directed at the Middle East. The European Union, for example, has launched many agreements with these countries to support the European Geostationary Navigation Overlay Service (EGNOS), and similar GNSS-related initiatives could pursued. Dr. Rashad asked Mr. Clore if he's approached the Middle East, or been approached by persons from the region?

Mr. Clore said the State Department is open to an approach from Egypt on GNSS. No formal agreement is needed as prerequisite to discussions. The U.S. has no formal agreement with Canada, but yet frequently discusses with them issues relating to GNSS.

Mr. Shields commented that various countries are moving toward requiring emergency notification systems in all automobiles. Russia has announced as an absolute requirement that any car sold in that country must carry GLONASS.

Mr. Clore responded that the U. S. has opposed singular geographic mandates, e.g. it opposed giving GLONASS any exclusive use. He has heard talk that Europe wishes to mandate use of Galileo. While the U.S. has no influence where foreign government operations are concerned, within the civil community it opposed such mandates.

Mr. Shields said that Russia is not seeking to prevent the use of GPS, but rather mandate support for GLONASS. Each region in the world could require the use of their own systems without forbidding the use of GPS. This is a significant issue for the auto industry.

Mr. Clore noted that where safety-of-life issues are concerned, each country makes its own determination of what is necessary. The U.S. is in no position to impose its view. So as long as no one acts to exclude GPS, the U.S. does not have a real objection it can press.

Mr. Shields, on a separate issue, said there has been considerable discussion on how to protect the GNSS spectrum both from out-of-band interference and from other countries intruding into the spectrum. On this issue, what is the relationship between the ICG and International Telecommunication Union (ITU)?

Mr. Clore said that the ITU is a longstanding organization through which countries convene to address spectrum issues. In contrast, the ICG is a voluntary group that lacks a similar decision-making capability.

Mr. Shields asked if the State Department has directed any initiatives at the ITU for protection of the GNSS spectrum.

Mr. Clore said a different department handles that matter, and it is keenly aware of the issue.

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Closing the morning discussion, Dr. Parkinson stressed that the world has moved from multi-GNSS from being a theoretical to being the actual circumstance: “As we speak, we are in a multi-GNSS world.”

Dr. Parkinson noted that the lunch hour would include the ethics training for the SGEs.

[The Advisory Board session broke for lunch.]

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International GNSS Service Multi-GNSS Experiment (IGS-MGEX):
Preparing for a Multi-GNSS World
Dr. Oliver Montenbruck, *GNSS Technology and Navigation*
DLR German Space Operations Center

Dr. Oliver Montenbruck identified the advantages in having GNSS systems in addition to GPS. More satellites mean more signals for better point positioning, more lines of sight to derive better information on the atmosphere, and better coordination of clock functions. GNSS systems are implementing new and modernized signals, and will have open signals on at least two frequencies. This greatly helps to counter the effects of atmospheric anomalies. New satellites also carry improved clocks, which will help in stabilizing timing measurements. Further, GNSS diversity will make the system “less incestuous” – that is, less reliant on a single constellation.

Dr. Montenbruck identified characteristics of the six current systems:

- The GPS constellation has become younger following the IIF launches. The clocks on IIF offer excellent short term and long term stability. GPS’ current 0.7 meter ranging accuracy remains the world’s “Gold Standard.”

- GLONASS is now a fully-operational 24-satellite constellation. Modernization is ongoing. The new K1 satellites are currently being tested, but little public record exists about their performance. It is interesting that microwave and optical link testing is, apparently, also under way but there is little information about it. GLONASS’ current system accuracy is 1.5-1.9 meters.

- On Galileo, to-date four In-Orbit Validation (IOV) and four Full Operational Capability (FOC) satellites have been launched. There has been a loss of the E5 signal on IOV-4. Also, both FOC-1 & 2 are fully functional, but because it ended up in the wrong orbit they lack almanac and ephemeris. FOC 3 & 4 were launched in March 2015, and their signals activated in May 2015. Galileo is using very high-grade clocks. The Signal-in-Space Range Error (SISRE) for Galileo has not been exceptionally good, although the early year performance of 1.5 meters had been reduced to 0.7 meter following a ground station update earlier in 2015.

- BeiDou has had an operational regional service for two years. Two open service signals are supplied. In mid-2014 one of the BeiDou Medium Earth Orbit (MEO) failed. The BeiDou satellite launched in March 2015 can accommodate long signals. The constellation uses mix of Chinese and European clocks that provide reasonably good performance. The current SISRE is 1.5 meters, which is “pretty good.”

- At present Japan’s QZSS consists of a single satellite. Its strong point is that it transmits six different signals, including signals capable of carrying higher data load. The on-board clock is the same as GPS IIF satellites, and that QZSS’s current SISRE is 0.6 meters.

- Finally, the Indian Regional Navigation Satellite System (IRNSS) has four satellites in operation. They carry high performance rubidium clocks. There is no independent characterization of the in-flight performance. Because of the signals used, there is almost no receiver data available to the GNSS community.

The IGS-MGEX was launched three years ago, and since then 30 countries have contributed in some form. It is very important that 120 stations worldwide are participating, including 75 in real-time. All the experiment information is readily available at the IGS website. From a global perspective, the MGEX network is geographically uneven. The equipment in use is rather heterogeneous, which is somewhat of a disadvantage as there are many potential sources of error. However, there are some advantages in using the equipment that is available on the open market. MGEX produces global and continuous coverage but, unlike commercial providers, IGS cannot guarantee its data. However, IGS data openly available to the scientific community and, therefore, assists a variety of research projects. Among other things, it provides a platform for understanding how all GNSS systems worked. Multi-GNSS products produced by IGS include: (1) post-processed products such as precise orbits and clocks, broadcast ephemerides, differential code biases; and (2) real-time products such as broadcast ephemerides, and corrections for orbit and clock. There is a single data stream now available that provides all course correction information.

Dr. Montenbruck presented a Galileo Orbit Comparison, noting that while it shows good consistency, consistency is not necessarily the same as accuracy. Galileo satellites are shaped differently from GPS and, consequently, classic orbit modeling introduces systematic errors into the Galileo equations. There are efforts underway to eliminate this error, as well as to get all GNSS systems to provide precision and accuracy equivalent to GPS.

Regarding clocks, all new systems generally have very good clocks and, in his view, the Galileo Hydrogen Maser clock is the best. BeiDou clocks are a bit worse, perhaps by a factor of two.

In terms of broadcast ephemerides in civil navigation, an 8-10 satellite sub-network is currently retrieving binary navigation messages and extracting CNAV. Manufacturers who wished to could download the CNAV messages. Since January 1, 2015, CNAV receives daily updates. Previously, updates occurred every three days.

On the topic of differential code biases, there are inconsistencies between the ranging signals on different frequencies and GPS L5 signals. This causes systematic offsets which, while stable, have to be allowed for in the calculations.

It is a task for the IGS to monitor all satellite signals. Real-time Broadcast Ephemerides are routinely collected by some real-time stations and then combined into a single stream containing the unique information. Efforts include providing Galileo with real-time orbit and clock corrections.

The standardization of RINEX, RTCM3, and ANTEX formats has been a difficult, but very important task. The intent is to “squeeze out” all information related to where the antenna is located on a given satellite.

In summary, MGEX’s achievements include establishing a global multi-GNSS network with a strong, real-time component. Further, it has developed a comprehensive class of products for multi-GNSS work, been engaged in creating standards for the world’s GNSS system, and attempted to understand, monitor, and exploit all GNSSs. However, challenges remain: the MGEX network needs to be integrated into the IGS core network to create a single network; as of yet IRNSS is not well supported by SBAS; and there is a need to combine orbit and clock products from the various analysis centers into a single product.

Dr. Parkinson thanked Dr. Montenbruck for his presentation.

Mr. McGurn asked if he has understood correctly that the update period in GLONASS was 10 hours.

Dr. Montenbruck said he believes uploads are daily.

Mr. McGurn asked if Dr. Montenbruck knows why with the Indian K-2 uses a Plus-7 frequency.

Dr. Montenbruck said this is a “kind of a spare frequency.” Though he has no official knowledge, his impression is that India wants to keep it separate from the other satellites.

Mr. Hatch asked if the “bumps” in the GPS clock could be caused by the fact that GPS repeats it orbit each day.

Dr. Montenbruck said it is a consequence of the thermal warming and cooling of the satellites as it moves in and out of view of the sun.

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Toughening Techniques for GPS Receiver Operations
Navigation Message Authentication
Dr. Todd Humphreys, *Assistant Professor*
Aerospace Engineering, University of Texas at Austin

Dr. Todd Humphrey explain his talk would cover the topic of how anti-spoofing efforts can be made more effective, and also describe types of spoofing attacks and defenses to such attacks. This approach is a major step toward developing a much needed threat assessment model. Dr. Humphrey said he and his students have studied spoofing for six years. The TechDemoSat-1 satellite, launched in 2014, has a downward pointing antenna that receive signals bounced from the Earth's surface to determine ocean temperatures and ice coverage. This has been quite useful because it also makes TechDemoSat-1 an effective spoofing detector, as shown over Ukraine.

