SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

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

Twenty-Seventh Meeting

November 16-17, 2022

Sonesta Redondo Beach

Redondo Beach, CA

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

Mr. James J. Miller, *Executive Director*

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Meeting Agenda

Day 1: November 16, 2022
Link to Day 1 video: https://youtu.be/-rnBa-az2dI

WEDNESDAY, NOVEMBER 16, 2022		
9:30-9:35 (5 min)	**BOARD CONVENES** *Call to Order, Logistics, & Announcements*	Mr. James J. Miller, *Executive Director, National Space-Based PNT Advisory Board, NASA HQ*
9:35-9:45 (10 min)	27th PNTAB Welcome & Introduction – Overview by Chairs – Meeting Goals & Objectives – Follow-up to Sep. 8 PNT EXCOM	ADM Thad Allen, *Chair, PNTAB* Dr. Brad Parkinson, *1st Vice Chair, PNTAB* Gov. Jim Geringer, *2nd Vice Chair, PNTAB*
9:45-10:15 (30 min)	Assuring PNT: Issues & Observations – ITAR Constraints on U.S. Innovation & Resilience **View PDF**	Dr. Brad Parkinson, *1st Vice Chair, PNTAB*
10:15-11:45 (90 min)	Subcommittee Updates: Topics & Priorities (15 min each) – Communications & External Relations (CER) **View PDF** – Education & Science Innovation (ESI) **View PDF** – Emerging Capabilities, Applications, & Sectors (ECAS) **View PDF** – International Engagement (IE) **View PDF** – Protect, Toughen, & Augment (PTA) **View PDF** – Strategy, Policy, & Governance (SPG) **View PDF**	Subcommittee Chairs – Mr. Dana Goward – Dr. Jade Morton – Dr. Penny Axelrad & Mr. Scott Burgett – Mr. Matt Higgins – Dr. John Betz – Mr. Jeff Shane
11:45-12:00 (15 min)	PNT EXCOM Policy Update: – Strategic Plan for Potential Interference (SPPI) **View PDF** – Temporary CORS (T-CORS) Project **View PDF**	Mr. Harold (Stormy) Martin III, *Director, National Coordination Office for Space-Based PNT*; and Ms. Juliana Blackwell, *Director, National Geodetic Survey, NOAA*
12:00-12:30 (30 min)	DOT Strategic Plan for GPS/GNSS Interference Detection: Notification & Action Framework **View PDF**	Ms. Karen Van Dyke, *Director, PNT & Spectrum Management, Dept. of Transportation (DOT)*
12:30-1:30	**LUNCH *(Seascape Room)***	
	Theme 1: International Engagement - Ensuring Interoperability & Innovation	
1:30-2:00 (30 min)	International Committee on GNSS (ICG) & Concise Update on International Traffic in Arms Regulations (ITAR) **View PDF**	Mr. Jeff Auerbach, *Acting Director, Office of Space Affairs, Department of State*
	Theme 2: Protect, Toughen, Augment (PTA)	
2:00-2:30 (30 min)	GPS Modernization Status: Enhancing Capabilities & Resiliency **View PDF**	Ms. Barbara Baker, *Deputy Program Executive Officer for MilComm & PNT, Space Systems Command, U.S. Space Force*
2:30-3:00 (30 min)	LEO Constellations for Navigation: Overview, Details of Starlink, How LEO can Backup GPS **View PDF**	Dr. Zak Kassas, *Director, DOT Center for Automated Vehicles Research with Multimodal AssurEd Navigation (CARMEN), Ohio State Univ.*
3:00-3:30 (30 min)	Leveraging a LEO Satellite Constellation for Accurate & Reliable PNT **View PDF**	Mr. Patrick Shannon, *Founder & CEO, TrustPoint, Inc.*
3:30-4:00 (30 min)	LEO PNT Constellation Progress & Technology Roadmap **View PDF**	Mr. Bryan Chan, *Co-Founder and VP of Business Development & Strategy, Xona Space Systems*
4:00-4:15	**BREAK**	
4:15-4:45 (30 min)	Supercorrelation: Software Upgrade to Toughen GNSS Receivers from Jamming & Spoofing **View PDF**	Dr. Ramsey Faragher, *CEO & CTO, Focal Point Positioning, Ltd.*
4:45-5:15 (30 min)	Broadcast Positioning System Using ATSC 3.0 TV Signals **View PDF**	Mr. Sam Matheny, *Exec. VP & CTO, National Association of Broadcasters (NAB);* and Mr. Tariq Mondal, *VP of Advanced Tech., NAB*
5:15-5:45 (30 min)	Quantum-enabled PNT Technologies for the Future: A Focus on Next-Generation, Deployable, Atomic Clocks **View PDF**	Dr. Judith Olson, *Senior Physicist, Head of Atomic Clocks Group, Cold Quanta*
5:45-6:00 (15 min)	Key Highlights & Closing Thoughts: *Deliberation Preparation for Nov. 17*	All members, led by ADM Thad Allen
6:00	**ADJOURNMENT**	

Day 2: November 17, 2022
Link to Day 2 Video: https://youtu.be/fvk9UOtnbUE

THURSDAY, NOVEMBER 17, 2022		
9:00-9:05 (5 min)	**BOARD CONVENES** *Call to Order*	Mr. James J. Miller, *Executive Director, National Space-Based PNT Advisory Board, NASA HQ*
9:05-9:15 (10 mins)	PNTAB Leadership Observations from Day 1 & Member Feedback	ADM Thad Allen, *Chair, PNTAB* Dr. Bradford Parkinson, *1st Vice Chair, PNTAB* Gov. Jim Geringer, *2nd Vice Chair, PNTAB*
9:15-10:45 (90 min)	Updates from International Members & Representatives (15 min each) – Croatia – Australia (Australia & New Zealand PNT Developments) **View PDF** – United Kingdom **View PDF** – Resilient Navigation and Timing (RNT) Foundation – Consumer Technology Association (CTA) – International Air Transport Association (IATA)	Representatives (At member's discretion) – Dr. Renato Filjar – Mr. Matt Higgins – Prof. Terry Moore – Mr. Dana Goward – Mr. David J. Grossman – Mr. Jeff Shane
10:45-10:55	**BREAK**	
10:55-11:55 (1 hr)	Roundtable Recommendation Presentation & Adoption **View PDF**	Subcommittee Chairs to Present Findings and/or Proposed Recommendations
11:55-12:00 (5 min)	Wrap-Up – Determine venue & date for next meeting	ADM Thad Allen, *Chair, PNTAB* Dr. Bradford Parkinson, *1st Vice Chair, PNTAB* Gov. Jim Geringer, *2nd Vice Chair, PNTAB*
12:00-1:00	**LUNCH – Working as needed *(Seascape Room)***	
1:00	**ADJOURNMENT**	

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Executive Summary

The National Space-Based PNT Advisory Board (PNTAB) held its 27th public meeting on November 16-17, 2022, in Redondo Beach, CA. The meeting was held under the provisions of the Federal Advisory Committee Act (FACA), with appropriate public notification & documentation for the public record. A fact-finding preparatory meeting was held on November 15.

On November 17, the board's six subcommittees presented the results from fact-finding meetings in support of a set of draft recommendations, which are summarized in Appendix D (Summary of Draft Recommendations), pp 98-102. The PNTAB reviewed and approved them. After the meeting, the draft recommendations were further refined, prioritized, and consolidated.

On January 27, 2023, the UAG Chair, ADM Thad Allen (USCG, ret.), submitted to the PNT Executive Committee (PNT EXCOM) co-chairs a report summarizing the meeting findings and recommendations. This report can be found in Appendix E (ADM Allen Report to PNT EXCOM Co-Chairs), pp 103-106.

The PNTAB recommendations were categorized into three major themes:

1. **GPS Monitoring, Disruption Public Warning, and Risk Assessment**

   PNT27-01-CER: The National Space-Based PNT Executive Committee (PNT EXCOM) is urged to develop a compelling, quantitative way to accurately express the economic damages to the nation attributable to extended disruptions to GPS services.

   PNT27-02-CER: The Department of Transportation is urged to issue public warnings to GPS users as soon as possible after the beginning of significant disruption events.

   PNT27-08-PTA: The U.S. Government (USG) should rapidly prototype a National GNSS Interference Detection and Reporting system based on mobile wireless technology. Such a system would have been very beneficial in responding to multiple interference events at major U.S. airports in 2022.

2. **Fully Integrating Threats to and Protection of PNT Technology Within Existing Cyber Security Measures**

   PNT27-03-CER: PNT security should be made a prominent part of the National Cyber Director's responsibilities. Departments and agencies should include PNT security in their cyber portfolios.

3. **Revision of Existing Response Doctrine, Plans, and Policies, Together with Increased Planning to Prevent, Detect, and Mitigate Disruptions**

   PNT27-04-ECAS: USG to develop and implement a GPS High Accuracy and Robustness Service (HARS) delivered to users via the Internet, with performance initially comparable to other GNSS, such as the European Union's Galileo High Accuracy Service (Galileo HAS). The service would provide corrections to support better than one-meter position accuracy, while providing cryptographically-protected satellite navigation data bits for integrity monitoring & spoofing resistance.

   PNT27-05-ESI: USG to invest in the future of U.S. PNT education and training. There is a definitive shortage of geodesy experts being trained in relation to competitor nations such as China.

   PNT27-06-PTA: There currently are wildly diverse opinions concerning the likelihood and extent that the GPS infrastructure could fail to provide useful signals in different time frames. Those making risk management decisions, and those investing in Protect, Toughen, and Augment, lack the information needed to select the appropriate approaches, and how urgent it is to implement them. Therefore, the USG should establish, publish, and maintain estimates of the likelihood that GPS would not provide sufficient useful civil signals, due to failures of the GPS infrastructure (GPS Ground Segment, GPS Space Segment, and GPS user equipment) from any cause.

   PNT27-09-SPG: Convene a White House summit to recognize and celebrate U.S. achievements with GPS and to launch an initiative to regain U.S. PNT leadership and ensure resilient, reliable PNT for critical infrastructure and the larger economy. GPS's capabilities are now substantially inferior to those of China's BeiDou.

   PNT27-10-SPG: The Executive Office of the President (EOP) should undertake an Administration-wide review of domestic radio spectrum regulation processes.

In addition, the PNTAB subcommittees is developing four White Papers to reinforce these recommendations:

1. *Celebrating GPS 50th Anniversary & Regaining U.S. PNT Leadership*: To highlight how essential GPS services have become to the U.S. and the world and to plan for regaining U.S. PNT leadership over the next decade, a White House summit should be convened on or around December 17, 2023, to commemorate the 50th anniversary of the start of the GPS program and to celebrate its achievements and the immense economic benefits to the nation. The outcome of the summit should be a statement of national resolve to regain U.S. global leadership of PNT technology, and a plan to achieve it.

2. *Addressing Shortfalls in PNT Education & Science*: To ensure the U.S. maintains its leadership, funding should be increased to enhance PNT Research & Development, including Geodesy, and to strengthen education and training across U.S. academia and research institutions.

3. *Implementing a GPS High Accuracy and Robustness Service*: To augment GPS and overcome some inherent limitations of space-based PNT, the USG should provide a service comparable to the European Union's Galileo HAS that provides signal corrections than enable better than one-meter level accuracy, as well as cryptographically-protected satellite navigation message data bits for integrity processing. The U.S. should develop and implement GPS HARS, based on the capabilities developed by the Jet Propulsion Laboratory (JPL) for the Global Differential GPS System (GDGPS), to be made available to users over the Internet.

4. *Modifying U.S. International Traffic in Arms Regulations (ITAR) on GPS Commercial Users*: To toughen GPS and enhance user access and reliability, the USG must modify export control regulations that are restricting commercial use of adaptive antijam antenna systems protecting GNSS receivers. The original intent to mitigate proliferation of this technology has been superseded by development and fielding of this technology by U.S. competitors.

This report summarizes the discussions & deliberations during this meeting. Snapshots of the briefings presented have also been embedded. For the full resolution briefing slides, see the embedded links in the meeting agenda (pages 3-4) and next to the briefing title in each section of the document.

Session of Wednesday, November 16, 2022

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

Mr. Miller noted this was the Call to Order for the 27th PNTAB meeting. Today is another beautiful California day. For many of us who traveled from the east coast cold, it is blue and sunny and warm. However, today is even more beautiful, than just another Wednesday morning in Redondo Beach. It is more beautiful, because it is a day already marked by success and progress for all of us, around the world! And this is because, just last night, prior to us all going off to sleep – the National Aeronautics and Space Administration (NASA) successfully launched, the first Artemis mission, towards the Moon, a critical first step, in a series of missions that will become as famous to our younger generation, as Apollo was to ours. Last night many of us, despite the concerns that haunt any rocket launch – we gathered as a group around the Hyperwall just outside, to wait and watch, as the Artemis rocket countdown continued, was then put on hold, then continued, and then put on hold. And finally, the world's rocket took off from the launch pad, and we all cheered as it flew forcefully skyward. Now the shouts in that room were loud and happy because we were all very excited. This moment was years in the making, and the Space Launch System (SLS), joined with its crew capsule Artemis, were new, untested technologies – being sent into the most hostile region between the Earth & Moon for the very first time. A failure could have harmed the U.S. space program for years to come – however instead as we all know -- we jump started it! And of course -- even our Artemis missions will be using the Global Positioning System (GPS) and other similar systems way beyond what they were originally designed for.

For today's meeting, let's try to recapture that feeling of accomplishment and national pride. It could be said that Dr. Parkinson initiated the GPS program in the early 1970s, at just around the same time that the Apollo Moon missions were drawing to a close. And so, in many ways, GPS became one of the many technology substitutes, for the Moon missions. Since then, GPS has come to serve the entire world, in many ways that we never imagined back then, just like the Apollo program created spin-fffs, that we still enjoy together, such as Velcro! When I came back to my room last night, I had several Congratulations from space sector friends around the world, ranging from the U.S. & Europe, to even colleagues in China. So that tells us that the world is watching again, and it would be in all our collective interests, if the world once again takes notice to what GPS still has to offer, building on so much of what it has already contributed to understanding our planet Earth, and in making our lives easier, safer, and more secure. So, with that note, let me please recognize Ms. Barbara Baker from the U.S. Space Force (USSF). She has come here as a contributor to our deliberations, and she represents the best of what GPS has to offer. Ms. Baker will provide us with an update of the newest capabilities that GPS will have in the coming decade.

Today's session is Chaired by ADM Thad Allen, former U.S. Coast Guard (USCG) commandant, and by our 1st Vice-Chair, Dr. Brad Parkinson, the chief architect of the GPS program. We do have some members who will be online virtually, and so I note for our Chair that we do have a quorum to proceed. As a reminder, PNT Board deliberations are governed by the Federal Advisory Committee Act (FACA), which means that discussions are open to the public, and meeting minutes will be posted online at www.GPS.gov, within 90 days for the record. We also strive to post all briefings within 24 hours of their presentation here, and several may be posted already this morning for all to follow along, thanks to our Commerce colleague, Mr. Jason Kim. All members were appointed by the NASA Administrator after going through a throughout vetting process of the PNT EXCOM, and they are here to provide diverse views as users, outside the traditional bounds of government. And so, PNTAB recommendations as independent advice and council, are meant to serve a critical function by assessing issues from the unique and transparent perspectives of Special Government Employees (SGE) and Representatives. Their time is volunteered, and they end to be straightforward and blunt. As SGEs deliberate, they must abide by established ethics laws that require them not to engage in any discussions that may create a potential conflict of interest. And because some of our topics may be complex -- if a member does believe that the appearance of a potential conflict on a particular matter is emerging, we ask that you proactively and clearly recuse yourself from that subject matter.

With this, Mr. Miller turned the meeting over to the Chair, ADM Thad Allen.

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27th PNTAB Welcome & Introduction
Goals & Objectives, Establishment of Six New Subcommittees
ADM Thad Allen, *Chair*

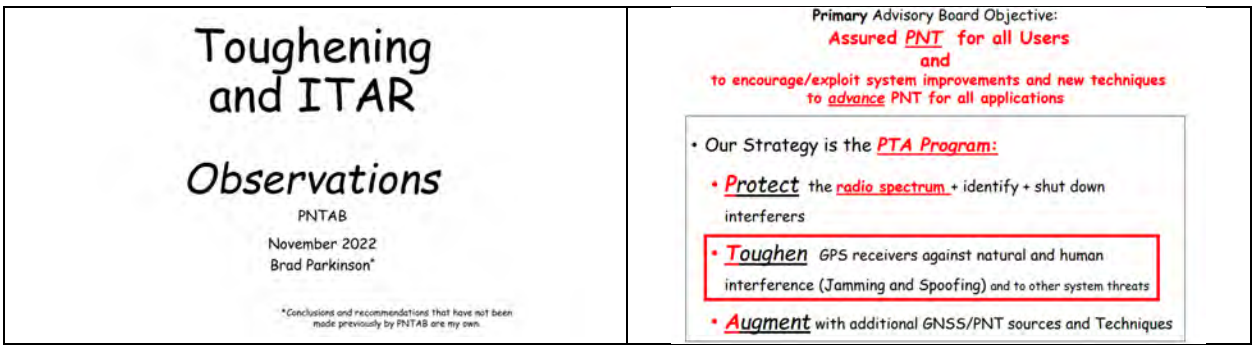
ADM Allen opened by stating that this Advisory Board is a work in progress. During the past couple meetings, the Board has tried to cover more ground by creating subcommittees to address issues.

ADM Allen introduced Dr. Brad Parkinson, who will discuss ITAR constraints and procedures.

* * *

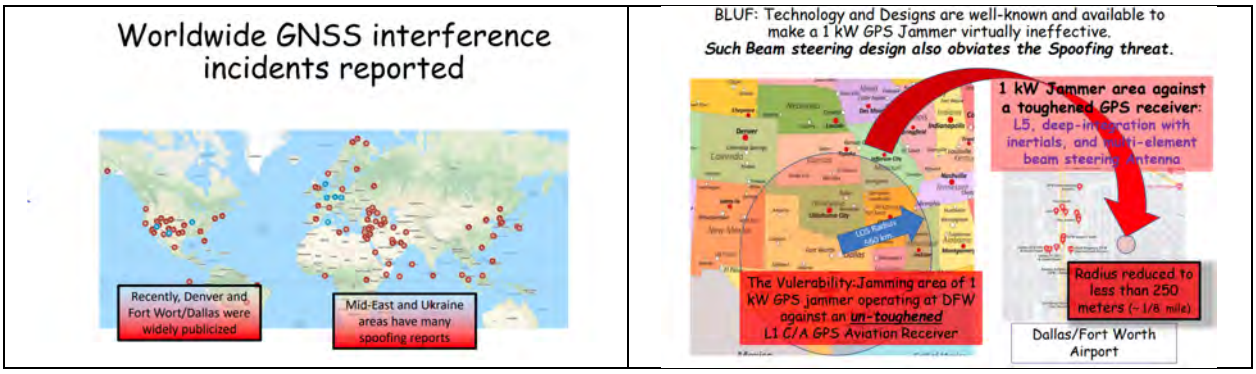
ITAR Constraints on U.S. Innovation and Resilience (View PDF)
Dr. Brad Parkinson, *1st Vice Chair, PNTAB*

Dr. Parkinson noted that the views presented are solely his (Slide 1). The purpose of the board is to ensure PNT to all users and encourage system improvements for all applications. That's how the board came up with the Protect, Toughen, and Augment (PTA) strategy. This briefing focuses on its Toughen component (Slide 2).



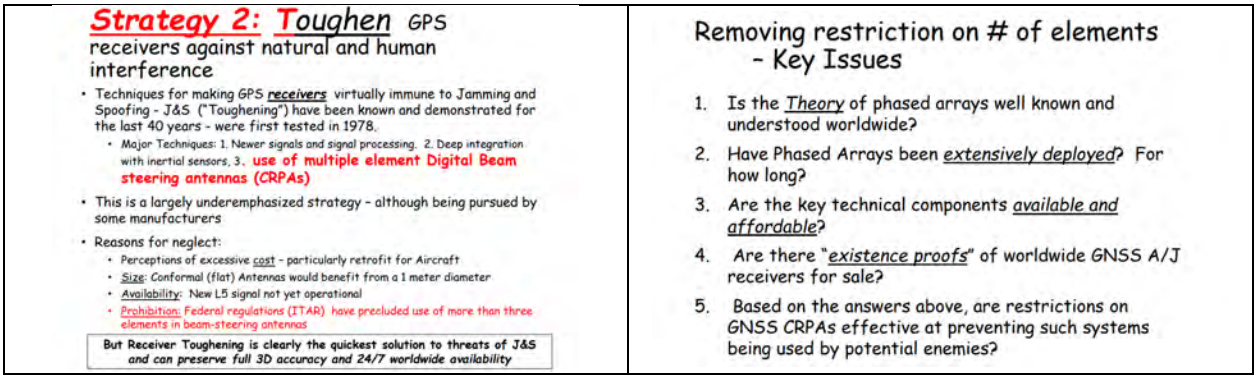
Slides 1-2

Slide 3 depicts examples of GNSS interference across the world. The real number of incidents is probably at least 10 times that what has been reported. Slide 4 shows the Bottom-Line Up Front (BLUF). There are GNSS receivers on the market able to defeat a 1 kW jammer, but they are not available to commercial operators. The map is centered on Dallas, and shows the vulnerability radius (approximately 550 km) for a 1 kW jammer when operating against an untoughened GPS L1 C/A receiver. When expanding the map, we can see the vulnerability radius of that same 1 kW jammer, when operating against a toughened receiver (i.e., one that that is using GPS L5, beam steering, etc.), receiver is much smaller (less than 250 m). Such capability, if implemented, would make GPS users essentially immune to such threats.



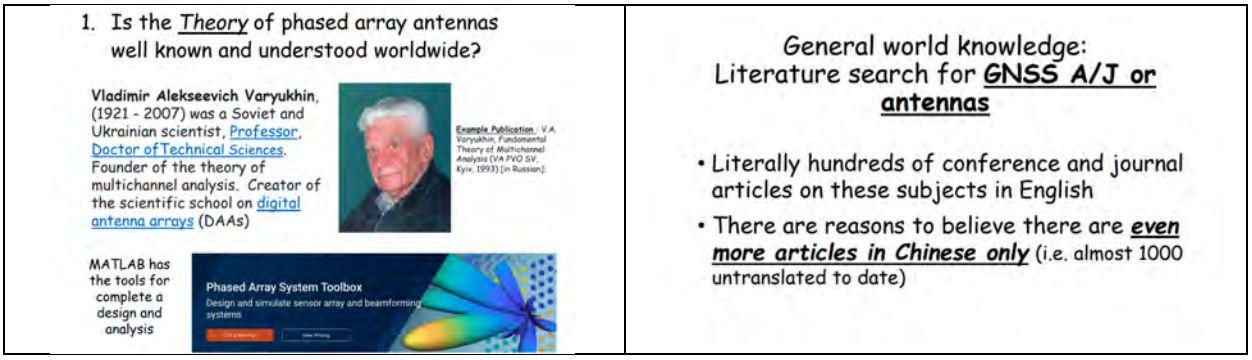
Slides 3-4

This brings us to the 'Toughen' component (Slide 5). The toughening techniques are well known. However, they are currently underemphasized because the GPS L5 has not yet reached full operational capability, and also because of the perceived cost to retrofit equipment. ITAR regulations restrict U.S. manufacturers from selling receivers with more than three elements in beam steering antennas (Slide 6). However, these regulations aren't really fulfilling their original intent. We are now going to address key issues regarding these regulations.



Slides 5-6

In response to the first question, the gentleman shown in Slide 7 is considered the father of phased arrays. In 1993 he wrote a textbook on phased arrays. The point is that this technology is very well known, and nowadays when you go into MATLAB there is already an entire toolbox dedicated to phased array design. So, the theory is well known. There are hundreds of published articles in English, and we have reasons to believe there many more, possibly over a thousand, written in Chinese (Slide 8).



Slides 7-8

The second question is whether phased arrays have been expensively deployed. The answer is yes. The L-band pencil beam antenna shown here was deployed over 50 years ago (Slide 9). The third question is whether key L-band technical components are available? The answer is also yes. One can go on the internet and find devices such as the one shown on Slide 10.

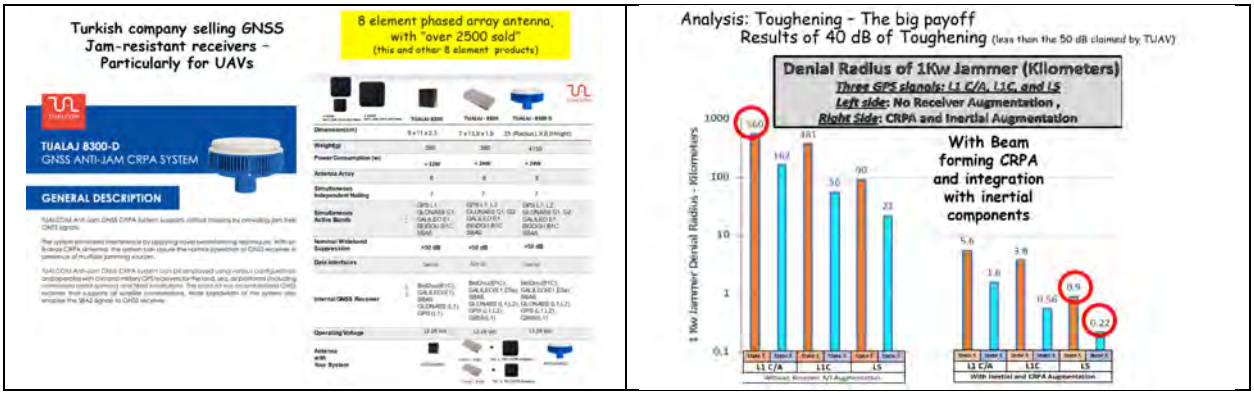
Slides 9-10

The fourth question is whether there is evidence of GNSS anti-jam receivers for sale around the world (Slide 11). Back in 1973 it was already clear to Dr. Parkinson that, because the GPS signal is weak, there was a risk that GPS would not be approved. Therefore, he sponsored a high anti-jam receiver demonstrator at the Air Force Research Laboratory (AFRL). The point is that over 40 years ago we built and demonstrated 50 dB (that's 100,000 times) improvement in resistance to jamming (Slide 12).

Slides 11-12

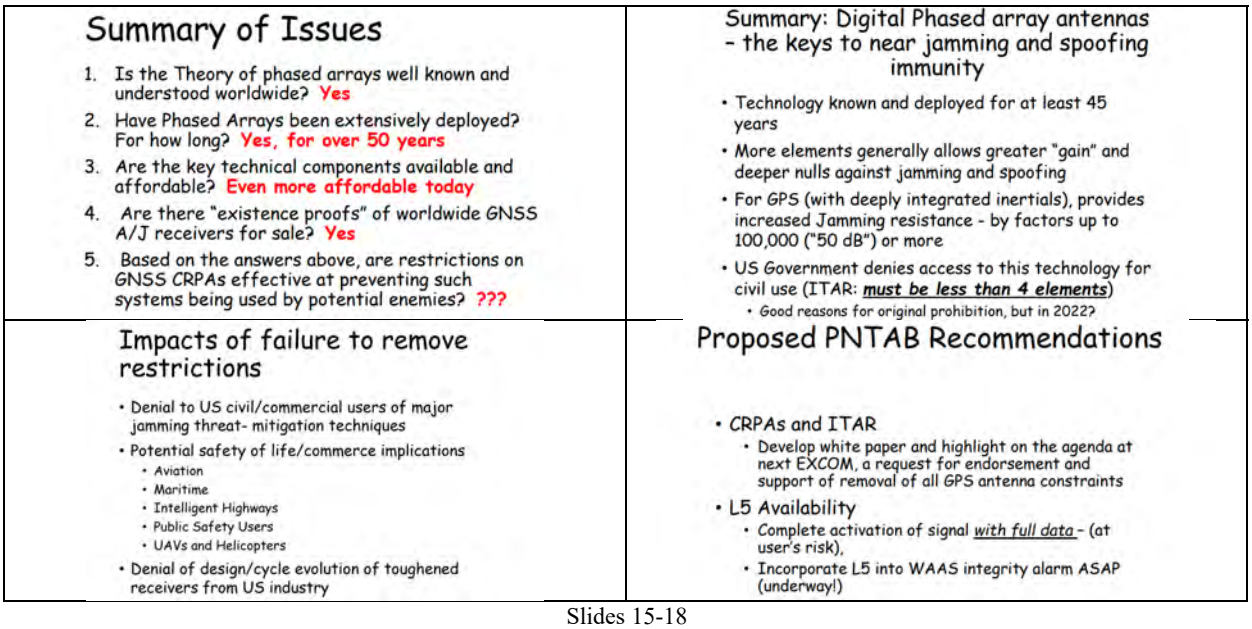
What about specific examples of anti-jam receivers around the world? There happens to be a company in Turkey that is already marketing GNSS anti-jam 8-element controlled reception pattern antennas (CRPS) system. This company has also indicated it will soon release a 16-element system (Slide 13). Note that ITAR restricts U.S. commercial equipment manufacturers to no more than three elements. Thus, Unmanned Aerial Vehicles (UAVs), equipped with foreign-built 8-element GPS anti-jam antennas jamming resistance over 10,000 times what the USG allows for commercial aircraft, may already flying over the Middle East. Clearly, the USG should fix these obviously ineffective restrictions on technology. Let's quantify what this means (Slide 14). On the left we have the effective jamming radius of a 1 kW jammer. The graph shows the effect on so-called State 3 (code tracking only) &

State 5 (code and carrier tracking). On the left we have the effective jamming radius when using an untoughened GPS receiver. When tracking the GPS L1 C/A signal, for State 3 tracking the receiver is jammed within 560 km, and if we add GPS L5 the jamming radius decreases to 90 km. On the right we see what happens when adding beam forming CRPA and integrating inertial components. The jamming radius decreases to 5.6 km for L1 C/A tracking, and just 0.9 km for L5 tracking (State 3). The bottom line is that a hostile 1 kW jammer would become an exercise in futility.