Civil GPS spoofing has been demonstrated in laboratory and controlled field tests. "Hostile" spoofing has also been detected. Spoofing is currently a mild nuisance, so equipment manufacturers are reluctant to invest in anti-spoofing measures. It is a situation of low probability, although consequences can be quite high. There are three issues that need to be addressed:

1. How effective are receiver-side spoofing defenses?
2. How effective are Signal-in-Space side spoofing defenses?
3. How much would spoofing defenses increase receiver cost?

The last point is very important because it has always been U.S. policy to encourage GPS use by making it inexpensive. Dr. Humphreys presented a detailed chart showing various means of attack, methods of defense, and the effectiveness offered by each defense against various forms of attack. In his view this includes all possible attack and defense categories.

Data shows that in Ukraine overflights of Unmanned Air Vehicles (UAVs) over areas under separatist control are being spoofed. The least expensive form of attack is that of an unsynchronized simulator. Five years ago, such a device might cost $500,000; today, $5,000 might be sufficient. Other examples of attack methods include: single-receiver-antenna; multi-receiver-antenna meaconing, and nulling. Nulling is the "the latest and greatest" attack methods. It requires "exquisite knowledge" of the phase center of the target receiver's antenna. With such knowledge one can annihilate the receiver's authentic signal with an antipodal spoofing signal. However, since nulling requires knowledge of receiver location to within 5 cm, it is a rather expensive form of attack.

Regarding defense, techniques such as Receiver Autonomous Integrity Monitoring (RAIM) offer a good and inexpensive approach. Receiver Power Monitoring (RPM) is also very effective and inexpensive. According to one expert, with power monitoring on his receiver he had little concern about spoofing because any inexplicable rise in power identifies a problem. The drawback is that occurrences other than spoofing could also cause an inexplicable power rise. Another defense is the so-called "the pincer defense" where at low power one searches for a spoofing signal closely matching the authentic signal. Such interaction usually causes disruption. Such disfiguration also occurs with multipath, but one can detect distinctions between signal distortions caused by spoofing and by multipath, thus identifying the former. At high power one can identify the spoofer through RPM and, thus, the spoofer is caught in a pincer between these two relatively inexpensive tests. Another valuable tool for all kinds of interference is "spectral analysis," which is the technique most commonly offered by manufacturers, although it leaves it up to the user to decide if an attack is in progress. Finally, "multi-antenna defenses" are extremely effective, but required additional hardware. They can only be overcome if simultaneously spoofed from multiple directions, which would be a very expensive form of attack.

It is important to know what type of attack each defense is most effective against. Obviously, one hopes for an inexpensive defense that works against all attacks. However, no such defense exists. RAIM, though inexpensive, does not offer broad defense. "Observables" achieve little more, as does Navigation Message Authentication (NMA). Better results are obtained by the pincer defense, by combining RPM with observables. If one combines the pincer defense with the multi-antenna approach then one is secure against the broad range of prospective attacks. Finally, combining NMA with Security-Code Estimation and Replay (SCER) detection offers substantial PNT security at low cost. Various experts advocate such approach. Further, Galileo is including NMA on its E1B open service, the most used signal. It is likely Galileo will employ NMA and present it as part of that system's benefit package. NMA would be less useful on GPS because of its more restricted uplink data rate.

In summary, arguments existed for and against the use of NMA with GPS. On the plus side, NMA would give users substantial improvement at relatively low cost. On the minus side, GPS' narrow uplink pipeline would lead to a 9-minute delay between authentications, compared to 10-20 seconds with Galileo. This 9-minute gap leaves one vulnerable, particularly if one's adversary knows when the last verification occurred. Manufacturers have little interest in NMA unless it would be available on GPS L1. Furthermore, its use would mean additional requirements for OCX requirements. Dr. Humphreys closed with four recommendations:

1. Implement NMA on WAAS quadrature channel and provide examples for other SBAS systems,
2. Digitally sign GPS Legacy Navigation (LNAV) data, and then broadcast signals over WAAS quadrature channel,
3. Encourage GNSS manufacturers to adopt simple receiver-autonomous defenses, such as pincer, and,
4. Plan for NMA on L1C.

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Automated/Autonomous Trucking:
Emerging Users – Terrestrial
Mr. Russell Shields, *PNT Board Member*

Mr. Russell Shields explained that driver errors are common in long-haul trucking. Indeed, 90% of commercial truck crashes are due to driver error. Therefore, automated driving will one day greatly improve safety and performance, particularly on Interstates. Further, automated driving will reduce fuel use, thereby reducing carbon emissions. This issue is currently receiving strong emphasis in Europe.

The National Highway Transportation Safety Administration (NHTSA) defines five levels of automated driving. This presentation focuses on 'Level 3', where automated functions control the vehicle but the driver remains present and can take over. The possibilities for Level 3 use are much higher in closed environments than on public roadways. At present, GNSS does not provide the minimum 10 cm required accuracy for this application. More precise positioning requires a number of sensors, some of them expensive and not yet ready for mass production. There are a number of ongoing efforts to incorporate roadside landmarks into positioning systems. Currently, automated driving is more commonly used in closed environments such as farming, mining, ports and border security.

Automated driving for trucks presents greater technical challenges than automated driving for automobiles. These challenges are often understated, including management of a much larger and heavier vehicle, variability in weight, and greater vehicle movement affecting sensors. Reliability is also a key issue. For example, Google has acknowledged 12 accidents in the "Google Cars" which, relative to miles driven, constitutes a higher accident rate than that of 75-year old drivers. Google has explained that those accidents were the fault of the other driver. If a vehicle is programmed always to stop on "yellow," then it will sometimes get hit by the car behind. This shows that automated driving still has a long way to go.

The trucking industry has already adopted various NHTSA Level 2 aspects of automated driving, such as adaptive cruise control and lane handling. Many automobiles have cameras and other visions systems that are steps in the direction of automated driving. People should remember, however, that the typical car control software now in use carries 500,000 lines of code, which makes it very difficult to achieve 100% percent reliability. Also, a braking system could potentially receive an over-the-air update which could expose it to hacking. In any case, considerable progress is being made by major truck manufacturers. Automated driving also exists in a regulatory context, and vehicle regulations can be complex. For example, the Vienna Agreement requires that "the driver must always be in control of his vehicle and his animals." This regulation is now being revised to: "The driver must always be able to take control of the vehicle," but the process involves involved a substantial regulatory effort and could take at least one year.

There is a reasonably high chance that by 2021 high-end automobiles will be able to perform automated driving from expressway entrance to expressway exit, although fog and other conditions may limit this capability. By 2024 similar features could be available on new long-haul trucks. However, these vehicles may not appeal to cost-conscious purchasers. In the short-term it is more likely we'll see automated trucking being used in closed settings such as farms, ports, and warehouses.

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Unmanned Aerial Vehicles (UAVs):
Emerging Users -- Aviation
Captain Joe Burns, *PNT Board Member*

Capt. Joe Burns noted he's been hired by Sensurion Aviation to do flight testing of UAVs, and the experience is quite different from the Boeing 747 he most recently flew. UAVs are a rapidly emerging industry, and GPS is critical to their performance. Strictly speaking UAVs are not new, but the degree of miniaturization and lower cost of electronics has enabled such growth. There are two basic types of UAVs: (1) UAV with multi-rotors that are excellent for short flights (25-30 minutes) where it was important to maintain line-of-sight between the operator and the vehicle; and (2) more conventional fixed-wing aircraft that can perform observation functions over many hours.

The potential UAV market is enormous. Current global sales are between $8 and $14 billion, and they are expected to increase to approximately $80 billion by 2025. The civil and commercial markets are expanding rapidly, particularly in oil and gas exploration industry, and to support the power grid where UAVs are especially well-suited for flying along high tension power lines to identify leaks. UAVs are also creating spinoff industries, e.g. there will soon be an entire industry to train people to fly them. There are also enormous untapped capabilities in agriculture and land conservation. The latter includes, for example, on-going use of UAVs to do bird counts. Currently, the U.S. military employs about 7,500 UAVs. Also, the number of commercial UAVs in operation probably already exceed the number of human-piloted aircraft. The international market is likely to become a big party because many foreign nations have had more flexible regulations.