Slides 13-14

In summary, the first four questions in Slide 6 have been addressed, and the answer to the fifth question (whether restrictions on GNSS CRPAs are still effective to prevent the proliferation of such systems) also seems clear. Digital phased array antennas are the key to near immunity from jamming and spoofing, while current ITAR restrictions have been superseded by events (Slides 15-17). To wrap-up, Dr. Parkinson presented two proposed recommendations: (1) Develop a White Paper on CRPAs & ITAR, and (2) Request the PNT EXCOM endorsement to remove ITAR restrictions & incorporate L5 into Wide Area Augmentation System (WAAS) integrity (Slide 18).



Slides 15-18

Discussion:

Mr. Shane asked who would be responsible for acting on these recommendations.

ADM Allen noted that following the ITAR briefing from the Dept. of State (DOS) in the afternoon, the board can discuss a path forward on this issue.

Mr. Higgins asked if there are benefits in GPS L5 and Galileo E5 tracking?

Dr. Parkinson said it would be a multiplier. The advantage in using GPS L5, and/or Galileo E5, is that they provide a wider bandwidth and stronger signal which, in turn, allows the user to average better. Effectively, it gives you a more robust signal.

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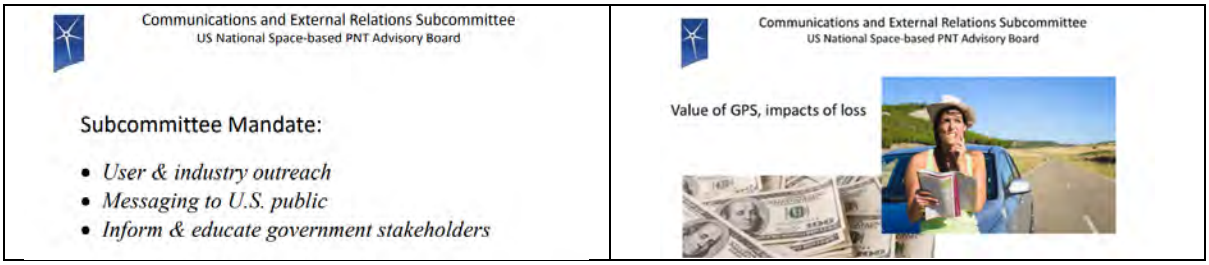
Subcommittee Updates: Topics & Priorities

ADM Allen asked subcommittee chairs to pr ovide an update and review their progress.

1) *Communications & External Relations (CER) Subcommittee (**View PDF**): Mr. Dana Goward*

Mr. Goward noted the that this briefing focuses on the value of GPS and the impacts of its loss, and we could improve outreach to users, industry, and the public (Slides 1-2). The RTI study conducted in 2018, sponsored by the Department of Commerce (DOC), found that about $1B/day would be lost in the U.S. economy should GPS not be available. This sounds like a big number when the total Gross Domestic Product (GDP) of the U.S. is considered, but GPS is essential to so many things that looking at the monetary cost alone may not be an accurate reflection of the total cost.



Slides 1-2

The subcommittee has discussed how the government talks about GPS disruptions (Slide 3). Dr. Parkinson previously discussed the two incidents that occurred this year in Denver & Dallas. The broader civilian community did not find out about the Denver incident until eight months later when presentation was given at the Civil GPS Service Interface Committee (CGSIC). However, the Dallas interference event made the news quickly. The government has not said a lot about either incident. The subcommittee has also discussed how the USG talks about PNT (Slide 4). Is it a cyber capability? Is it an IT capability or electronic warfare? Or is it something else? The way we talk about PNT, and the impact to it being disrupted, influences the public's understanding of GPS capabilities and limitations.

Slides 3-4

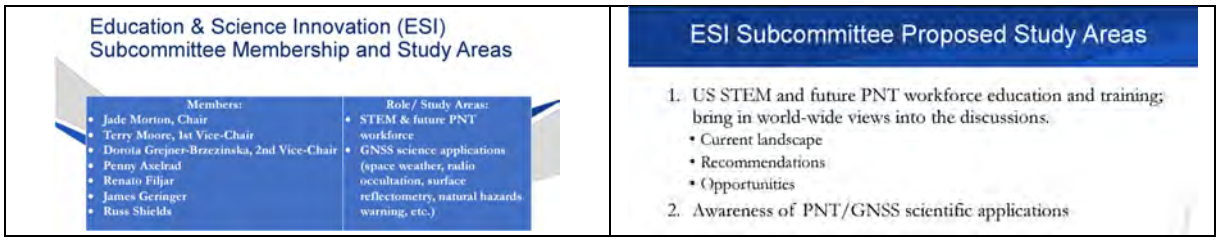
The subcommittee has received input pointing out that there is a communications issue (Slide 5). The USG is telling us to protect ourselves against attacks by using proper equipment, but the USG itself is not doing. This makes it difficult for users to take this threat seriously. The subcommittee is currently reviewing the Federal Radionavigation Plan (FRP), which includes language on the value of GPS and its applications (Slide 6).

Slides 5-6

Discussion: None.

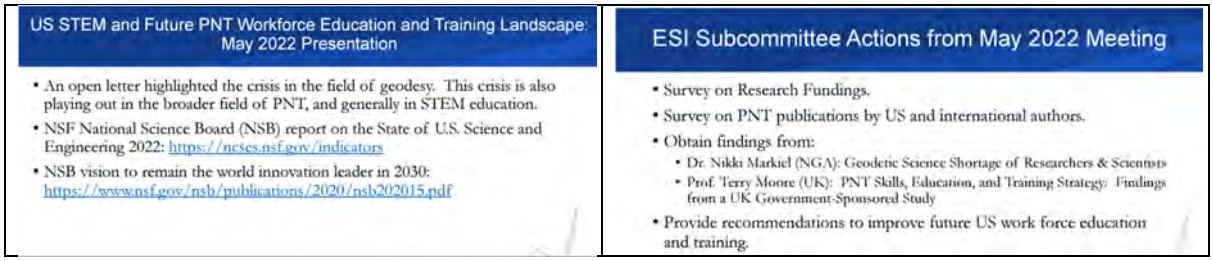
2) *Education & Science Innovation (ESI) Subcommittee (**View PDF**): Professor Terry Moore provided on behalf of Dr. Jade Morton, who was not able to attend the meeting in-person due to COVID-19*

The subcommittee is looking at the state of education and training in the U.S. relating to Science, Technology, Engineering, and Math (STEM) subjects, particularly relating to the PNT workforce (Slides 1-2). The goal of the subcommittee is to provide recommendations to mitigate some of the issues we have identified. The subcommittee is also looking at scientific applications of PNT that may have unexpected uses and, as a result, could have unexpected effects following a disruption.



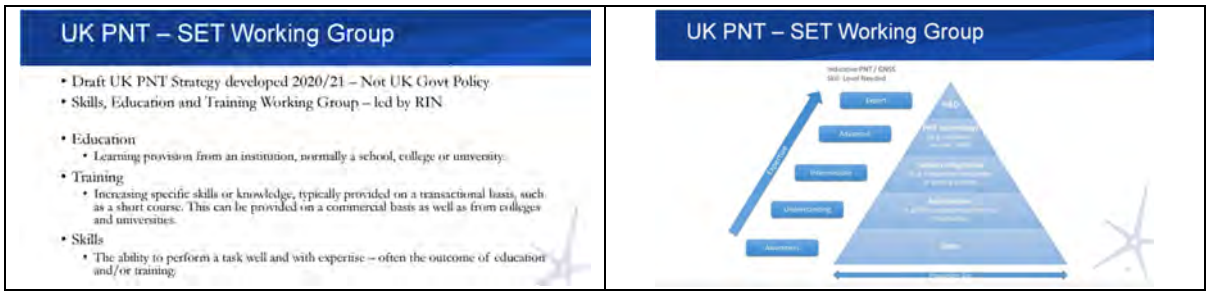
Slides 1-2

At the last PNTAB meeting, the subcommittee's focus was on an issue relating to the geodesy crisis, particularly pertaining to the education and training in the field of geodesy, which is a key factor in PNT) (Slide 3). Additionally, the National Science Foundation (NSF) National Science Board (NSB) reported on the state of U.S. education and training in the field of science and engineering, and the board stated their goal of growing the leadership role of the U.S. in this field. After these discussions, the subcommittee was tasked with following up on these items (Slide 4). It compared the U.S. funding for PNT research, as well as the number of PNT publications coming out of the U.S. to that of other nations. We obtained information from two sources: (1) *Geodetic Science Shortage of Researchers and Scientists* from the National Geospatial-Intelligence Agency (NGA), and (2) *PNT Skills, Education, and Training Strategy: Findings from a United Kingdom (UK) Government-Sponsored Study* by Professor Terry Moore.



Slides 3-4

The Draft UK PNT Strategy was developed by representatives from academia, industry, and organizations to study the state of skills, education, and training related to PNT in the UK (Slide 5). Unfortunately, the report is heavily redacted. Additionally, none of the recommendations are a conclusion. The group was led by the Royal Institute of Navigation (RIN). The first action the group took was defining "education, training, and skills." Education: learning provisions from an institution normally a school, college, or university. Training: dedicated, specific instruction, sometimes related to a specific task, such as a short course. Skills: the ability to perform a task will and with expertise, which is often the outcome of education and/or training. The subcommittee also investigated the different levels of education and training, from basic awareness to expert level (Slide 6). The width of the triangle shown on slide 6 illustrates the number of people that need to be trained and/or educated in the PNT field at the various levels. The Research and Development (R&D) group is at the top of the triangle, represents the smallest group of people that need to be PNT experts, and general user awareness represents a larger portion of the population.

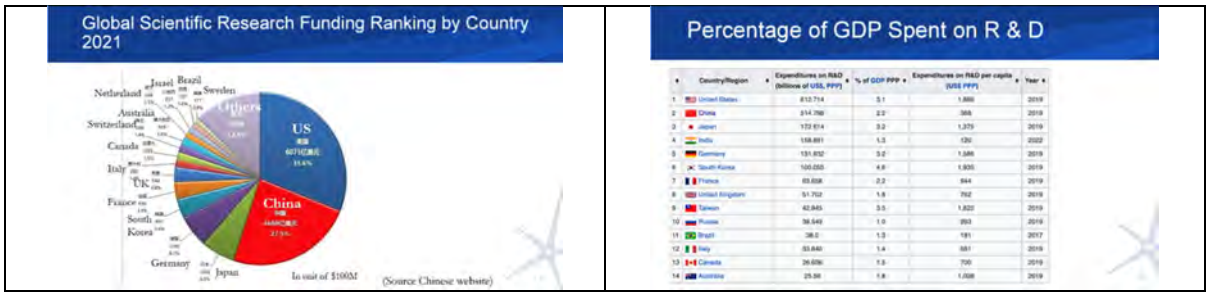


Slides 5-6

A key finding is the importance of the collaboration between industry and academia (Slide 7). The subcommittee also looked at the state of education provision and found that there is no PNT or GNSS overall degree course at any university in the UK, at the graduate or undergraduate level. There are, however, individual courses or modules in other degrees. Regarding training provisions, there are several good examples of organizations are providing training, but there is no systematic provision or provider of this training anywhere in the UK. There are eight recommendations that Prof. Moore could not share, as well as two "red flag" conclusions. These two conclusions are critical in the UK and must be addressed. The recommendations are organized as short term, medium term, and long term, as well as strategic and tactical. Slide 8 specifically illustrates the need to address PNT at *all* levels of education.

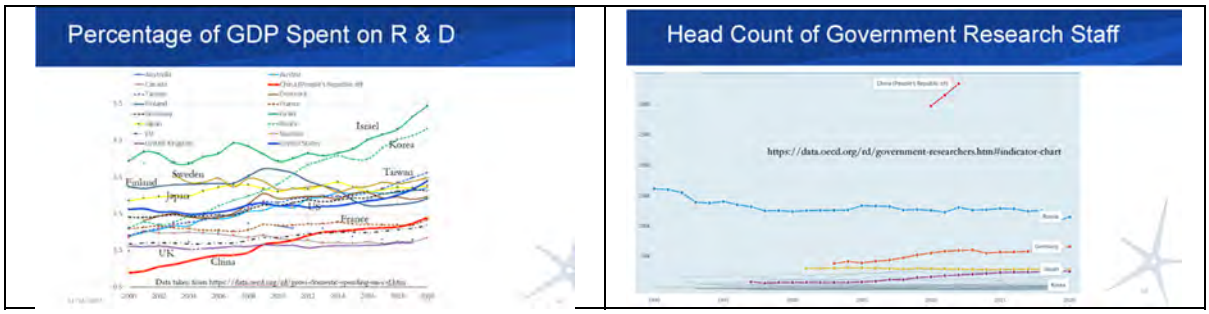
Slides 7-8

The graph on slide 9 was originally from a Chinese source, but Dr. Morton was able to translate. The table on slide 10 lists the top 14 countries that spend the most on R&D. The list includes their spending in both American dollars and percentage of their respective GDPs. The money spent on R&D may buy more in some countries compared to others. For example, although we spend more on R&D in the U.S., there may be more value on what is spent in China. The European Union (EU) is also a major spender in R&D but did not make the list of the top 14.



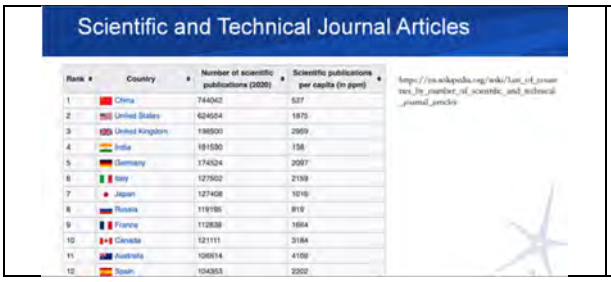
Slides 9-10

Slide 11 demonstrates how the figures in slide 10 have changed over time. The x-axis is in years, and the y-axis is the percentage of GDP. One of the most striking things about this graph is that over time, the gap between the U.S. and China is closing. Slide 12 illustrates the number of people working for government-funded research organizations. Sadly, there was no comparative data for the U.S., and very limited data for China.



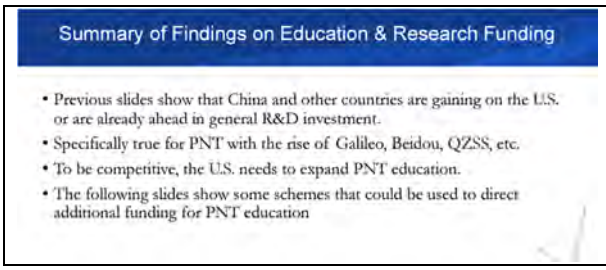
Slides 11-12

Slide 13 depicts the top 12 countries that have published the most scientific and technical journal articles in 2020. Although countries frequently launch new journals, China has launched a satellite navigation journal with high-quality articles (Slide 14). Also, China's "Institute of Navigation," originally maritime-based, is moving into the science & technology sector.