Regarding regulation, the FAA Federal Aviation Regulations (FAR) 107 Notice of Proposed Rulemaking (NPRM) is an important proposal. This NPRM applies to UAVs weighing less than 55 pounds and for use in daylight line-of-sight operations where operators are required to have a pilot's license. The new regulation should be issued within two years. Rules for UAVs over 55 pounds in weight are also forthcoming. Additionally, Academy Model Aeronautics (AMA) Rule AC 91-57 (available at www.modelaircraft.org/files/540-c.pdf) governs the use of UAVs by hobbyists, whom often fail to understand they are not allowed to fly over 500 feet. This rules allows individuals to obtain a Special Airworthiness Certificate (SAC) to operate a certified UAV. Current regulations can at time be confusing as, for example, existing rules that require all flight vehicles to be equipped with seatbelts. Certificate of Waiver or Authorizations (COAs) allow companies to operate UAVs commercially. Over 400 COAs have been granted so far. Many are used in the film industry, where highly-sophisticated octocopters keep cameras aloft and stationary. The FAA has published an Unmanned Aircraft Systems (UAS) Blueprint/Roadmap which, although recently published (2014), is already in need of updating.

Capt. Burns presented a photograph of Inertial and Mag Components, demonstrating the degree of miniaturization and low cost that has been achieved. He also identified the GPS components used by UAVs, and presented a schematic of the typical UAS' avionics power section, which is only about the size of a football but can generate three horsepower and 100 amps.

There are many differences in the PNT services required for UAVs operating within Vehicle Line of Sight (VLOS) and those operating Beyond Visual Line Of Sight (BVLOS). Also, traffic awareness is an important issue because currently a UAV operator does not know what else is in the airspace and how it is to be avoided. This is why it is necessary to have collaboration in order to maintain safety in a shared airspace. Interested trade groups should be informed; educational meetings should be held with members of Congress, and other aviation trade groups need to be brought into the discussion. It is essential for the UAV community to work with, and not against, such agencies as the FAA, International Civil Aviation Organization (ICAO), France's Directorate General for Civil Aviation (France), United Kingdom's Civil Aviation Authority, and others.

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Enhanced 911 (E911) GNSS Geolocation:
Emerging Users – Terrestrial
Mr. Dean Brenner, *PNT Board Member*

Multi-GNSS is a fact and, in consequence, receivers should be made as robust and accurate as possible. Individual receivers capable of receiving multiple-GNSS are clearly superior and costs have been driven down tremendously. A second GNSS system should be added to GPS-capable chips in order to improve performance. Issues persist regarding the FCC rule that a user is required to have a waiver to receive foreign signals in the US, but it isn't clear who should make such request. The unintended effect is that the FCC is making it difficult for manufacturers to take advantage of improving GPS' capabilities through access to additional GNSS signals. Studies show that tracking additional GNSS systems, such as GLONASS, would provide PNT users with up to 30% higher yield and up to a 50% reduction in vertical error within dense urban environments. Also, strenuous efforts have been made to eliminate the possibility of malware gaining access through reception of foreign GNSS systems. When the issue of foreign GNSS-use first arose, the United States and Russia were on friendlier terms. Current concerns with GLONASS use are understandable given the latest political circumstances, but the final decision should be made based on technical merits. It is a clear technical fact that multi-GNSS receivers enhance services provided to the user.

> Mr. McGurn said he is not convinced that 50% performance can be achieved by combining two identical signals.
>
> Dr. Parkinson said he believes the figure refers to improvement due to increased signal availability in urban canyons.
>
> Mr. McGurn noted that Russia has 22 GLONASS tracking stations. One can obtain tracking results for GPS-only, GLONASS-only, or the two combined, and the largest accuracy improvement he's seen is approximately 20%, and an average of 7%.
>
> Dr. Parkinson observed that if he was in a restricted area with only three GPS satellites on view, adding GLONASS should bring an accuracy improvement.
>
> Mr. McGurn said that if only tracking two GPS and two GLONASS satellites it is not clear how such improvement would improve (over tracking, say, 4 GPS satellites). Also, in view of the GLONASS incident last year we need to be mindful of potential issues with its overall integrity.
>
> Dr. Parkinson acknowledged the GLONASS incident, which lasted for hours, and the lack of an adequate explanation from its operators.

Mr. McGurn said his concern is that there was no announcement that a satellite was 'bad' and, thus, should not be used. The GLONASS system needs to address the issue of providing such warnings to users.

Dr. Beutler said an important distinction exists depending on whether one is undertaking point positioning navigation or stationary navigation.

Mr. McGurn said the current discussion focuses on a stationary situation.

Mr. Higgins said that the receiver market is heading towards GNSS differentiation, but the question remains which other GNSS system will provide such differentiation.

Mr. Brenner said this is a very good question. The race to develop GNSSs is far more competitive than commonly thought, and almost akin to an "arms race." If one GNSS system gets a particular new capabilities then all the other systems will also want it.

Dr. Parkinson asked Mr. Brenner to please keep the Advisory Board informed on developments regarding discussions with the FCC.

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GPS Space Service Volume (SSV):
Emerging Users – Space
Mr. Frank Bauer, *FBauer Aerospace Consulting*

Mr. Bauer said he represented a team that is currently reviewing how to preserve existing GPS capabilities across future GPS Block III increment builds, and his briefing will provide an overview; show accomplishments, and explain a potential loss of capabilities that should be addressed.

The civil and military space communities have recently crossed a "game-changing" threshold 20 years in the making. Space operations taking place in High Earth Orbit (HEO), Geostationary Orbit (GEO), or Geosynchronous Orbit (GSO) above the GPS constellation, can now benefit from significantly improved PNT capabilities thanks to GPS. GPS satellites operated at approximately 20,000 km altitude. By definition, the GPS Terrestrial Service Volume covers the volume of space between the surface and 3,000 km altitude. The volume of space beyond 3000 km altitude is called the Space Service Volume (SSV) and includes two regions: (1) a SSV for Medium Altitudes (3,000 to 8,000 km altitude); and (2) a SSV for High/Geosynchronous Orbit altitudes (8,000 to 36,000 km altitude).

GPS signals were originally designed to work best on, or near Earth's surface. On-orbit performance of GPS varies significantly between block builds due to variances in the main lobe antenna gain and bandwidth. With the pending deployment of the first batch of GPS III satellite vehicles 1-10 (SV), and an on-going development of GPS III SVs 11, a team has been established with the intention of ensuring current GPS capabilities are preserved by establishing objective requirements for improved performance. This effort is important because both government and commercial organizations can use GPS signals to support space operations in higher orbits. Two strategically important activities in higher orbits include Earth weather and space weather. Use of GPS signals above-the-constellation can improve weather prediction and space weather observations. Space missions benefiting from use of these signals include the Geostationary Operational Environment Satellite (GOES) –R weather satellite series, and the NASA Magnetospheric Multi-Scale (MMS) launched on March 12, 2015. The MMS mission is initially in an elliptical orbit with an altitude apogee (highest point in an orbit) of nearly twice that of GEO, with an eventual increase of apogee to 150,000 km, approximately 40% of the distance between Earth and the Moon. This was not a "fly by night" capability, but rather one on the cusp of broad use by military, civil, and international organizations.

Since the initial SSV specifications were established in 2004 for GPS III SVs 1-9 (formerly called 'III-A', and now extended up through SV 10), GPS-based navigation capabilities for users in HEO/GEO have significantly improved when tracking not just the GPS signal's "Main Lobe," but also the so-called "Side Lobe" (sometimes also referred to as the "1st side lobe"). For example, measured data at Geostationary Orbit altitude shows that when tracking only the Main Lobe there are no GPS satellites visible 41% of the time. However, when also tracking the Side Lobes there is at least one GPS satellite visible at all times, and four GPS satellites visible 99% of the time. Therefore, it is clear that protecting the capabilities provided by the GPS signal's side lobes is important to ensure GPS signal availability throughout the SSV.

Recent flight data from the MMS mission, a four-satellite formation flier with 12-channel GPS receivers, has demonstrated 5-10 meter real-time position accuracy even at an altitude of 76,000 km, which is over twice the distance between the surface and GEO. This is quite remarkable and "groundbreaking."

Development continues at NASA's Goddard Space Flight Center (GSFC) for even more advanced GPS flight receivers, including radiation hardening, weak signal acquisition and tracking, and an integrated on-board navigation filter that allows a satellite to "flywheel" through GPS data outages.

Therefore, preserving the capabilities of the GPS side lobe signals, and the continued development of even better flight receivers, is critically important to all space users. When defining specifications to support space users, two key things are availability and signal strength. The SSV team is developing recommendations on how to define the capabilities available by the GPS side lobes. Initial analysis shows that no changes are needed in overall GPS signal strength. The key question is how to define the signal received power within the side lobes. This can be done in a number of ways. It would not be appropriate to specify an "antenna pattern" since that could unduly constrain the design of a GPS satellite, so the team is looking at other options. Work is also proceeding from a "worst case" scenario based on a 24-satellite constellation. The GPS constellation is not being asked to do more than it is already doing. Initial analysis shows that potential approach is to specify received power within a certain range of angles "off Nadir" such as, for example, between 30° and 60° and defining a mean value and standard deviation for received power within that range.

In summary, GPS is critical to navigation in space. The overall objective sought is to protect the 'P' in PNT, and this could be achieved by modifying the GPS specifications to protect the capabilities enabled by the GPS side lobes. At present GPS is the only GNSS that specifies a Space Service Volume, but work is underway with the international community to develop interoperability to support users in space.

The way ahead for the SSV Team is to:

1. Flush-out the specifications for the GPS side lobe through analysis of recent flight data;
2. Socialize these changes within the civil and DoD communities; and
3. Work with the GPS-D, U.S. Air Force and DoD leadership to incorporate a modification to system specifications for future GPS Block III increment builds.

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Raw Data to Improve Accuracy, Integrity, & Availability of SatNav
Dr. James L. Farrell, *VIGIL, Inc.*

Dr. Farrell reported the results of a flight test conducted at Ohio University to compare the phase residuals, or difference between expected and actual measurements, rarely vary by more than 4.5 cm. The residuals are not 'zero' because neither the estimates nor the measurements can be perfect. Also, data shows such variance is not due to the speed at which one is moving. The analysis of sequential changes in 'raw data' can be used to obtain a tremendous improvement in performance.

> Dr. Parkinson asked if the sequential changes are independent changes or sequential filter.
>
> Dr. Farrell said they are simply a direct look at the data. One of the consequences is that while the data itself does not give one a position, it does wonders in terms of velocity in cm/s.

Another test involved flying two aircraft in what would have been a collision course had they not been separated in altitude. The test did not rely on latitude, longitude, speed and direction but, rather, by using raw carrier phase measurements. This method produces cm/s-level relative velocity measurements. One may wonder why this cm/s-level measurement is so important. A typical performance measurement to avoid collision is 90 seconds to closest approach. Automatic Dependent Surveillance Broadcast (ADS-B) accuracy is approximately 10 meters/second, so an aircraft would travel 900 meters in the 90 seconds. However, with a 1 cm/s accuracy it would travel 0.9 meters over 90 seconds. This shows that relative velocity measurements are of value in determining collision avoidance. ADS-B may not be able to handle the anticipated increase in air traffic, which is why Dr. Farrell has long advocated the use of raw data measurements, instead of coordinates, which offer a 1,000-factor advantage.

The need for measurement-based positioning is going to become more urgent over time. For example, warfighters may not have enough GNSS satellites in view when operating in obstructed terrain, and in these cases GNSS satellite data available is simply thrown away. However, measurement-based techniques could still derive useful information from incomplete data. Such techniques also help reduce the demand for data. They can also be applied to other technologies such as radar-based tracking, eLoran, and others.

A road test demonstrated a vehicle was able to proceed down a road despite there being tall trees on both sides. In this test satellite signals sparkled in and out, and many signals were not good, but a high speed processor was able to process what data was available. These tests show that it is beneficial to use "every morsel of information." It is regrettable that many in industry have allowed measurement capability to slip through its fingers. Reliance on the accuracy GPS offers has led to complacency. Ten or twenty years ago the common argument was that there was no need for additional data as there was already more data than one could actually use. This is no longer the case.

Also, reliance on ‘full fixes,’ such as RAIM, has worked its way into performance specifications. One of the consequences has been that every time a change is made the resulting cost can rival the price of the original acquisition. The overall goal of this technique is to deliver whatever performance is reachable from all available information, incomplete as it may be.

> Dr. Parkinson said he strongly agreed with Dr. Farrell’s comment. Indeed, the matter could be pushed into additional areas; e.g. aircraft landing on carrier decks through use of differential velocity. This would also provide a new approach to detect spoofing.

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The Economic Value of GPS: Preliminary Assessment
Dr. Irving Leveson, *Founder, Leveson Consulting*

Dr. Leveson explained this study is a result of the PNT EXCOM tasking that an interagency mechanism be created to “develop a way forward for an updated, authoritative GPS economic benefits assessment.” The Department of Commerce (DOC) has taken the lead on this effort. The current study has two major objectives: (1) provide a “more complete and methodologically sound” estimate of the economic value of GPS services; and (2) assess non-economic benefits; international benefits and the likely costs of the long-term denial of such services. The results have been summarized in a “showcase report” intended for broader audiences, and is supplemented by a detailed report. The report is not yet another academic exercise but, rather, is intended to inform decisions on policy, budget, spectrum allocation, possible back-up systems, and other needs. The study also provides a baseline against which to measure changes in a rapidly developing field.

The briefing being presented represents an initial assessment. Its scope includes identifying direct economic benefits, including payment for services, and also the value to users of GPS services above the costs of those services. The study includes the value of GPS augmentations because there is no practical way to separate them from stand-alone GPS. Indirect benefits, such as cost savings due to use of GPS and its augmentations, have been included whenever they were documented. Other indirect benefits, such as health, safety, and environment, etc., will be considered subsequently. These could be quite large.

The team supporting this study was drawn from a dozen government agencies, and includes 24 economists and six engineers. It has been meeting on a monthly basis since December 2014. The intention was to deliver an estimate as robust as possible, that is, a conservative estimate that can be defended.

Whenever there were limitations to the available data the team proceeded on a basis of “considered assumptions.” For example, data on the value of GPS to rail and maritime transportation was included even though the current available estimates are of “lower quality.” Some sectors were excluded because either no data exists or lacks rigor. Within each sector, the share of benefits attributable to GPS was based on an informed estimate. More robust estimates will require an extensive data collection and interview process greatly exceeding the resources and time available for the current study. The GPS/GNSS “value chain” focuses on the timing function because of, for example, its importance to critical applications such as electrical power distribution. The value chain includes a broad range of GPS applications and identifies benefits such as savings in costs and time, promotion of innovation, and others. These applications includes some which are safety-of-life.

The study group decided to make estimates by ranking sectors in accordance with the apparent reliability of the data, namely: confident, indicative, or merely notional. Notional data was excluded from the study. A total of 70 studies were tabulated. Dr. Leveson noted that, in his opinion, the figured being presented considerably underestimate the economic value of GPS. In part, this is because some estimates omit numerous things for which no reasonably reliable data existed. Omitted sectors include Geographic Information Systems (GIS) (with exception of the development of nautical charts), location-based services (other than vehicle location), weather prediction, space science, construction (other than earth-moving), and others. Another reason for the estimates being low is that very conservative estimates were used when assessing the value of time saved when using GPS. The economic value resulting from reduced accident rates was not included. Other difficulties included, for example, determining the portion of value the internet attributes to GPS’ timing function. Further, one cannot simply compare the value of current technology to that of previous technology since, in absence of GPS, alternative paths would most likely have been created. The study group also attempted to determine what might have happened in the absence of GPS timing, and two comparisons were used: one based on widespread use of eLoran, and the other based on the use of a series of geodes.

Results show that the mid-range GPS economic benefits for 2013 was $68.7 billion, or about 0.4% of the U.S. Gross National Product. This figure more than doubles the $32.5 billion previously estimated. Even so, the figure is still low due to the exclusions discussed earlier. Other studies include: (1) Frost & Sullivan pegged the global location-based services market as 22.8 billion Euros in 2012, forecasting a rise to 32.0 billion Euros by 2015; and (2) BCG estimated the 2011 revenue of the U.S. GIS industry at $83 billion. These studies disagree widely not only on the size of particular markets but also on what share of that market’s benefit is attributable to GPS. There were also a number of gaps in these studies, in particular when assessing productivity. Some studies were outdated. For example, National American Industrial Classification System (NAICS) did not create a separate economic category for the internet until 2012.

Lessons learned from this effort include: (1) there is a need for much more systematic data, longitudinal data, and "granular" data (e.g. determining GPS value not simply to agriculture but to plowing, seeding, fertilizing and harvesting); (2) data collection on GPS value lags considerably behind reality; (3) a special effort is needed to assess the impact of rapid integration of new technologies; (4) the value of augmentation systems and other GNSS systems needs to be tracked for major applications; (5) attention needs to be paid to emerging technologies: (6) expert opinions should be secured to better assess the share of benefits that can be attributed to GPS; (7) estimates are needed for the additional tax revenue flowing from the increased economic activity caused by GPS; and (8) efforts are needed to assess the value to safety and health (including, for example, how better safety encourages consumer demand), as well benefits to the environment.

Dr. Leveson closed by noting the study contract expires in late July 2015, so it is important that comments be submitted as soon as possible.