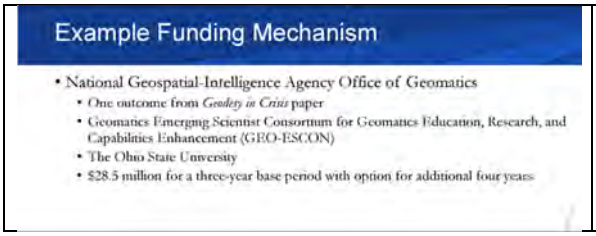
Slides 13-14

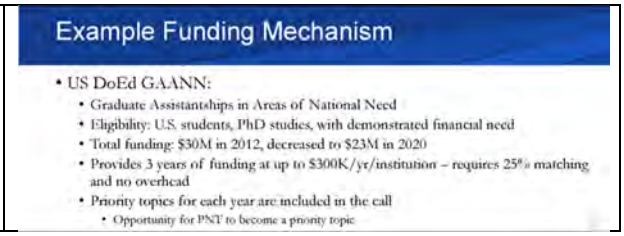
Other nations are gaining on R&D investments (Slide 15). Particularly, we've seen this gain with PNT due to the rise of new systems, such as Galileo, BeiDou, NavIC (Navigation with Indian Constellation), and QZSS (Quasi-Zenith Satellite System). It is the subcommittee's belief that the U.S. needs to expand PNT education. Dr. Axelrad provided a list of existing federally funded fellowship programs with potential to support student research in PNT (Slide 16). A wide variety of graduate-level fellowships, from NASA to defense to transportation related, could be used to support work in PNT.



Slides 15-16

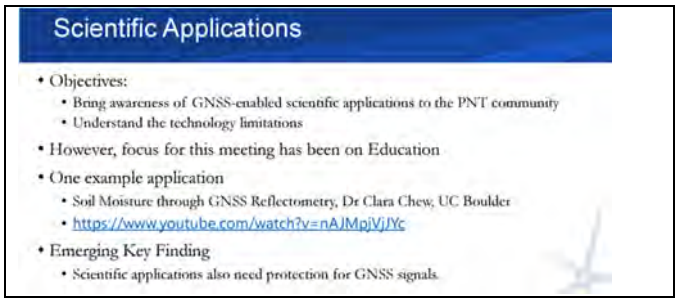
The NGA Office of Geomatics funding scheme was almost a direct result of the *Geodesy in Crisis* paper (Slide 17). Funds were awarded to The Ohio State University for 'Geomatics Emerging Scientist Consortium for Geomatics Education, Research, and Capabilities Enhancement'. Almost $30 million will be given over a three-year period with opportunity for potential expansion. Another funding scheme is from the U.S. Department of Education for U.S. PhD students (Slide 18). The challenge is to get PNT recognized as one of their priority areas.





Slides 17-18

Another role of the subcommittee is to consider scientific applications. The YouTube link shown in slide 19 shows measuring soil moisture using GNSS reflectometry. In the video, a scientist in was calibrating data by looking at data in a desert area in North Africa, where low levels of moisture are expected. When taking measurements in Libya, she was getting unusable noisy GNSS data. Further investigations found that it was due to interference and jamming. Thus, when discussing "protection" we need to consider scientific applications as well.

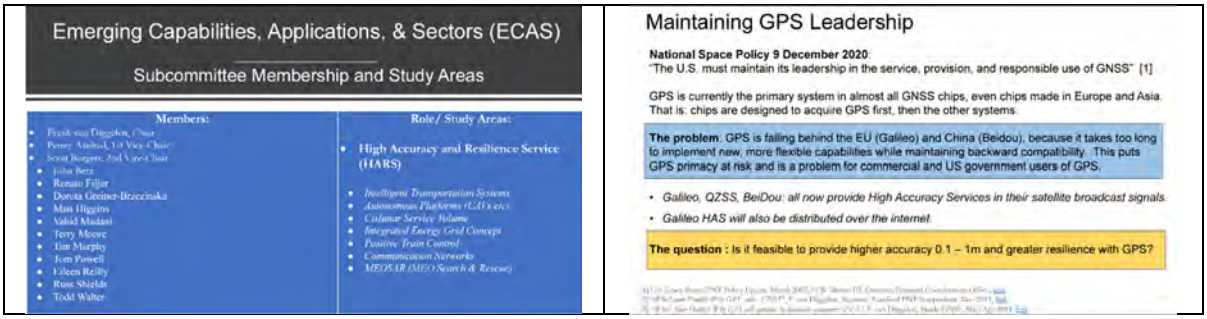


Slide 19

Discussion: None.

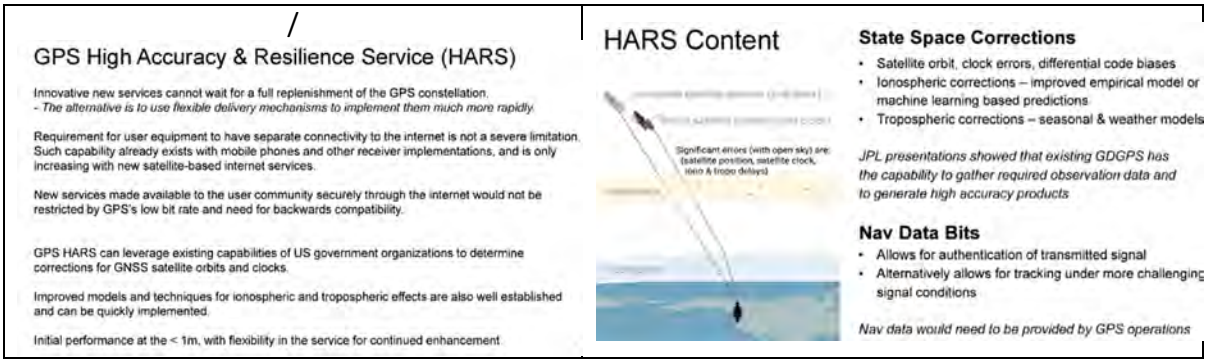
3) *Emerging Capabilities, Applications, & Sectors (ECAS) Subcommittee (View PDF): Dr. Penny Axelrad provided the update for the on behalf of Frank van Diggelen, who could not attend the meeting.*

Since the last PNTAB meeting, the subcommittee's focus has been on developing a High Accuracy and Robustness Service (HARS). Other subcommittee areas of interest are listed on the right side of the table on slide 1. This presentation focuses on HARS. The motivation behind HARS is to ensure that GPS maintains its leadership role in the PNT world, primarily with GNSS. As shown on slide 2, GPS is currently the primary system in almost all GNSS chips, even chips made in Europe and Asia. These chips are designed to acquire GPS first, then the other systems. The problem is that should GPS fall behind Galileo and BeiDou, this could change. This is partly due to the acceleration of improvements in Galileo and BeiDou, and an increasingly less need for backward compatibility. In fact, backward compatibility is one of the reasons that is keeping GPS maintaining its lead. Galileo, BeiDou, and the Quasi-Zenith Satellite System (QZSS) are now providing High Accuracy Services (HAS) within their satellite broadcast signals. It is currently not feasible for GPS to also do this. Additionally, Galileo (and perhaps BeiDou) are also providing HAS corrections via the internet. The question that the Subcommittee investigated is whether it would be feasible to provide higher GPS accuracy in the 0.1-1 m range, and with greater resilience. Is there a way we could do this within the existing GPS infrastructure? We believe the answer is yes.



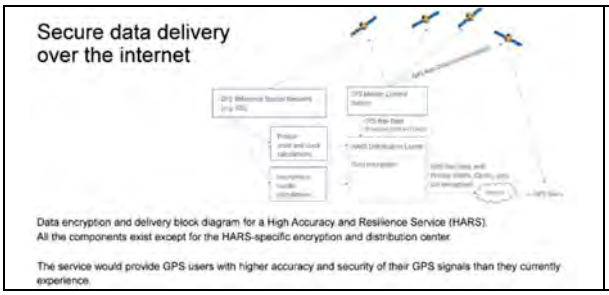
Slides 1-2

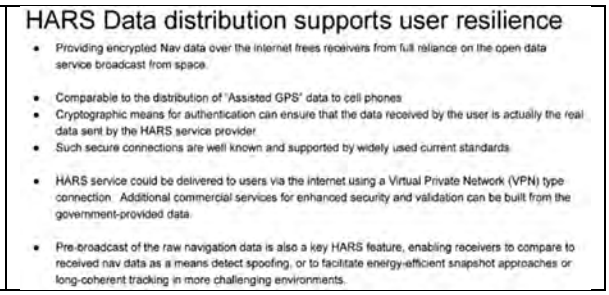
The subcommittee studied what it would take to introduce HARS into GPS (Slide 3). We believe bringing innovation to GPS cannot wait for a full replenishment of the GPS constellation, but there is an alternative to use flexible delivery mechanisms to implement some changes more rapidly. When GPS was first envisioned, the idea to be able to navigate without anything was extremely important because the internet and smart phones did not exist yet. Today, having constant access to internet can be comparted to having constant access to air, it is expected. Services made available to the user community through the internet would not be restricted by GPS's low 50-bit per second data rate and need for backwards compatibility. The subcommittee has been investigating the possibility for GPS HARS to leverage existing capabilities of USG organizations to determine corrections for GNSS satellite orbits and clocks, as well as to provide improved models and techniques for ionosphere and tropospheric effects. There are already existing capabilities to do this, such as NASA's Jet Propulsion Laboratory (JPL)'s GDGPS Global Differential GPS (GDGPS) service. The subcommittee has been discussing how to achieve initial performance at the better than one-meter level, with flexibility for a HAS to continue to improve and enhance service for users. The illustration on slide 4 shows the HARS content that would be transmitted to users using such a service. Regarding the State Space Corrections, JPL presentations showed that existing GDGPS has the capability to gather required observation data and to generate high accuracy products. The subcommittee has also discussed the idea of providing raw Navigation Data Bits to users via the internet. This would allow users to authenticate the signals by comparing the data bits they get through the internet to those they get from space and therefore confirm the legitimacy of the signal. This would also provide flexibility for tracking under more challenging signal conditions. This piece of HARS would require the navigation data to be provided to the service by the GPS operations center or extracted from other data sets used to produce the navigation data products.



Slides 3-4

An important question to consider is how to secure data delivery over the internet. The data encryption and delivery block diagram on slide 5 shows the components in data delivery. Every piece of this block diagram already exists, except the dotted box representing a HARS-specific encryption and distribution center. This service would provide GPS users with higher accuracy and security of their GPS signals then they currently experience. Providing encrypted navigation data over the internet freed receivers from full reliance on the open data service broadcast from space, and it is comparable to the distribution of "assisted GPS" data to cell phones- (Slide 6). HARS service could be delivered to users via the internet using a Virtual Private Network (VPN) type connection. Additional commercial services for enhanced security beyond what is provided by the HARS service. Pre-broadcasting raw navigation data enables users to compare navigation data directly from the satellites with what they receive over the internet to increase resilience, or to allow a receiver to operate in an energy-efficient mode.





Slides 5-6

Discussion:

ADM Allen rhetorically asked who the subcommittee is sending this recommendation to, should they come up with one.

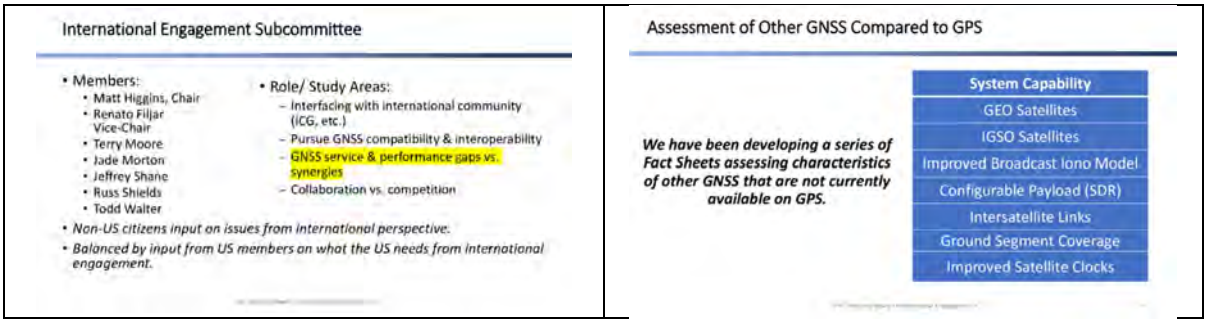
Dr. Axelrad responded by saying that this can be done in a way that will not impact the satellite. The fact that these capabilities already exist is very exciting, so a recommendation could naturally arise once we tap into the capabilities.

4) International Engagement (IE) Subcommittee (View PDF): Mr. Matt Higgins

Mr. Higgins opened by introducing the members of this subcommittee and stating that the former Brazilian 2nd Vice Chair, unfortunately, had to step down so they are currently operating without that position (Slides 1-2).

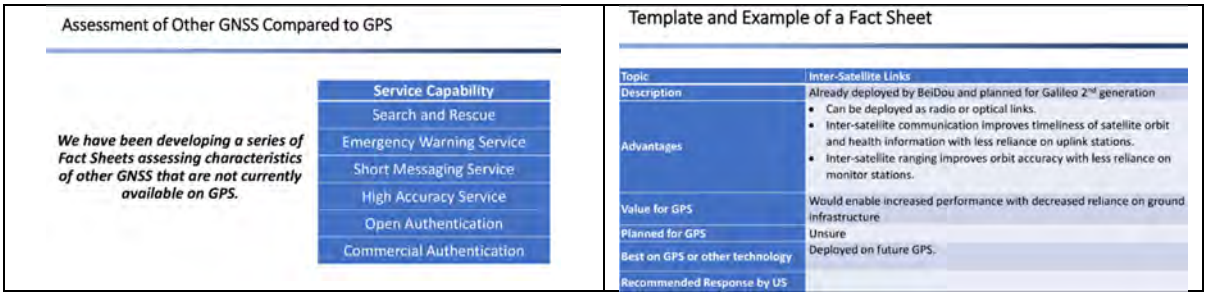
Slides 1-2

The subcommittee includes balanced mix of International & U.S. representatives to study a variety of areas, including GNSS service & performance gaps (Slide 3). Largely, it is considering whether GPS still the gold standard. At the last meeting, we displayed several tables illustrating capabilities that GNSS servers may have that GPS does not. Since then, the subcommittee has been developing a series of fact sheets assessing characteristics of other GNSS that: (1) are not currently available on GPS, and (2) could be improved in GPS (Slide 4). For example, BeiDou has Geosynchronous Orbit (GEO) satellites directly in its system. Other, such as QZSS, have an inclined geosynchronous orbit (IGSO). Specifically, QZSS was deliberately designed to operate at a high altitude in order to provide more coverage. One priority for GPS is to improve the broadcast ionospheric model. Configurable payloads are being discussed for Galileo 2. Many systems either have implemented or will implement intersatellite links. Galileo also has more uplink stations around the world that GPS and therefore does not have as many problems regarding data as GPS does. Lastly, Galileo's clocks are state of the art, compared to that of GPS.