> Dr. Parkinson expressed concern that Gov. Jim Geringer, the board member most closely associated with the economic analysis, was unable to be present. Dr. Parkinson added that he will contact Gov. Geringer for comments he may have.
>
> Mr. Goward noted it is nearly impossible to overstate the importance of the question of GPS economic value, or to overstate the difficulty in answering this question. A key matter that still needs to be assessed is what would happen in absence of GPS? Also, how could we quantify the impact to society? These are the real measures of the value of the system.
>
> Mr. Murphy asked whether Dr. Leveson has taken the value of weather forecasting into account.
>
> Dr. Leveson said little data is available on that subject, but hopes to include this in the next round.
>
> Mr. Murphy said he has given Gov. Geringer information on the National Oceanographic and Atmospheric Administration (NOAA) estimates of cost savings from GPS.
>
> Dr. Leveson identified two questions: (1) what is the value of the forecasts; and (2) what is GPS' contribution to that value.
>
> Ms. Neilan said that some years ago she approached the International Center for Atmospheric Research (ICAR) director on how GNSS could be used to improve atmospheric observations. The director was initially very skeptical, but became very interested as he began engaging the issue. This person could also be a good source for information on benefits in weather forecasting.

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Mr. Miller thanked everyone for their participation in the day's meetings, and suggested board members focus on the next day's pending discussion of priorities to put before the PNT EXCOM at its next meeting.

Dr. Parkinson suggested that board members review the published list of possible issues and pass him a note identifying their own top priorities. This will enable him to prepare a ranked list.

The Thursday, June 11, 2015 meeting of the Space-Based PNT Advisory Board adjourned at 6:04 p.m.

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The Friday, June 12 session of the 15th Space-Based PNT Advisory Board was called to order at 10 a.m.

Board Convenes

Dr. Parkinson, the 1st Vice-Chair, welcomed all to the second day of the meeting.

Mr. Miller noted that Thursday's session had been devoted to reports. Today, the Advisory Board will focus on what message it should present to the next PNT EXCOM meeting (now scheduled for September 3, 2015).

Dr. Parkinson thanked Mr. Stenbit for collecting member's "ballots" on the proposed priorities for the board.

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International PNT Board Member Regional Updates & Perspectives

1) Real-Time and Ionosphere in the IGS
Dr. Gerhard Beutler (Switzerland)

Dr. Beutler noted that on the previous day Dr. Oliver Montenbruck addressed a number of topics he was going to cover, therefore to avoid duplication, today's briefing focuses on real-time monitoring and measurements of the ionosphere. The IGS was founded in 1991, and since then has expanded from a network of 20 geodetic receivers to over 400. In 1992 IGS provided an orbit determination service for 15-20 GPS satellites, and now provides ephemerides for all active GNSS satellites. Additionally, IGS archives all globally-relevant GNSS observations, provides satellites and receiver clock corrections, and provides information on polar motion, length of day, atmospheric information, and satellite clock corrections. The "2014 Workshop Compendium" captures the activities of the summer 2014 IGS workshop. IGS has become the premier source of the highest-quality GNSS data products. As a federation of 200 scientific institutions worldwide, it follows an open data policy. The "miracle" is that all this has been achieved without a central funding source.

The IGS Real Time Service (RTS) is an international effort of many contributors, including: station operations, data centers, analysis centers, combination centers, analysis coordination and the Networked Transport of RTCM via Internet Protocol (NTRIP) caster operation. It was launched in 2013 and became a statistically stable service. If one tracking station fails another jumps in. Between GPS and GNSS, at least ten satellites were always visible, which gives strength to the IGS RTS' statistical products. The ephemerides and clock time data of all satellites in view can be downloaded.

The IGS also operates the Ionosphere Working Group. It began research in 1995, and currently every two hours produces a map of the free electrons within the ionosphere. Results show that GNSS receivers used by IGS vary in their resistance to ionospheric variations. Also, the sun itself is not rigid and different latitudes rotate at different speeds thus adding to such variations.

The Rate of TEC Index (ROTI) varies substantially between a quiet geomagnetic day and a disturbed day, the latter affecting IGS measurements. This brings us to an example satellite missions, specifically one of the two Gravity Recovery and Climate Experiment (GRACE) satellites as observed in the first half of 2014. This is a pair of low-earth orbit satellites that scans one Earth meridian every 90 minutes, and by combining several months' worth of data one obtains excellent complementary information to the IGS Global Ionosphere Maps (GIMs). It is interesting that when one compared IGS- and GRACE-derived GIMS there is strong match between both sets of data.

Dr. Parkinson asked if any relationship exists between monitoring networks.

Dr. Beutler explained some exists between the Global Differential GPS System (GDGPS) and IGS, with the IGS network being globally denser.

Dr. Parkinson asked if the two share a common format.

Dr. Beutler said they do. Everything IGS does is to a common standard, although the IGS sometimes can take more than 24 hours to make its data available.

Mr. Hatch asked how erroneous data is removed.

Dr. Beutler said it is not a trivial matter because while positioning data is in real time, ionospheric data is not.

Dr. Beutler concluded by noting the IGS website contains detailed information on all the ionospheric products.

2) GNSS Market Report
Mr. Arve Dimmen (Norway)

Mr. Dimmen noted that *GNSS Market Report: Issue 4* provides a good insight into the current GNSS market. At present four billion GNSS receivers are in use. This number should double over the next four or five years. Of these 100% track GPS, 60% support SBAS, 30% track Galileo, and 20% can track all four GNSS constellations. On the maritime side, he noted that 35% can track all four GNSS constellations. These figures do not indicate market penetration but, rather, what is currently being offered on the market. The IMO has recently approved a performance standard for navigation receivers. Previously, no performance standard existed for those using a combination of GNSS systems. Nearly 80% of maritime receivers include SBAS, which is interesting as SBAS does not have maritime performance standards. SBAS use improves accuracy, but it is uncertain how integrity is affected. There are on-going discussions in Europe on the possibility that an improved EGNOS could provide integrity. RAIM offers another alternative. Which approach may be best requires discussion by the Advisory Board.

> Dr. Parkinson suggested that some version of Mr. Dimmen's graphs of the current usage of various GNSS systems should be presented to the PNT EXCOM.
>
> Mr. Martin said the graphs clearly contrast the present with the future.
>
> Mr. Dimmen said the graphs will be made available.

3) International Member Regional Update: Australia
Mr. Matt Higgins (Australia)

Mr. Higgins said he would speak about developments with the global geodetic reference frame before addressing topics more directly related to Australia.

The United Nation's Information Management Group has a subgroup chaired by Norway and Australia that recently completed the process leading to formal United Nations (UN) recognition of the Global Geodetic Reference Frame (GGRF). The UN has praised GGRF for enhancing global cooperation; implementing open sharing of geodetic information; improving and maintaining appropriate geodetic infrastructure; engaging in multilateral cooperation, and developing outreach programs, particularly to developing nations. Passage was unanimous and signed by 36 member states. This a very good development for global geodesy.

Australia has finally adopted its National Positioning Infrastructure (NPI) plan. The plan is quite good and currently awaits $100 million for its implementation. In the meanwhile the Australian government is creating governing structures for this plan, including: (1) a committee on PNT that works across all government departments; and (2) an NPI Advisory Board (NPI-AB) similar to the PNT Advisory Board. Mr. Higgins noted he's serving as liaison between these two bodies. The committee is currently focused on infrastructure to support national positioning, and the NPI-AB has four priorities: improved governance; ground infrastructure development; GNSS analysis capability, and data & service delivery.

There is an area of Australia measuring 1,000 by 2,000 km that has no terrestrial mobile communications and, therefore, the NPI solution to this problem is requiring SBAS. The business case for SBAS is not strong case for aviation applications, but Cooperative Intelligent Transport Systems (C-ITS) and other high integrity applications bolster the case.

In terms of spectrum issues, note the 2nd paragraph in the Remaking the Space Object Class License stating RNSS use in Australia would be facilitated by creating an alternate licensing regime to apply for RNSS receiver operations. In his view this is a good approach as it would allow foreign space objects to meet the requirements for Australian registration.

Regarding Multi-GNSS, at times there are up to 23 GNSS satellites were visible from Brisbane, Australia. Each generation of satellites not only has more signals, but also better signals from these satellites. The advantage in having four GNSS systems is that they could provide millimeter-level accuracy in just eight minutes.

The Australian government has continued interest in QZSS and is engaged in two R&D projects with Japan Aerospace Exploration Agency (JAXA). These projects include automated vehicle driving, such as automated mining. On-going developments could result in automated trains that move from the mine to a seaport the 280 to 360 million tons of coal annually exported to China. Also, automated trucking could eliminate 70,000 miles in driving distance.

> Mr. Miller noted that the PNT Advisory Board has long urged other nations to create similar citizen-based advisory groups comprised of users, and, thus, welcomed Australia's move in this direction.

Mr. Higgins said the Australian and U.S. PNT advisory boards should exchange Meeting Minutes.

Dr. Beutler noted that UN recognition is also very important and, perhaps, such recognition should also be sought for RNSS spectrum issues.

Dr. Parkinson endorsed this idea.

Mr. Higgins said the recent UN resolution on geodetic frames shows it was possible to “sell” complex ideas to the UN.

Dr. Pace observed that many UN member states have observer status within the ITU. Therefore, passage of such resolution is feasible.

Dr. Beutler agreed, and said the UN Committee on the Peaceful Users of Outer Space (COPUOUS) should be approached. Acceptance of such resolution is more likely if it is recommended by various sources.

Dr. Camacho-Lara noted that participants at the upcoming ICG-10 meeting in November 2015 represent a significant portion of COPUOUS and, therefore, he urges such effort to go forward and be coupled with a statement that the entirety of Latin America supports this step.

Dr. Parkinson asked who should take the initiative. He suggested Dr. Camacho-Lara, Dr. Pace, and Mr. Higgins to discuss what the Advisory Board can best contribute.

Mr. Higgins noted that Ms. Neilan has been heavily involved in securing the UN endorsement.

Dr. Parkinson noted he finds it interesting that China was among the signatories.

4) Assurance of PNT Outside North America
Dr. Refaat Rashad (Egypt)

Dr. Rashad said he would speak to the issue of “protection” and “toughening” outside of North America. Protection involves enforcement of national laws and regulations. The majority of the world’s nations do little to enforce laws regarding GNSS spectrum protection. Relatively little thought is given to geo-location and detection. Therefore, it becomes necessary to seek agreements with equipment manufacturer to market smart receivers that are more resistant to interference.

On GNSS augmentation, accuracy and integrity are typically provided through national differential GPS systems and through SBAS, such as EGNOS-augmented GPS over the Europe and the Mediterranean. In terms of backups, if eLoran were implemented in Loran-C sites throughout the world, then GPS would have a smooth and wide backup in the event its signals are not available. At the moment only a few countries (United Kingdom and South Korea) have decided to deploy eLoran. In addition, there is talk in northern Europe on creating a chain of eLoran stations. Therefore, there is a very real problem of what is going to be the backup system in the rest of the world. If one looks at Africa, there are large areas of significant economic and political disruption, and they are “spreading like a cancer.” Political terrorism could lead to possible jamming/spoofing attacks. This underscores the need for a GPS backup system. One cannot afford to leave these threatened areas without assured backup. At this time there is no simple solution that can offered to protect GPS worldwide, but at the very least we should seek to establish more bilateral and multinational agreements, including ways to enforce them.

On the question of recovery, detection and mitigation of interference and spoofing is difficult and costly in the U.S. In many countries, detection and mitigation is virtually impossible without international assistance. Technical support from the U.S., Europe, and Japan is essential to pursue this effort. Assuring PNT within U.S. borders is not sufficient.

5) GNSS Activities of the Regional Center for Space Science and Technology Education for Latin America and the Caribbean
Dr. Sergio Camacho-Lara (Mexico)

The Regional Center for Space Science and Technology Education for Latin America and the Caribbean was established through the initiative of the UN in 1984, on the premise that developing countries need to have access to high-level, in-depth education and training. Existing international education and training programs were not sufficient. Even in the developed world, few academic programs are directed specifically towards space science. Most relevant programs are short-term and directed to specific subjects. Now a regional center exists for space science and technology education, with full campus operations in Brazil and Mexico. The objective is to give education to anyone who needs additional training in space science to further their own work. The curriculum has over time been revised in response to the needs and demands of those seeking training. The Center is hosted by the National Institute of Astrophysics, and offers fellowships to cover the 11-month education program. These fellowships make it possible to relieve students of the need to have side jobs while pursuing their education. The Center has also focused its programs on Space Policy and GNSS. It also provides travel and moving expenses, which help in bringing students from Central America and the Caribbean. As a result, many graduates from this programs are having impact on political and policy decision-makers in their countries.

Relating to GNSS, one of the first things done was to gain status as a Galileo Information Center in 2005-2006. Most of this work was done at the Brazilian campus. GNSS and other curricula was developed by “the best people we could find around the world,” so the program would achieve credibility. In many countries there is no traditional awareness of the importance of international behavior with respect to space. Governments do not necessarily know that if they want to start something they’ll need international support.

For GNSS to be used throughout the world, a prerequisite is that people know what is there; what it can do, and how to do it. This required an awareness effort coordinated with capacity-building. Dr. Camacho-Lara explained he has proposed to the ICG that existing centers have a regional reach into Latin America. The Center is a degree-granting institution, both at the bachelor’s and doctoral level. It is hoped master’s degree programs will be added in the areas of space weather, near-earth objects, and broad space research.

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ROUNDABLE DISCUSSION: Recommendations for PNT/EXCOM
Discussion led by Dr. Bradford Parkinson, 1st Vice-Chair

Dr. Parkinson reported the results of the Advisory Board’s straw vote on priorities to be addressed to the EXCOM, namely:

1. GPS as Critical Infrastructure: <u>9 votes</u>
2. GPS Threat Assessment (amended to include “and responses to include detection, pinpointing and elimination”): <u>8 votes</u>
3. FCC Licensing of non-U.S. GNSS Services (current FCC policy conflicts with National PNT policy for a level playing field and risks retaliation. The policy needs to be revisited with input from the Office of the Secretary of Defense Space Policy and Department of State): <u>6 votes</u>
4. Pseudolite Licensing in RNSS Bands: <u>3 votes</u>
5. Strategies for International Engagement – Reciprocal Effects: <u>3 votes</u>
6. Vision for U.S. role in scientific and technical advancement of GNSS (including: (a) develop the vision, and (b) recommend its implementation): <u>3 votes</u>

Dr. Betz said the statement added to the second point (“and responses to include detection, pinpointing and elimination”) should, in his view, be a separate concern. Threat assessment is a technical undertaking, whereas threat response is a matter for government action.

Dr. Parkinson said he views threat assessment in broader terms, and that it should include spectrum threats. As noted by a board member, the highest threats occur when frequencies are no longer available or if regulatory agencies forbid the use of foreign GNSS signals. In this context he likes the approach proposed in Australia which simply defines navigation signals as existing in a category for which no receiver permission is required. The Advisory Board, in presenting to the EXCOM, could restate or provide further justification for earlier recommendations, and this could also serve an educational role. Such educational role is necessary for GNSS, inertial systems, and eLoran. Further, the EXCOM could be given a snapshot of the multi-GNSS satellites now in use, thus underscoring that the “multi-GNSS” world is not a prospect but a reality. Finally, the Board could describe the problems caused by the conflict between current FCC policy on the use of foreign signals and the fact that millions of users already use such signals. Along with this educational role, the Board could reemphasize whatever previously-made points it wishes to restate.

Mr. Shields said that, in his view, the top-rated points are problems the EXCOM is already aware of. The EXCOM may prefer hearing suggestions on how these problems should be addressed.

Dr. Parkinson agreed. In his view the first point (critical infrastructure) is a shorthand suggestion that granting GPS critical infrastructure status – a likelihood which is "slight" – would prompt greater emphasis on threat assessment and mitigation. On threat assessment itself, the Board has previously provided the EXCOM with a statement of need (of how the NCO would coordinate the effort) and a roadmap of pertinent steps.

Mr. Shields reiterated that it is preferable to discuss solutions rather than problems.

Mr. Goward said clear communication with the EXCOM is essential. It is important to bear in mind that EXCOM members may lack familiarity with matters within the Board's range of concern.

Dr. Parkinson agreed. EXCOM members are intelligent, but not necessarily familiar with GPS-related issues. Also, the EXCOM recently had considerable turnover.

Dr. Betz said Dr. Parkinson faces two challenges. First, he must make a presentation that couples with its audience. Second, he may face credibility issues since he's seen as "a GPS guy."

Mr. Faga said he believes securing critical infrastructure status should be the highest priority. Still, the discussion is somewhat semantic since one could also argue for the phrase "critical-enabling capability" vs "critical infrastructure." Perhaps more needs to be known on the consequences of achieving that such status before pushing to achieve it.

Mr. Lewis said that in his view there would be little consequence following such designation other than, perhaps, becoming a "member of the club." The Board should, perhaps, think about the consequences of such designation before making a major effort to gain it.

Dr. Parkinson said he hopes such designation would, at the very least, be a "general alert" to federal agencies to avoid actions harmful to GPS.

Mr. Lewis agreed with Dr. Parkinson's earlier suggested use of "critical-enabling infrastructure," as it points towards continuing support. Further, regarding the 2nd bullet point, it emphasizes the need for system protection.

Mr. Higgins said that during similar discussions in Australia, recognition as a "critical enabling infrastructure" was deemed a more powerful position. As noted by Admiral Allen, the status of "critical infrastructure" could carry things the board may not welcome.

Dr. Parkinson said the critical infrastructure recommendation has already been forwarded to the EXCOM. Perhaps, at this time, the Board may wish to modify its view.

Mr. Higgins said the central need is recognition of GPS' importance.

Mr. Goward said such recognition needs to be communicated broadly. It may sound like a public relations task, but it is perfectly valid. In general, the better GPS is understood, the better it is likely to be protected.