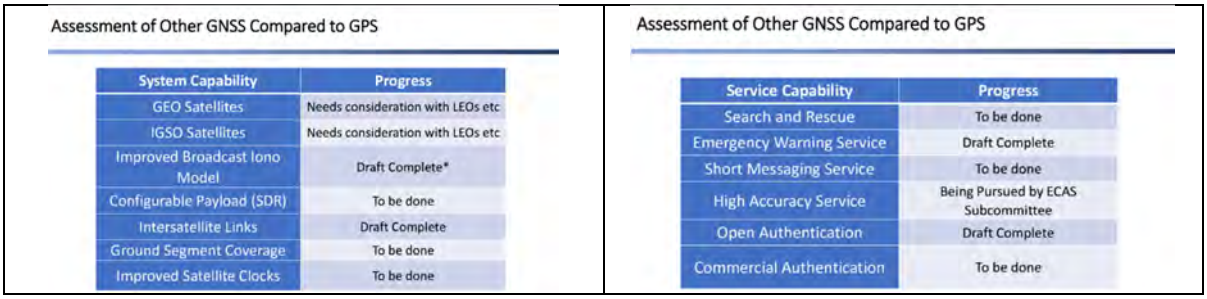
Slides 3-4

We have also been looking at the service capabilities of other GNSS systems (Slide 5). Search and Rescue is one of GPS's capabilities but Galileo, for example, now has a downlink that alerts the individual(s) in destress that they're signal has been received. If a person sends a distress signal but does not know that anyone has received it, they will not be inclined to stay in the same location. The EU is discussing the implementation of emergency warning services in Galileo. In practice, if a natural disaster where to wipe out cell phone service to a particular area, emergency warning signals would still be able to reach a cell phone through a GNSS chip. BeiDou has short messaging services, although this may not be something the U.S. wants to implement on GPS. The EU is also discussing implementing open authentication and commercial authentication for Galileo. Slide 6 shows an example of the Fact Sheets that the subcommittee has been developing.



Slides 5-6

The subcommittee needs to further discuss Low Earth Orbit (LEO) PNT before providing a fact sheet on GEO and IGSO satellites (Slide 7). The drafts regarding the improved broadcast ionospheric model and intersatellite links have been completed. The fact sheets on configurable payloads (Software Defined Radios, or SDR), ground segment coverage, and improved satellite clocks are currently being drafted. Regarding fact sheets on service capabilities, the drafts on emergency warning service and open authentication are completed (Slide 8). The drafts on search and rescue, short messaging service, and commercial authentication are currently being worked on. The ECAS subcommittee is drafting the fact sheet on high accuracy services.

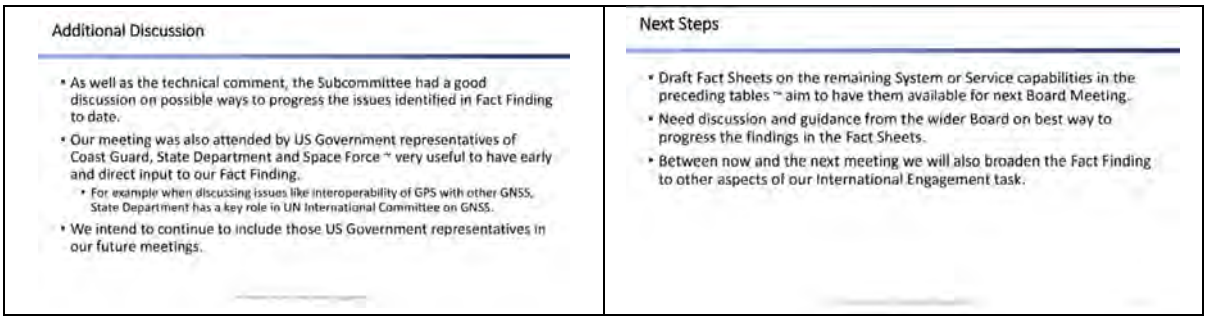


Slides 7-8

The subcommittee meeting was attended by USG representatives such as Rick Hamilton from USCG, Jeff Auerbach from DOS, and Chris Erikson from the USSF (Slide 9). This was extremely useful because the subcommittee was able to streamline its recommendations to the USG. For example, Jeff Auerbach (DOS) is heavily involved in the ICG, so he can keep the subcommittee up to date on discussion topics at the ICG. The subcommittee intends to include USG representatives in future meetings.

Next steps are:

- Finish up the draft fact sheets within the next few months.
- Discuss with the wider board on the best way to progress the findings in the fact sheets. For example, should the Subcommittee propose a recommendation for each Fact Sheet, or should there be one overarching recommendation based on all six of the fact sheets?
- Broaden the fact-finding to other aspects (this will be addressed more in the next PNTAB meeting).

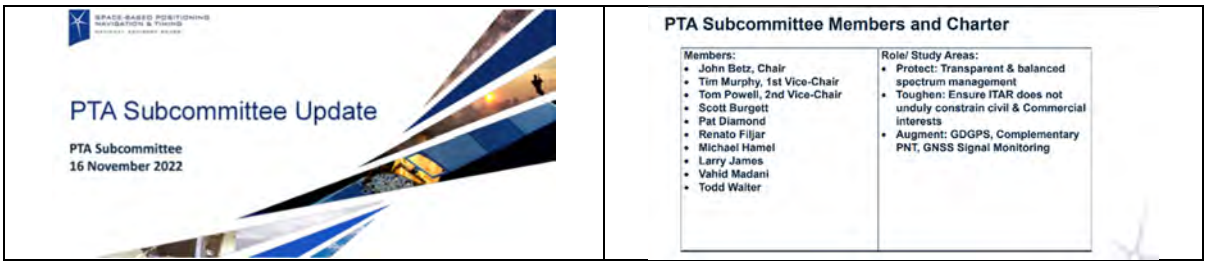


Slides 9-10

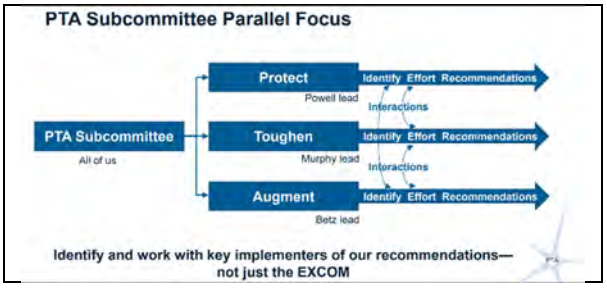
Discussion: None.

5) *Protect, Toughen, & Augment (PTA) Subcommittee (**View PDF**): Mr. Tim Murphy provided the update for the on behalf of Dr. John Betz, who could not attend the meeting.*

The subcommittee is separated into three Working Groups (WGs), each focusing on the areas of protect, toughen, and augment respectively (Slides 1-4). Members of the subcommittee are working with the key implementors of their recommendations, and not just members of the PNT EXCOM. The subcommittee has also been reaching out to stakeholders in their fact-finding meetings that have an interest in what they're working on.



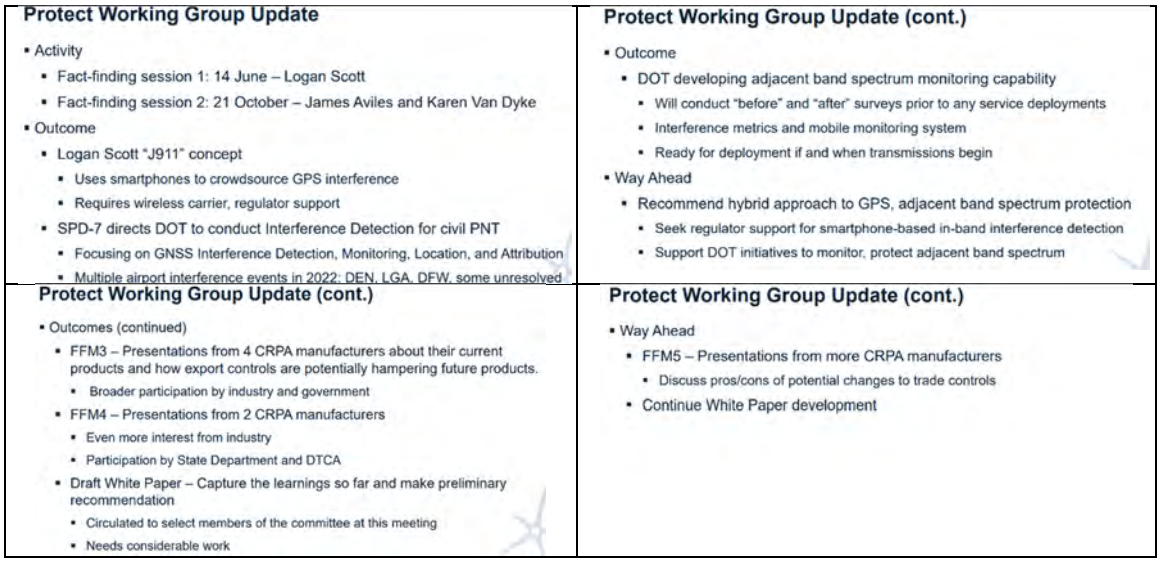
Slides 1-2



Slide 3

5.1) Protect Working Group (Slides 4-7)

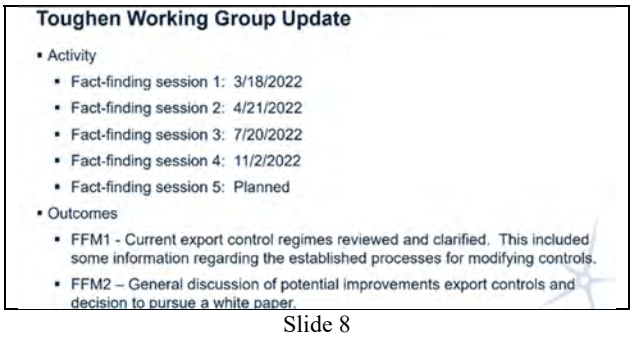
There were two fact-finding sessions that too place since the last PNT Advisory Board meeting. The first was held in June and the second was held in October. In June, Logan Scott gave a presentation about the concept of detecting interference using the ability of cell phones crowdsource interference. James Aviles and Karen Van Dyke gave presentations at the second fact-finding session in October regarding the efforts to locate interference at major airports and the preparation for adjacent band interference. Ms. Van Dyke and her team at the Department of Transportation (DOT) are preparing for possible adjacent band interference, and the subcommittee has a few different ideas for the recommendations they will put forth, which will be discussed in further detail tomorrow (during Day 2). [Note: On slide 6, DTCA should read DTSA, Defense Technology Security Administration.]



Slides 4-7

5.2) Toughen Working Group (Slide 8)

There have been four fact-finding meetings since the last PNTAB meeting, with a fifth one planned. The first meeting was focused on trying to understand what the export control regimes really are understand how they are impacting the potential market for adaptive antennas. They also reviewed the process for making changes and/or modifying those controls. The second fact-finding meeting covered general discussion of potential improvements to export controls. It was noted at that meeting that the WG needs more information from manufacturers about how the current export rules are potentially impeding their ability to develop these technologies for civil use. Additionally, the WG will pursue capturing this information via White Paper. Fact-finding meeting number three was the first meeting where the WG brought in CRPA manufacturers to discuss their current products and what their future products would look like (15-minute presentations each). Additionally, these manufacturers discussed how export controls were hampering their ability to develop future products. The WG received a broad participation from the industry and the government. The fourth fact-finding meeting involved presentations from two more CRPA manufacturers (one was a repeat from the previous session), and more interest from DOS and DTSA. These participants were very interested in the data that the WG is producing. The WG now has a draft White Paper, which captures the learning so far, and includes some ppreliminary recommendation material. The Paper will be circulated to some select members of the subcommittee to ensure that we are headed in the right direction. There will be one more fact-finding meeting, which will include presentation from at least two more CRPA manufacturers. At this meeting, the paper will also be put on the table for wider discussion.



Slide 8

[Ed. Note: There was not an update from the Augment WG]

The PTA subcommittee will put forth three recommendations, one from each of the WGs.

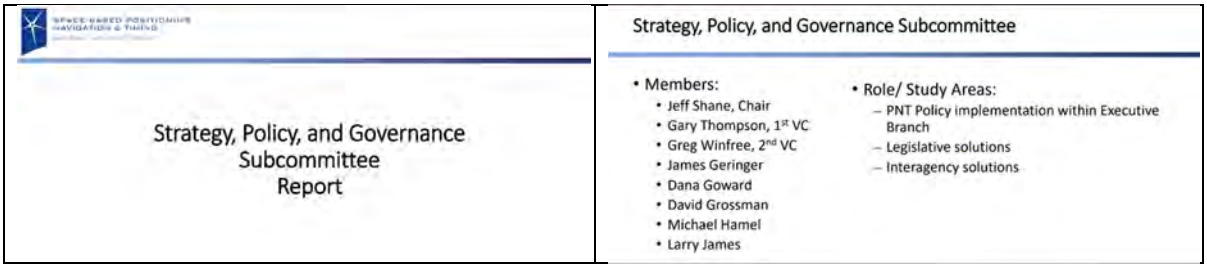
Discussion:

ADM Allen commented that: (1) We will be receiving comments from DOS regarding the export control regimes, and (2) A White Paper is something that we need to collectively develop, but the question is, who gets it and where does it go? Regardless, this is something that needs to involve those at a higher level.

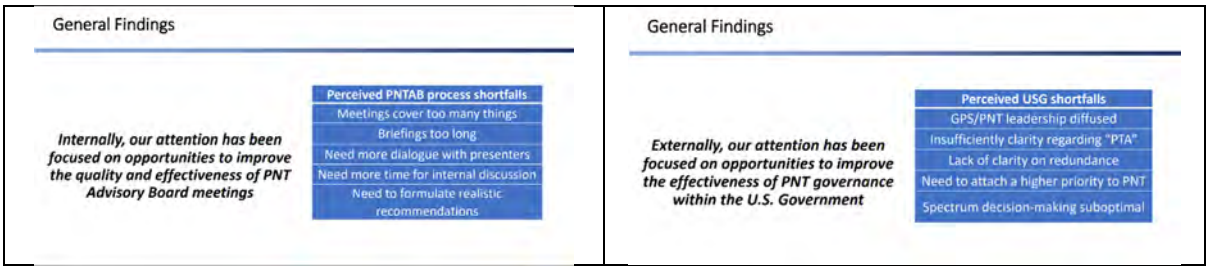
Mr. Murphy acknowledged that Dr. Parkinson has been a very active member of the Toughen WG and had participated in all of the fact-finding sessions.

6) *Strategy, Policy, & Governance (SPG) Subcommittee (**View PDF**): The Honorable Jeff Shane*

GPS is not only a miracle but one of the most important gifts any country has ever given to mankind. First, we were jarred out of our indolence when the USSR successfully launched Sputnik 1 in the 1950's. By the 1960's, The U.S. was producing Navstar. In 1972, a young Air Force Lieutenant named Bradford Parkinson was tasked with taking Navstar to the next level, and thus, we now have GPS. The U.S. should be very proud of GPS, but it has been a long time since it was made available to the world 30 years ago. Now, instead of having a single constellation of satellites orbiting the earth, there's a constellation of constellations. There are systems that are doing better than GPS, but the U.S. should be proud that we engendered "copycats" for the next generation, that have capabilities that we have not been able to match. This can serve as a wake-up-call, just at Sputnik was in the 1950's. The question now is, "are we going to wake up?" The Subcommittee has not only been looking at the way our USG works externally, but also how the PNTAB works internally.



Slides 1-2



Slides 3-4

Earlier this year, we submitted several recommendations to the leadership of the board. We found that the board was covering too many issues with briefings that were too long and too detailed. Additionally, there was not sufficient opportunity for dialog between PNTAB members and subject matter experts, and there was not enough allocated time to discuss a best path forward regarding the subject matter. Because of this, some of the recommendations submitted by the board were not as achievable and targeted as they should have been. One of the most important recommendations we produced was to create subcommittees, which evidentially came from leadership. Through this change, presentations are now generating rich, in depth, quality information that the PNTAB has never been able to create in the past.

An important question for GPS is who is in charge. We have a PNT EXCOM consisting of two Deputy Secretaries: Dep. Sec. of Defense and Dep. Sec. of Transportation. Recent reports have highlighted that the Deputy Secretaries have not been attending those meetings. Although it's easy to hold them accountable for not attending, the larger question is whether they believe that attending those meeting the highest and best use of their time. Perhaps they do not think that this is the best use of their time. The fact is the system seems to be running itself. We do not know where the leadership is and because of this, we are going to continue to fall short of the decision making we need. Even if the EXCOM does accept the recommendations that the PNTAB is putting forward, they then have to make a pitch to those that are in charge of the specific issues. There are too many layers between the ideas and the execution.

Additionally, the government decides on an allocation of spectrum (which is getting increasingly crowded) in ways that Executive Branch agencies, such as the Department of Defense (DoD) and DOT, feel are suboptimal and can create out-of-band interference with critical systems such as GPS. Examples of this include the Ligado situation and 5G issues around major airports. The governance within our Legislative structure should have prevented those incidents. Because we have an independent agency in charge of spectrum, conflicts arise when multi-agency issues occur, such as aviation safety. Something such as aviation safety should never be called into question and this can, again, be attributed to the fact that the U.S. does not have a single person or entity in charge of PNT.

Discussion: None..

* * *

PNT EXCOM Policy Update

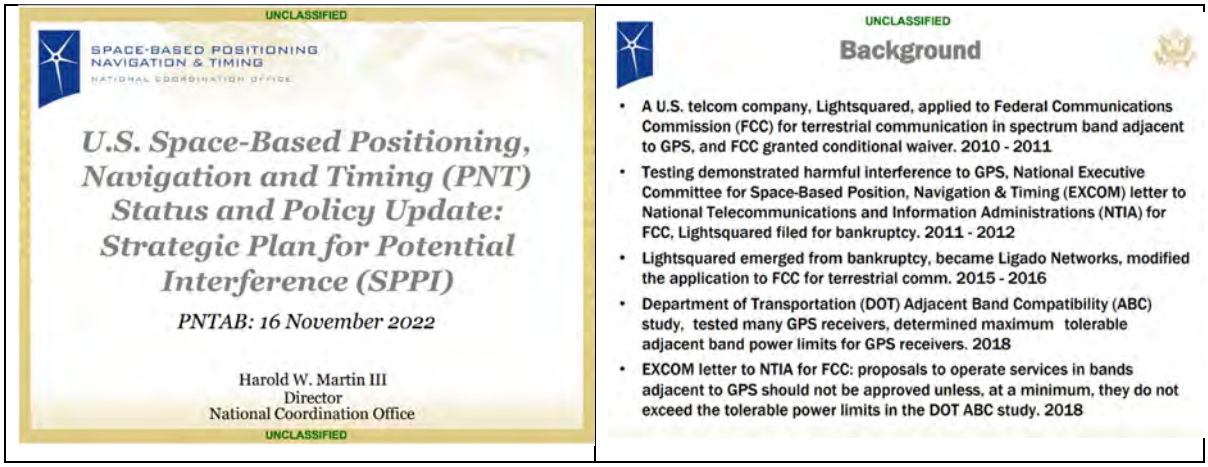
Mr. Harold "Stormy" Martin III, Director, National Coordination Office (NCO) for Space-Based PNT
Ms. Juliana Blackwell, Director, National Geodetic Survey, NOAA

ADM Allen stated that the Advisory Board will be discussing the Ligado situation in the next portion of the agenda; however, Mr. Martin will first give an EXCOM update.

1) *Mr. Harold "Stormy" Martin III, Director, National Coordination Office for Space-Based PNT (**View PDF**)*

Mr. Martin started off by stating that "like GPS, this Board is a national treasure. You are a brain trust that this country needs," and the USG needs to be able to understand the great ideas that the PNTAB can bring to the table. Additionally, it is incredible that America is going back to the moon (referencing the Artemis 1 launch that took place the night before this meeting), and that GPS is going along. Artemis is equipped with GPS receivers designed to support operations in LEO, but NASA is going keep these receivers on during the entire journey to collect GPS tracking [Ed Note: the data collected will be useful to NASA's on-going efforts to develop receivers capable to track GPS signals at Lunar distance]. Mr. Martin congratulated NASA for the incredible achievement. Discussion topics for this presentation include activities that the EXCOM has been conducting, specifically the Strategic Plan for Potential Interference (SPPI) to GPS from Ligado transmissions (Slide 1).

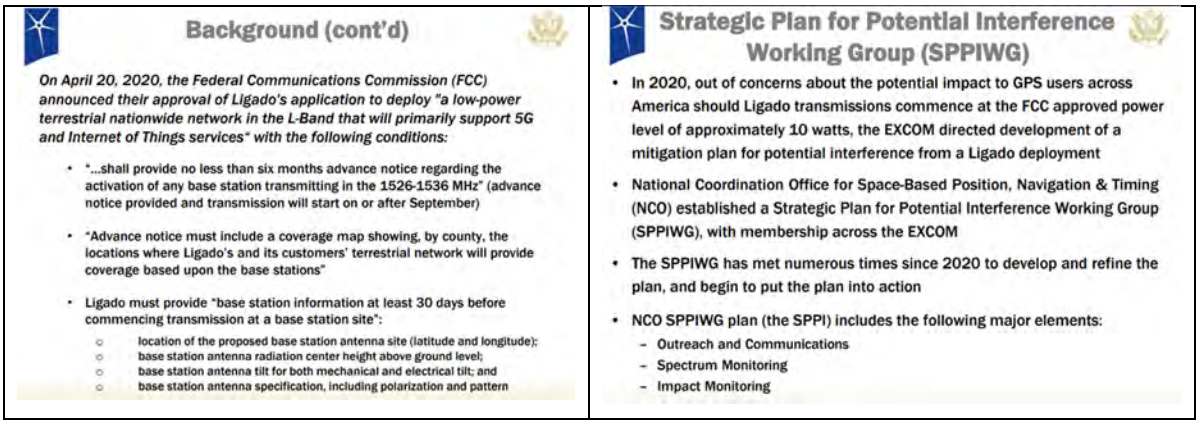
In 2010/2011, a U.S. telecom company called Lightsquared applied to the FCC for terrestrial communication in spectrum band adjacent to GPS, and FCC granted them a conditional waiver (Slide 2). Over the next couple of years, the EXCOM, DoD, DOT, etc. banded together to conduct testing to evaluate the plan, and they determined that there was going to be harmful interference to GPS. The EXCOM sent a letter to the National Telecommunications and Information Administrations (NTIA) aimed at the Federal Communications Commission (FCC) stating these concerns. Lightsquared filed for bankruptcy in 2012. A few years later, Lightsquared emerged from bankruptcy, became Ligado Networks, and modified their application to the FCC for terrestrial communication. In 2018, the DOT conducted the Adjacent Band Compatibility (ABC) study, where they determined the maximum tolerable adjacent band power limits for a wide variety of GPS receivers. Based on that study, the EXCOM sent another letter to NTIA for the FCC stating that proposal to operate services in bands adjacent to GPS should not be approved unless they do not exceed the tolerable power limits in the ABC study.



Slides 1-2

Unfortunately, in 2020, the FCC approved Ligado's application to deploy their terrestrial network adjacent to the GPS L-band (Slide 3). There are several conditions including a six-month advance notice before deploying or activating of any base station, a coverage map showing where the network is going to be deployed, and a 30-day notice with specific base station information prior to operation of any site.

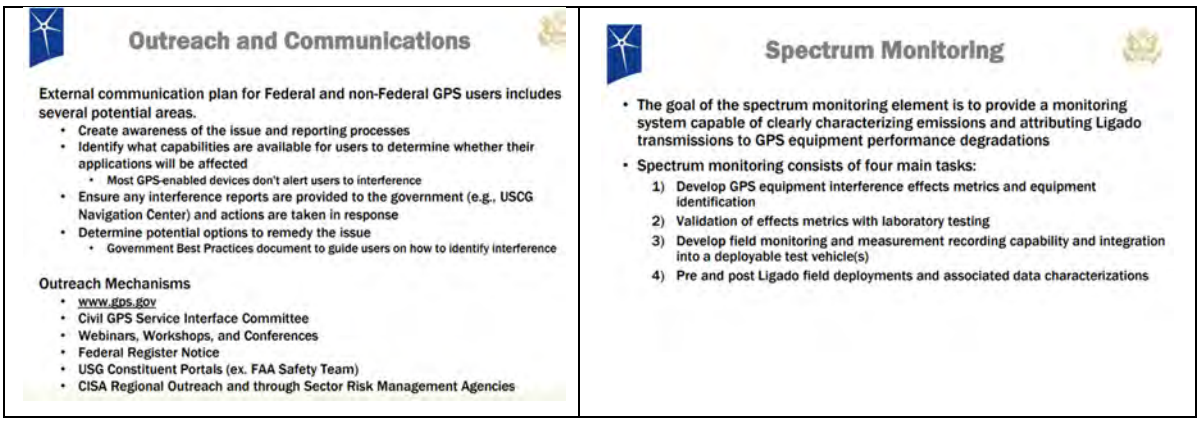
Out of concern about the potential impact to GPS users across America should Ligado transmissions commence at the FCC approved power level of approximately 10 Watt, which is higher than the maximum tolerable adjacent band power limits for a wide variety of GPS receivers determined by the ABC study, the EXCOM directed development of a mitigation plan for potential interference (Slide 4). The NCO established a work plan with membership across the EXCOM, which started the Strategic Plan for Potential Interference Working Group (SPPIWG). The SPPIWG has met numerous times since 2020 to develop and refine the plan and begin to put the plan into action. The plan's major elements include outreach and communications, spectrum monitoring, and impact monitoring.



Slides 3-4

Regarding outreach and communications, potential areas that the plan includes are to create awareness of the issue and what reporting processes are available, help identify what capabilities are available for users to determine whether their applications will be affected (most GPS receivers so not alert the user when interference occurs), ensure any interference reports are provided to the government (such as to the USCG Navigation Center, or NAVCEN) and actions are taken in response, and determine potential options to remedy the issue (Slide 5). A variety of outreach mechanisms are illustrated in the plan, including this PNT Advisory Board meeting.

The goal of spectrum monitoring is to be able to characterize emissions to be able to attribute Ligado transmissions to performance degradations in GPS equipment (Slide 6). There are four main tasks in the spectrum monitoring: (1) Develop GPS interference metrics, (2) Validation of metrics with laboratory testing, (3) Develop field monitoring and measurement recording capability and integration into test vehicles, and (4). Pre- and post- Ligado deployment and associated data characterizations. Both DOT and DOC, specifically NOAA, have worked on this.

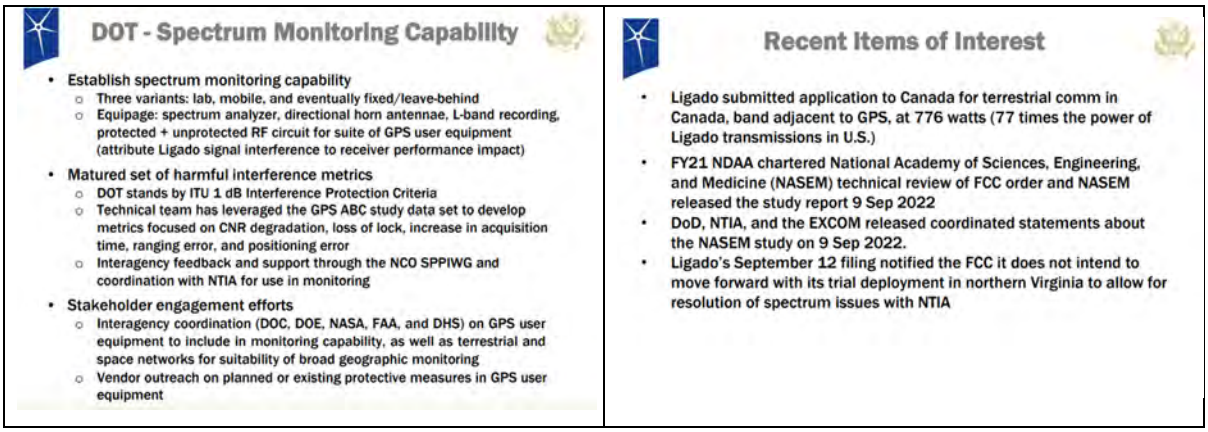


Slides 5-6

Mr. Martin stated that he would not go into much detail regarding DOT's spectrum monitoring capability because DOT will be giving a much more detailed presentation. DOT aims to establish three variants of spectrum monitoring capabilities: lab, mobile, and eventually fixed (Slide 7). Regarding harmful interference metrics, DOT and the EXCOM stand behind the International Telecommunication Union (ITU) 1 dB Interference Protection Criteria. The technical team DOT worked with also looked at other metrics including noise degradation, loss of lock, increase in acquisition time, etc. There was a lot of interagency feedback through the NCO SPPIWG and coordination with NTIA for use in monitoring. DOC, Department of Energy (DOE), NASA, the Federal Aviation Administration (FAA), and the Department of Homeland Security (DHS) coordinated their efforts to include in monitoring capabilities on GPS user equipment, as well as terrestrial and space networks for suitability of broad range geographic monitoring.