Mr. Hatch noted that "critical infrastructure" leads cleanly to the second bullet on "threat assessment and mitigation." He stressed that placing "identification" before "mitigation" is "putting the cart before the horse." Mitigation should be the first priority. Mr. Hatch noted he supports toughening of receivers and providing an immediately-available backup. Many existing systems – including communications, aviation, and high speed trains – can only tolerate six to ten seconds of signal downtime.

Mr. McGurn said too much worry is focused on mitigation. By the time a Tiger Team is dispatched, it may all be over.

Dr. Parkinson generally agreed. As shown by the New Jersey interference event, if in that situation one were dependent on Ground-Based Augmentation Systems (GBAS), the entire airport would have been shut down. However, if the signal were restored quicker then flight paths could be reestablished.

Mr. McGurn said his priority would be to toughen GBAS.

Dr. Axelrad opposed substituting the term "critical-enabling" because many other infrastructures – the power system, for example -- could be similarly viewed.

Dr. Parkinson said the root problem is that a federal definition is having the effect of preventing GPS from achieving "critical infrastructure" status. Hopefully DHS would find a way to declare GPS a "critical enabling infrastructure" without have to go through the full bureaucratic process.

Dr. Betz noted that 13 of the 16 designated critical infrastructures have critical dependence on GPS and, thus, perhaps what is needed is a redefinition of the lexicon.

Dr. Parkinson said the Board's initial recommendation was a good early attempt to educate the marketplace, but many still do not realize their degree of dependence on GPS.

Mr. Harold Martin suggested it may be wise to "tack away" from some of the semantic issues. Some of the words in PPD-21 carry considerable "bureaucratic baggage." Conversations have been held with critical infrastructure stakeholders. Each stakeholder faces a huge risk portfolio which they are trying to address with finite resources. The portfolio includes threats such as hurricanes, earthquakes, homeland security, etc., all of which have actually occurred. It is difficult to persuade people to assign already limited resources to protect GPS from threats critical infrastructure operations haven't experienced yet. Also, 99% of the critical infrastructure is privately-owned. We need to talk to the system operators in a language they can understand. Operators act in accordance with their own understanding and, as such, it becomes difficult for them to believe that concerns for GPS could be on the scale of, for example, Hurricane Sandy.

Dr. Parkinson said the Board understands that the effort to secure "critical infrastructure" may simply be in the "too hard" box and may not be what was needed. His general thinking is that the highest need is a formal recognition of the importance of PNT/GPS and of how federal decisions may affect GPS. Once this is achieved the second priority – creating a threat assessment and a planned response – follows naturally.

Mr. Martin suggested the statement be oriented away from the federal agencies who, in fact, "are already believers." The tough part is, for example, making the case to the privately-owned corporations that actually run the power grids.

Mr. Goward suggested that along with federal agencies, the understanding of the Congress is also required.

Dr. Parkinson said he likes the proposal for development of a vision for technology development along with recommendations for its implementation. A subgroup could be convened to develop concrete wording on the matter. He asked Dr. Axelrad to head this effort and report to the next board.

Dr. Axelrad accepted.

Dr. Parkinson asked Dr. Betz whether the presentation made on spoofing has covered well what the "Toughen" group may wish to present.

Dr. Betz said it has, and added he has prepared a slide that speaks directly to this.

Dr. Parkinson asked that this slide be placed on www.gps.gov.

Ms. Ciganer presented on behalf of the Advisory Board's Working Group 1 ("Protect"):

> RNSS and GNSS operators would be in a stronger position if they took a common position on regulatory matters. The Conference of European Postal and Telecommunications Organizations (CEPT) is circulating a recommendation to allow the use of indoor pseudolites. This could lead to partial, or total, GNSS degradation unless indoor pseudolites are restricted to a dedicated code, which is not something CEPT is requesting. Also, the Electronic Communications Committee (ECC) in Europe has presented a recommendation that states: "Considering that indoor GNSS pseudolites may have the potential to cause partial or total degradation of the accuracy of other position location devices, in particular of non-participative GNSS receivers; that these potential degradation and interference . . . the ECC recommends that indoor GNSS pseudolites should use dedicated codes only as reserved by the corresponding GNSS system operators." Ms. Ciganer then called attention to the following points:
>
> - Point 2.3: The GPS-Directorate does not support civil/commercial terrestrial transmissions in the GPS frequency bands due to the potential to degrade GPS performance.
> - Point 2.4: Issuance of GPS pseudorandom noise (PRN) codes to an administration is not an endorsement or approval of the system for use by the GPS Directorate or the United States Air Force. Administrations are responsible for the operation of their system in accordance with all applicable rules and regulations.

> Ms. Ciganer added that Working Group 1 wishes to make a recommendation for ICG consideration; specifically, that ICG seek harmonized regulation of GNSS commercial pseudolite operations in order to guide operations outside of the band 1559-1610 MHz (and all RNSS and ARNSS bands) on a frequency neutral basis.

Dr. Parkinson expressed concern the ECC's wording could be interpreted as there being no problem if someone were to choose a different PRN code. This issue has been studied in detail and, as indicated by Ms. Ciganer, the best solution is to ensure such devices are kept entirely out of RNSS frequency bands.

Mr. Hatch agreed.

Ms. Ciganer said she will present the recommendation to the appropriate ICG working group.

Dr. Parkinson asked whether endorsement from the board would be of assistance.

Mr. Matt Higgins said that while the Advisory Board by statute reports to the EXCOM, it can nonetheless gain international recognition by simply noting that in a public meeting it has reached a consensus view on this matter and wishes to make that known.

Dr. Parkinson asked Dr. Pace if he sees any difficulty in with this approach.

Dr. Pace said that the extent to which the Advisory Board can perform an educating role it would serve as a constructive step.

Dr. Parkinson asked Dr. Pace to work with Mr. Miller to develop language which, while not a formal recommendation, nonetheless reflects the Advisory Board's strong consensus in support of the recommendation advanced by Ms. Ciganer.

Mr. Higgins asked if anyone has raised this issue at the ICG-9 session in Prague, Czech Republic.

Mr. Miller said Dr. Parkinson gave a presentation. However, when the ICG-10 session is held in November 2015, it would be advantageous to clarify that the Advisory Board has discussed the matter.

Summarizing, Dr. Parkinson said that for the forthcoming EXCOM session, he will put together a briefing including: (1) a short tutorial on PNT alternatives, strengths and weaknesses; (2) Mr. Dimmen's chart showing multi-GNSS use; and (3) Mr. Higgins' chart showing the multiplicity of satellite signals available in Brisbane, Australia. Further, he will modify the Advisory Board's earlier recommendation regarding critical infrastructure to address the difficulty in its implementation as discussed earlier. All Board members will have an opportunity to review this statement before it goes to the EXCOM.

The Advisory Board agreed with this approach.

Dr. Parkinson invited other comments.

Mr. Kirk Lewis said he is concerned that the embrace of multi-GNSS could lead to pressures for reducing individual budgets. Given current operations and launch schedules, there is a foreseeable three- to ten-year period in which no new satellites may be required. As a result, once launches cease they could prove difficult to restart. Furthermore, regarding national sovereignty issues, there is still a need for a minimum number of GPS satellites required to ensure at least 4 are available at any time. This view needs to be defended against potential wishes that "budgeters of the world" may have about spreading costs.

Dr. Parkinson recommended that at the Advisory Board's next session, a Working Group be established to consider this matter and then report to the full Board during the public session.

Mr. Lewis commented this is an issue that needs to be addressed sooner or later. He also suggested that slides also be developed for circulation at the next meeting.

Dr. Parkinson suggested that Mr. Higgins work on this statement so that it can be addressed at the next session.

Mr. Miller and Dr. Parkinson thanked all for their efforts and attention.

The 15th session of the Space-Based Positioning, Navigation, and Timing Advisory Board adjourned at 12:04 p.m., Friday, June 12.

Appendix A: Membership, National Space-Based PNT Advisory Board

Special Government Employees

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

Representatives

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

Executive Director

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

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

Special Counselors

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

Appendix B: Presentations

All presentations are posted on: www.gps.gov (under: www.gps.gov/governance/advisory/meetings/2015-06/)

Briefings presented:

- Assured GPS Strengths and Synergies/Dr. Bradford Parkinson
- National Policy Update: Space-Based PNT Advisory Board/Mr. Harold W. Martin III
- Update on GP S Modernization Efforts/Col Steve Whitney
- GPS; Civil PNT Update/Ms. Karen Van Dyke
- GNSS Multinational Activities Update: Multilateral and Bilateral Issues/Mr. Raymond Clore
- IGS-MGEX: Preparing for a Multi-GNSS World/Dr. Oliver Montenbruck
- Toughening Techniques for GPS Receivers: Navigation Message Authentication/Dr. Todd Humphreys
- Automated Driving for Trucks: Potential, Status, and Challenges/Mr. T. Russell Shields
- Unmanned Aerial Vehicles [UAVs]: Emerging Users – Aviation GPS in UAVs/Captain Joe Burns
- GPS Space Service Volume [SSV]: Ensuring Consistent Utility Across GPS Design Builds for Space Users/Mr. Frank H. Bauer
- Raw Data to Improve Accuracy, Integrity [and] Availability of Satellite Navigation/Dr. James L. Farrell
- The Economic Value of GPS: Preliminary Assessment/Dr. Irv Leveson
- Real-Time and Ionosphere in the IGS/Dr. Gerhard Beutler
- GNSS Market Report/Mr. Arve Dimmen
- International Member Update – Australia/Mr. Matt Higgins
- Assurance of PNT Outside of North America/Dr. Refaat Rashad
- GNSS Activities for the Regional Centre of Space Science and Technology Education for Latin America and the Caribbean/Dr. Sergio Camacho-Lara

Additional Working Group Discussion Topics:

- Working Group 1: Assured Availability -- Protect the Clear and Truthful Reception of Radionavigation Signals/Ms. Ann Ciganer and Mr. Ron Hatch
- Working Group 2: Toughen Team/Dr. John Betz
- Report by the Augment Working Group 3 and International Subgroup/Dr. Matt Higgins and Mr. Terry McGurn

Appendix C: Sign-In List

Thursday, June 11, 2015

PNT Advisory Board members:

Penina Axelrad, Colorado University/Boulder
John Betz, MITRE
Gerhard Beutler, AIUB
Scott Burgett, Garmin International
Dean Brenner, Qualcomm
Sergio Camacho-Lara, CRECTEALC
Ann Ciganer, GPS Innovation Alliance
Arve Dimmen, Norwegian Coastal Authority
Martin Faga, MITRE
Dana Goward, PNT Foundation
Ron Hatch, consultant, John Deere
Matt Higgins, IGNSS
Larry James, Jet Propulsion Laboratory
Terry McGurn, self
Ruth Neilan, Jet Propulsion Laboratory
Brad Parkinson, Stanford University
Refaat Rashad, Arab Institute of Navigation
Russell Shields, Ygomi LLC

Other NASA employees:

Barbara Adde, NASA HQ
Ben Ashman, NASA
Elizabeth Blair Carter, NASA
Benjamin Drew, NASA
James J. Mille, NASA HQ
A. J. Oria, NASA/ Overlook Systems Technologies
Joel Parker, NASA
Calvin Ramos, NASA HQ
Stephanie Wan, NASA/ Overlook Systems Technologies

Other attendees:

James Arnold, Department of Transportation
Frank Bauer, Fbauer Aerospace Consulting
Mark Bernstein, ASRCMS
Jim Burton, National Coordination Office
John Cabala, Federal Aviation Administration
Jim Campion, Department of Defense
Ray Clore, Department of State
Rob Crane, Department of Homeland Security/National Coordination Office
Dee Ann Davis, *Inside GNSS*
Chris Eagan, National Coordination Office
Jim Farrell, VIGIL, Inc.
John Grosspietsch, Roberson & Associates
Steve Grupenhagen, SAF
Glenn Guempel, United States Geological Service
Jonathan Hardin, NIST
Jim Johansen, Aerospace Corporation
Matt Jones, Boeing
Jason Kim, National Oceanographic and Atmospheric Administration
Max Larosa, Thales
Rick Lee,
Irv Leveson, Leveson Consulting
J. Kirk Lewis, IDA [special counselor]
Tim Logue, Thales

Harold Martin, National Coordination Office
Jeff Miller, A4A
John McDonald, Harris Corporation
Oliver Montenbruck, DLR [German space agency]
Fred Moorefield, Department of Defense
Dave Olsen, Federal Aviation Administration
Scott Pace, George Washington University [special counselor]
Tom Powell, Aerospace Corporation
Morgan Roper, United States Coast Guard
Charles Schue, URSA Nav
Karen Van Dyke, U.S. Department of Transportation
Jerry Waldron, Covington
Kyle Wesson, Zeta Associates
Col. Scott Whitney, U.S. Air Force

Friday, June 12, 2015

PNT Advisory Board members:
Penina Axelrad
John Betz
Gerhard Beutler
Ann Ciganer
Arve Dimmen
Martin Faga
Ron Hatch
Matt Higgins
Peter Marquez
Brad Parkinson
Russell Shields

Other NASA employees:
James J. Miller, NASA HQ
Stephanie Wan, NASA/ Overlook Systems Technologies

Other attendees:
Mark Bernstein, ASRCMS
Dee Ann Davis, *Inside GNSS*
John Grosspietsch, Roberson and Associates
Max Larosa, Thales
L. Kirk Lewis, IDA
Tim Logue, Thales
Jeff Miller, A4A
Mitch Narins, Federal Aviation Authority
David Olsen, Federal Aviation Authority
Scott Pace, George Washington University
Tom Powell
Paul Swain, Covington & Burling, LLP
Karen Van Dyke, Department of Transportation

Appendix D: Acronyms & Definitions

ADSB	Automatic Dependent Surveillance Broadcast
AMA	Academy Model Aeronautics
ARNSS	Aviation RNSS
ASF	Additional Safety Factors
BeiDou	China's GNSS
CEPT	European Conference of Postal and Telecommunications Administrations
C-ITS	Cooperative Intelligent Transport Systems
CNAV	GPS Civilian Navigation Message
COA	Certificate or Waiver of Authorizations
COPUOUS	Committee on the Peaceful Users of Outer Space
CPNT	Complementary PNT
CRECTEALC	UN Center for Regional Education of Science and Space Technology for the Caribbean
DHS	Department of Homeland Security
DOC	Department of Commerce
DoD	Department of Defense
DOT	Department of Transportation
E911	Enhanced 911. A system in the U.S. that links emergency callers with the appropriate public resources.
ECC	(European) Electronic Communications Committee
EGNOS	European Geostationary Navigation Overlay Services
eLoran	Enhanced Loran
ESG	PNT EXCOM's Executive Steering Group
EXCOM	PNT Executive Committee
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FOC	Full Operational Capability
FRA	Federal Railroad Administration
FRP	Federal Radionavigation Plan
Galileo	European GNSS
GBAS	Ground-Based Augmentation System
GDGPS	NASA Global Differential GPS System
GGRF	Global Geodetic Reference Frame
GIS	Geographic Information Systems
GLONASS	Russian GNSS
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPS-D	GPS Directorate
GRACE	Gravity Recovery and Climate Experiment
GSFC	NASA Goddard Space Flight Center
GSO	Geosynchronous Orbit
HEO	High Earth Orbit
ICAO	International Civil Aviation Organization
ICAR	International Center for Atmospheric Research
ICG	UN International Committee on GNSS
IGS	International GNSS Service
IGS-MGEX	International GNSS Service Multi-GNSS Experiment
IMO	International Maritime Organization
IRT	Independent Review Team
IOV	In-Orbit Validation
ITU	International Telecommunications Union
L1 C/A	GPS L1 Coarse Acquisition (C/A) Signal
L1C	GPS 4th civilian signal
L2C	GPS 2nd civilian signal
L5	GPS 3rd civilian signal
LNAV	Legacy Navigation
Loran-C	Long Range Navigation
M-Code	GPS New Military Signal

MEO	Medium Earth Orbit
MGUE	Military GPS User Equipment
NAICS	National American Industrial Classification System
NASA	National Aeronautics and Space Administration
NDGPS	Nationwide Differential GPS
NCO	National Coordination Office
NHTSA	National Highway Traffic Safety Administration
NMA	Navigation Message Authentication
NOAA	National Oceanographic and Atmospheric Administration
NPI	Australia's National Positioning Infrastructure Plan
NPI-AB	NPI Advisory Board
NPRM	Notice of Proposed Rulemaking
NTRIP	Networked Transport of Radio Technical Commission for Maritime Services (RTCM) via Internet Protocol
OCX	GPS Next Generation Operational Control System
PNT	Positioning, Navigation, and Timing
PPD	Presidential Policy Directive
PRN	GPS Pseudorandom Noise Code
QZSS	Japan's Quasi-Zenith Satellite System
RAIM	Receiver Autonomous Integrity Monitoring
RNSS	Radio Navigation Satellite Service
ROTI	Rate of Total Electron Count (TEC) Index
RPM	Receiver Power Monitoring
RTCA	Formerly the Radio Technical Commission for Aeronautics, now RTCA, Inc.
RTS	IGS Real Time Service
SBAS	Space-based Augmentation System
SCER	Security-Code Estimation and Replay
SGE	Special Government Employee
SISRE	Signal-in-Space Range Error
SSV	Space Service Volume (volume of space between 3000 km and Geosynchronous Orbit altitudes)
SV	Satellite Vehicle
UAS	Unmanned Aircraft Systems
UAV	Unmanned Air Vehicle
UN	United Nations
VLOS	Vehicle Line of Sight
WAAS	FAA's Wide Area Augmentation System