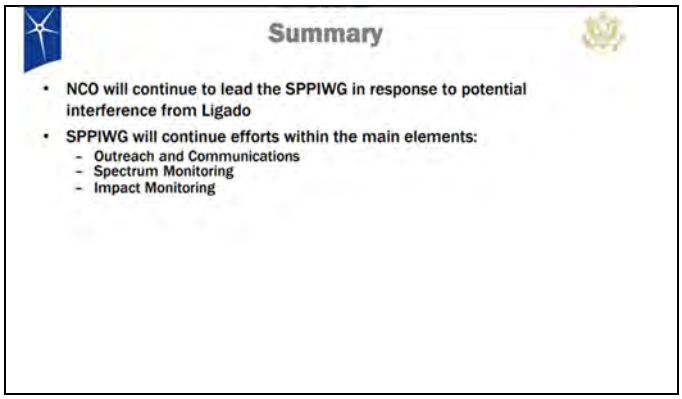
Ligado recently submitted an application in Canada for terrestrial communications there with the same and adjacent to GPS, but at a power level of 776 Watt (Slide 8). This is roughly 77 times the power of Ligado transmissions in the U.S. In Fiscal Year 2021, the National Defense Authorization Act (NDAA) chartered the National Academy of Sciences, Engineering, and Medicine (NASEM) technical review of the entire issue, including the FCC order. NASEM released the study report on September 9, 2022. On the same day, DoD, NTIA, and the EXCOM released coordinated statements about the NASEM study. The EXCOM appreciates the NASEM study on the important topic of interference to GPS capabilities, including those critical to national, homeland, and economic security. The EXCOM, chaired by the Deputy Secretaries of Defense and Transportation

and with membership from over a dozen agencies, supports the stated national policy goal to protect the spectrum environment that GPS uses and its augmentations including critical systems for the federal government, the men and women of our military services, the economy, scientific advancements, and U.S. critical infrastructure. The EXCOM will review the NASEM study carefully but agrees with statements by the DoD and NTIA that our nation requires a solution that ensures continued operations of critical systems. The study confirms that the GPS interference testing approach used by DOD and DOT based on signal to noise ratio is more comprehensive and informative. Additionally, EXCOM agrees with NASEM's assessment that the FCC's proposed mitigation and replacement measures are impractical, cost prohibitive, and possibly ineffective. The EXCOM looks forward to continuing its work with departments and agencies on this topic. Shortly after those statements came out from DoD, NTIA, and the EXCOM, Ligado filed a letter with the FCC stating that is does not intend to move forward with its trial deployment in Northern Virginia. This letter of intent did not formally withdraw notification of deployment that they previously filed with the FCC, stating that deployment in the Northern Virginia area would occur on or after the 30th of September. Although the deployment has not started yet, there is a "rolling, potential 30-day clock," as Ligado can submit their 30-day notice of deployment at any time.



Slides 7-8

Moving forward, NCO will continue to lead the SPPIWG in response to potential interference form Ligado (Slide 9). The departments and agencies are committed to continue efforts for outreach and communications, as well as spectrum and impact monitoring.



Slide 9

Discussion:

Dr. Parkinson thanked Mr. Martin for the presentation. Mr. Parkinson continued to state that as a taxpayer, it is striking that some in the USG have been paying tens of millions of dollars to try to resolve this issue, which was obvious to many people about 12 years ago and has been confirmed several times since then. Mr. Parkinson asked, "why is Ligado not responsible for all of the costs USG has incurred in this massive and relatively futile exercise?"

Mr. Martin answered by stating that this is a legal question. NTIA made the rare move by sending a petition for reconsideration to FCC, and there are legal discussions currently going on. FCC has not yet made a ruling regarding their reconsideration, so Mr. Martin is not able to comment on those legal discussions. That was not specified in the FCC order or authorization, which states that Ligado is liable for certain things but the cost of the ABC study, for example, is not one of those things. Stormy will defer to the legal experts for this question.

ADM joked that the PNTAB would not force Mr. Martin to practice law without a license.

Mr. Shane commented that the answer to Dr. Parkinson's question is that Ligado has a license from the FCC, so there is no occasion to impose liability on them. The license includes liability for federal expenditures to address interference and there is legislation pending in Congress that would extend that liability to harm that befalls on any citizen, however, that legislation has not passed. Mr. Shane also thanked Mr. Martin for the briefing and asked whether in addition to attempting to mitigate the perceived interference, has there been any discussion on the fact that this whole problem could have been avoided by simply having the FCC pay more attention to the equities being expressed by federal agencies? Is there any concern about the possibility of replicating a case like this in the future? Mr. Shane continued, stating that the U.S. is the only developed nation in the world that continuously shoots itself in the foot when it comes to protecting critical, spectrum-based infrastructure.

Mr. Martin noted he could not comment on the discussions, but noted that FCC and NTIA have published a new Memorandum of Agreement (MOA) for spectrum management. So, there is a realization that improvements can be made to spectrum management in the U.S., and the MOA lays out a process that they're trying to work through. Mr. Martin does not believe that this is going to be a quick process, but there is at least a new MOA, which the Advisory Board may take a look at and provide thoughts on its proposals.

ADM Allen asked Mr. Shane if the MOA is held in his subcommittee (the SPG Subcommittee) or if he has seen it yet.

Mr. Shane answered no.

Mr. Goward commented that it is hard to imagine the FCC would want a replication if this multi-decade debacle, so they may go to great lengths to try to avoid that. The announcement of the establishment of a Space Bureau is evidence that they are trying to keep this from happening again. Regarding the present dilemma, Mr. Goward stated that he hopes they will respond to the seven petitions for reconsideration, but that remains to be seen.

Mr. Martin agreed, saying that a lot of good people are trying to work through some unfortunate challenges.

ADM Allen commented that he and Mr. Martin were at the last EXCOM meeting, of which the FCC recused themselves. He continued, stating that it is "extraordinary when you have an interagency meeting, and another government agency recuses themselves."

Mr. Goward responded, saying that over the decades, the FCC seems to be transitioning to a more legalistic approach and less engineering and technology orientated. And perhaps this may be necessary.

Mr. Shane stated that the Board needs to be fair with the FCC because they operate pursuant to legislation, including the Administrative Procedures Act which makes the agency independent. Because of this, the FCC cannot play fast and loose with the rules. Whether agencies, such as DoD and FAA, who manage critical systems rely on clean spectrum should be treated as parties of interest in litigated and administrative proceedings in the FCC is the question at hand. The answer to that question today is "absolutely" because that's what the law states, but Mr. Shane does not believe that is fit for purpose. The FCC is making decisions that are affecting national security and the safety of life, and the Communications Act of 1934 was not intended to give it that power.

Mr. Higgins commented that the press release regarding the new Space Bureau at the FCC discussed the implementation of 60,000 new satellites in the last two years and the need to improve licensing for them. Mr. Higgins stated that he is doubtful that there were 60,000 new PNT satellites in the last two years, so he doesn't think it should be assumed that the FCC is going to be focused on PNT.

ADM Allen thanked Mr. Martin for the presentation. He noted that at the recent EXCOM there was a briefing on Test Continuously Operating Reference Stations (T-CORS), a monitoring system in search of anomalies, and the wanted the Advisory Board to be aware of it. [Ed. Note: in some sources T-CORS is also defined as 'Temporary' CORS]

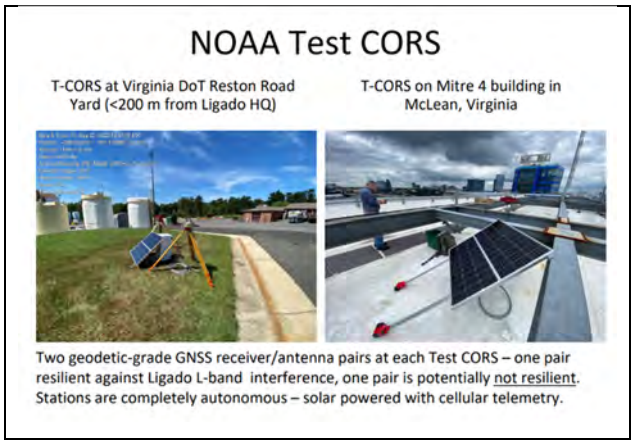
2) *Dr. Juliana Blackwell gave a presentation on the T-CORS Project (**View PDF**)*

Dr. Blackwell started by providing background information on CORS. Under the DOC, NOAA has responsibility for providing that National Spatial Reference System, which is relied on very heavily by GPS. As part of this, there are over 1,800 continuously operating reference stations that collect GPS data, which is then assimilated into the National Spatial Reference System as geodetic control. They provide three-dimensional positioning, information for meteorology for space weather, and other geophysical applications.

The network that NOAA manages is owned and operated by hundreds of partners. Of 1,800 stations, 40 are owned and operated by NOAA and the rest are operated by partners from the academic and private sector organizations. Due to the need for these stations to continuously operate in order to provide positioning information, NOAA has a role in managing the data and helps provide the public an opportunity to connect to these stations 24/7. Surveyors, GIS users, engineers, scientists, and others who collect GPS and GNSS data use the NOAA CORS network data as geodetic control for precise positioning for their surveys, and they align their work to the National Spatial Reference System.

In support of the strategic plan for potential interference, NOAA's National Geodetic Survey (NGS) has established two "test CORS," which are temporary CORS which were established near the locations of what was thought to be the locations of potential interference that may occur as early as September 2022. The reason these "test CORS" were established is because NOAA did not have any permanent stations near the potential interference locations. At each of the two stations, there is a PNT resilient setup and a non-resilient setup, to track if there is any interference detected.

Referring to the slide, the picture on the left is in Reston, VA. That test CORS is in a location where loss of L1 signal lock would occur on the non-resilient antenna pair. There is a sound barrier made up of trees and a highway that prevent a line of sight between the Ligado HQ, which is where NOAA is expecting transmission, and this Reston, VA test CORS.



Slide 1

The picture on the right of the slide shows a pair of receivers and antennas on top of a MITRE building in McLean, VA. This site is about ten kilometers from Ligado HQ and within the L-band broadcast area indicated by Ligado.

NOAA set up these temporary test CORS in September prior to when they thought transmission would begin. To date, there is no indication of interference to the GPS L1 signals at either of these test CORS. NOAA continues to look at the data to see if stations are continuing to track L1, which they are. NOAA is also utilizing a spread spectrum analyzer to look for any signs of interference, either intermittent or long-term. The data are being looked at 24/7 to see if there is any interference occurring at either of these locations. At this time there are no reports issues and there haven't been any reports from the local county or DOT surveyors in these areas. For now, NGS will continue to run these stations. If in the next few months there is not any indication of change, NOAA may be asked to remove their equipment from these locations. As of now, NOAA has a good partnership with DOT and MITRE, but these test CORS are temporary in nature. NOAA does not currently specialize in identifying GNSS signal interference in real time but could work in the future with other network operators who are doing real-time work to enhance their real-time network or provide them with technical assistance.

Discussion:

Dr. Parkinson stated that NOAA is performing a great service for the U.S.. He noted his concern over the spacing of the transmission towers from Ligado because the initial analysis assumed a series of spacings on the order of 400 to 1,000 meters because that was the normal laydown for the type of services that they were contemplating. If NOAA is not monitoring this very closely, in terms of geography, it seems that they are not understanding the total impact. Perhaps in addition to these test CORS, there should be monitor stations within at least half a normal spacing distance of wherever Ligado is planning on doing their transmissions. Dr. Parkinson welcomed comments from Ds. Blackwell & Ms. Van Dyke.

Ms. Van Dyke commented that Dr. Parkinson has a very good observation, and DOT's mobile monitoring capabilities can be a useful tool. At the time of filing with the FCC, DOT did not know what Ligado's exact plans were in Northern Virginia. They did not know if there was going to be one transmitter or if they were going to be spacing every 400 m. DOT would like to see what that laydown is going to be before putting in fixed sensors.

Dr. Parkinson responded, saying that means we still don't have insight into what the spacing is going to be.

Ms. Van Dyke stated that we only know what they filed with the FCC, and what the FCC agreed to in their order of operation. When Ligado filed in March 2022, there was no information regarding the location or number of transmitters of their initial deployment. It could have been one or multiple and, as Mr. Martin noted, Ligado needs to provide that information within 30 days of deployment.

Dr. Parkinson stated the heart of the issue is the density of the laydown of the transmitters. The board has not been able to get from Ligado what the spacing is.

Dr. Blackwell noted that if we had more information, then we could manage our monitoring differently. If we knew where the locations of the transmissions were, we could set up before and during to provide data on the impact and be able to connect with other surveyors in the area that are experiencing similar interference problems. Knowing those locations and being able to establish equipment that would be able to detect and track interference is what we are all seeking. Ideally, we hope that none of this happens and that we can all go back to doing our main mission.

Mr. Higgins asked Dr. Blackwell if NOAA is using receivers with spectrum analysis in them, or if they are analyzing the raw GNSS data.

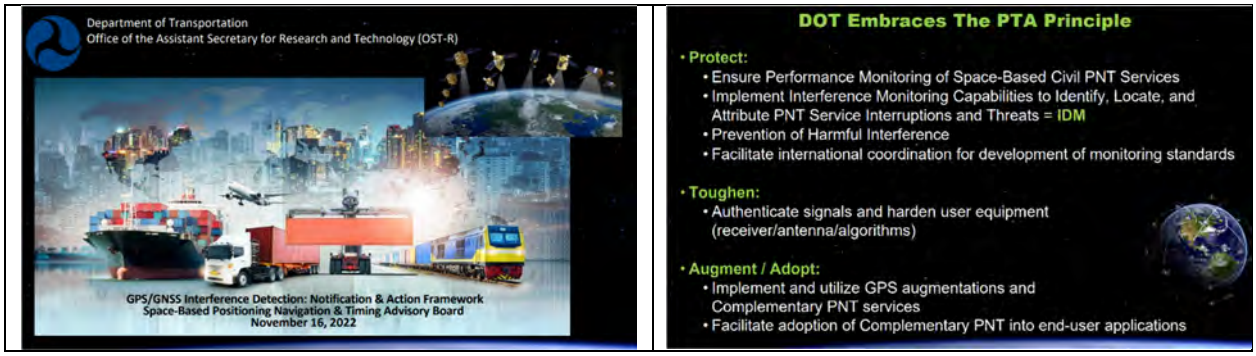
Dr. Blackwell answered, saying that she is not the one who is looking at the data, but her analyst told her that they are using a spread spectrum analyzer, so she assumes that is something that comes with the equipment for these two setups, but she will verify that with her analyst.

Mr. Higgins stated that it would be good to understand the capabilities that you can buy off the shelf.

* * *

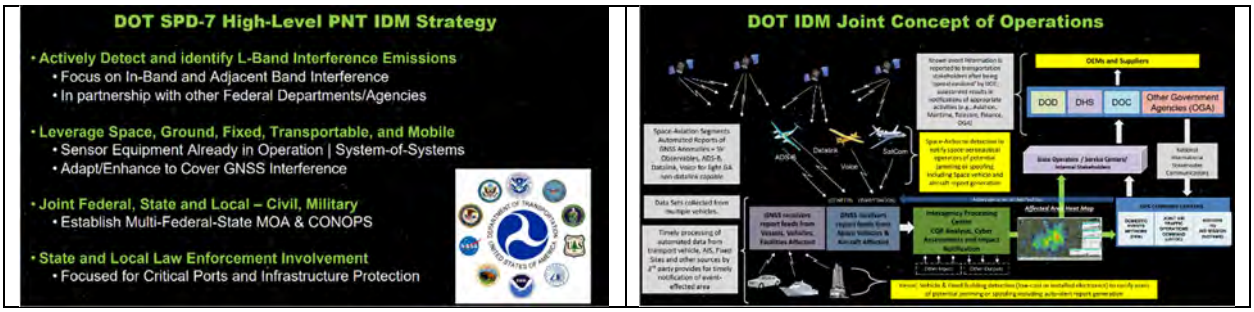
DOT Strategic Plan for GPS/GNSS Interference Detection (View PDF)
Ms. Karen Van Dyke, Director for PNT and Spectrum Management, DOT

Ms. Van Dyke thanked everyone and stated that it is always a pleasure to brief the PNTAB. DOT appreciates everything that the PNTAB has been doing regarding the PTA principles. The primarily focuses on detection and mitigation, as well as SPD-7, which was heavily discussed at the PTA Subcommittee meeting the day prior (Slide 1). Since the last PNT Advisory Board meeting, DOT held a space based PNT summit at the end of May 2022 which was co-chaired by the Deputy Secretary of Transportation and General Thompson, the USSF Chief of Space Operations. The summit was very beneficial, particularly to have a face-to-face event after the COVID-19 pandemic. Ms. Van Dyke stated that she'd be happy to brief anyone on other topics relating to the work DOT has been doing, particularly in implementing Executive Order 13905, "Strengthening National Resilience Through Responsible Use of PNT Service." This briefing, however, will focus on Interference, Detection, and Mitigation (IDM) and the work that the PTA Subcommittee has been doing regarding detection and mitigation (Slide 2).



Slides 1-2

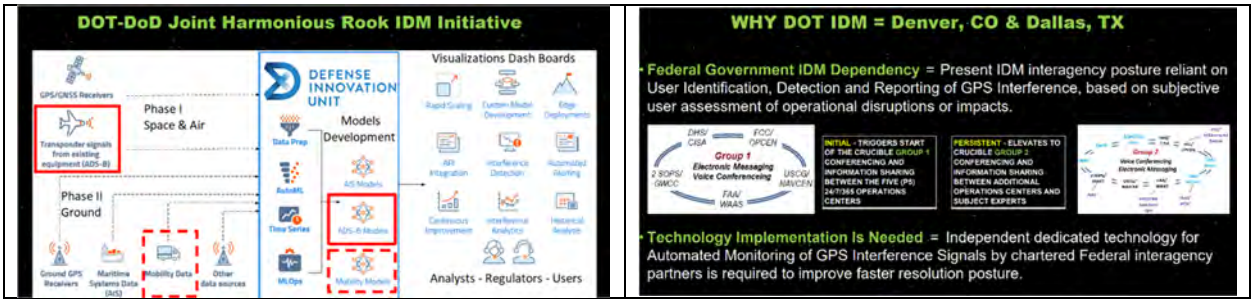
There is a need to identify sources of L-band interference. Today, we rely on user reports, from pilots reporting to air traffic control, to NAVCEN Center receiving reports from civil users. Dr. Brad Parkinson previously showed that we are only receiving a fraction of interference incidents that occur. We need to embrace both in-band and adjacent band interference. This is a multilayer approach that does not involve just DOT. This is truly an interagency effort that requires all of our capabilities, including industry, state, and law enforcement capabilities. The mitigation (the "M" in IDM) does not fall under DOT, which is focused on detecting sources of interference, but does not have the power to remove those sources. DOT has been working on a concept of operations (Slides 3-4), thinking about how we embrace technology. Ms. Van Dyke credited Mr. Goward with bringing up a good point, saying that there are interference events all of the time. The most notable events from 2022, Denver, CO and Dallas, TX were not the only two instances of interference. Mr. James Aviles, who has been on detail in Ms. Van Dyke, has been a great help in tracking GPS interference sources. He can attest that relying on user reports to track interference sources is no longer reliable, especially after the incident in Newark, NJ. When users experience interference, they often do not know the difference between an equipment error and a larger issue. It is important for the government to push out information so users can identify if there is either a common issue in any given area (suggesting interference), or if the issue is isolated to the device (suggesting an equipment malfunction). Therefore, identifying interference incidents is a matter of situational awareness and reigning in all available resources.



Slides 3-4

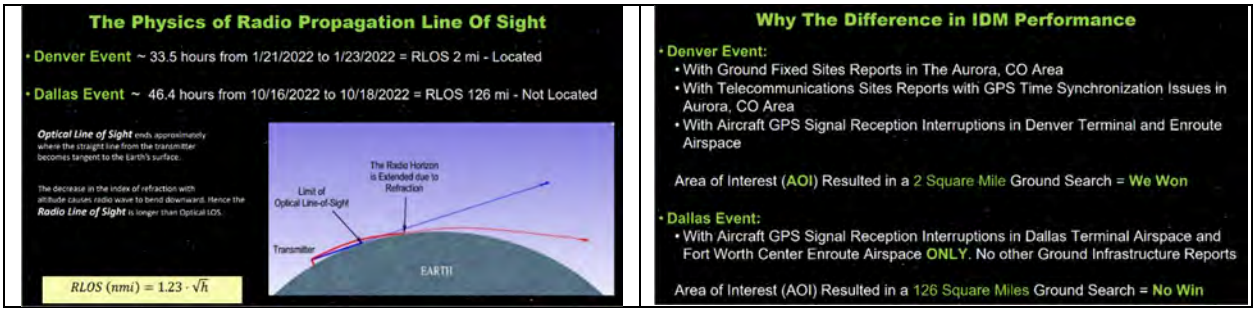
DOT has recently entered into a partnership with the Defense Innovation Unit, or DIU (Slide 5). They have a program called Harmonious Rook which focuses on GPS interference detection. The basis of the program is to leverage GPS receivers that are out there, allowing every GPS receiver to monitor the environment when interference occurs. If the information can be harnessed and brought into a common operating platform where artificial intelligence (AI) can be applied, the location of the interference can be determined. DIU started by using the Automatic Dependent Surveillance-Broadcast (ADS-B) data (referring to slide 5), Hawkeye 360. DIU also uses the Automatic Identification System (AIS) for the maritime environment, as well as information from fixed and mobile ground surface sensors. DOT has several reference receivers across the U.S. and has been talking to some of the automotive Original Equipment Manufacturers (OEMs) about CORS. This issue is important because we have been relying on user reports for initial interference detection, such as the incidents in Denver, CO and Dallas, TX (Slide 6). It is time consuming

to gather these reports that often turn out to be inadequate. We are shooting ourselves in the foot by not taking advantage of technology and all of the receivers that are out there.



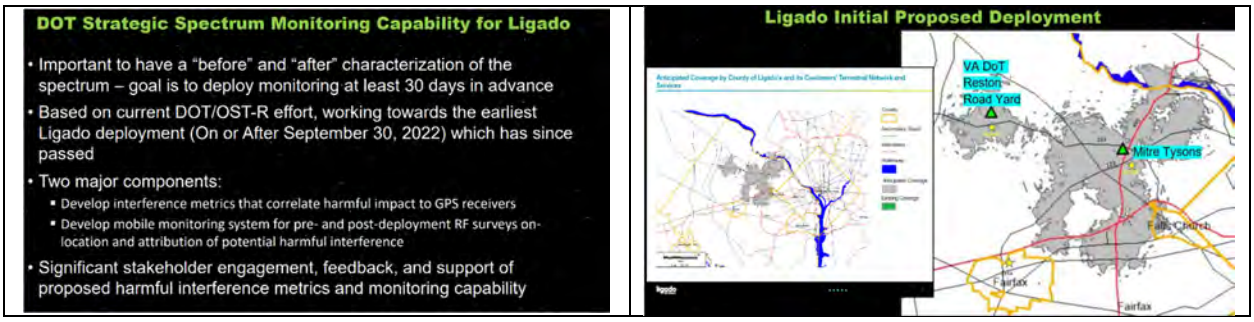
Slides 5-6

As shown on Slide 7, the Denver, CO incident lasted for 33.5 hours. Through multiple sources, we were able to get the radio line of sight down to two miles to locate the source of interference. In Dallas, the interference lasted for 46.4 hours with a radio line of sight of 126 miles. That source of interference was never located. This was not due to a lack of trying (Slide 8). The FAA had two flight check aircraft flying over TX during the event, which was quite expensive (the flight check aircraft costs about $3,800 per hour per aircraft). There was also ground-based sensing from multiple USG agencies trying to determine the source.



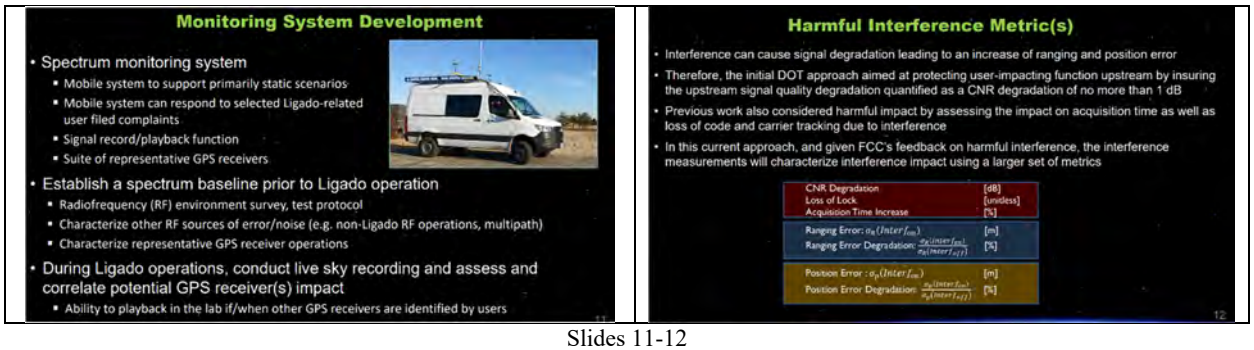
Slides 7-8

When Ligado announced, on March 30, 2023, that it was going to deploy in Northern Virginia at the end of September, DOT was already concerned due to the previous situation with Lightsquared. DOT recognized it would need to get out ahead of any deployment and be able to directly attribute interference due Ligado (Slide 9). DOT also recognized that the mitigation measures put in place by the FCC's order of authorization were not adequate. As Mr. Stormy Martin previously mentioned, DOT was focused on two major components: (1) Interference metrics that correlate actual impact to receivers, and (2) Develop capabilities through mobile monitoring to be able to characterize spectrum before and after Ligado's deployment. We need a structural baseline because we do not expect Ligado to admit to interference. They would likely say that there is already interference in the area and that they are not the source. DOT has spent time with stakeholders to gain an understanding of the capabilities necessary to stand up to scrutiny. On slide 10, the image on the left is the graph that Ligado submitted to the FCC in their filing. They did not specify where their transmitter(s) are going to be, so this image depicts what DOT anticipated in advance of their 30-day notification of deployment. As mentioned, DOT is working very closely with MITRE & Zeta Associates, both located closely to where Ligado is looking to broadcast. Ms. Van Dyke also gave a "shoutout" to NGS's temporary CORS network, which stations are very sensitive to L-band interference. One station is located on top of a MITRE building in Tyson's Corner, VA, the other station is near a DOT building in Reston, VA, right across the street from Ligado HQ. Although it may seem like we are stalking them, NGS did great work to put a T-CORS capability on that Virginia DOT building.



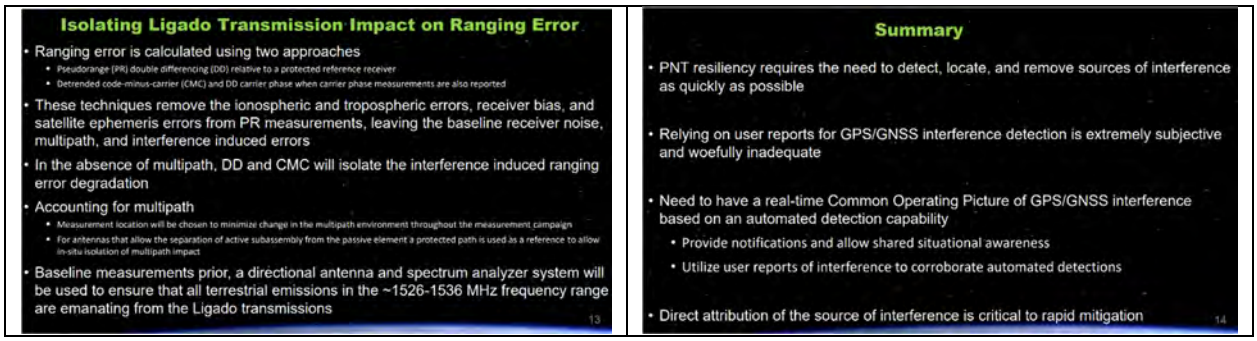
Slides 9-10

The van on slide 11 is equipped to have mobile spectrum monitoring capabilities. DOT was waiting for Ligado to announce where their transmitter is going to be so that they would be able to collect information to create the spectral baseline. DOT was also working with the interagency on receivers that they wanted to have included in the monitoring network once Ligado did start transmitting. Importantly, DOT recognized that they could not carry around all of the receivers that everyone may be interested in so the mobile monitoring equipment had the ability to record and play back data so DOT could evaluate the impact on other receivers. Mr. Martin previously discussed some of the interagency conversations occurring within the SPPI Working Group and NTIA regarding harmful interference metrics. DOT, and others, have made it very clear that they embrace the 1dB C/N_0 degradation interference protection criteria, but they recognize that the FCC did not accept that criteria in its order of authorization (FCC was very clear about this). This has forced DOT and other agencies to look at other metrics that could be used to prove that GPS receivers were being interfered with (Slide 12). These other avenues included assessing an increase of acquisition time, impact on ranging error, and impact on position error. Ms. Van Dyke applauded NTIA leadership and engineers for working with DOT to put together an "air-tight case" to directly attribute interference with Ligado.



Slides 11-12

Ensuring that DOT can isolate the Ligado transmission and their impact on ranging error means removing all other sources of ranging error (Slide 13). So, using double-differencing and a code-minus-carrier approach to isolate the interference sources has worked, except with multipath. Thus, we need to remove multipath as well. The goal is to have a "before" picture, so once Ligado starts broadcasting, we can see the difference in the spectrum environment. The fact that Ligado has not started broadcasting is not good for DOT because they have put together multiple capabilities to assess the Ligado situation, but there is no telling when or if Ligado will deploy its network. Ms. Van Dyke applauded all of the great work DOT and others have done to get them to this point. Regarding resource, this was a significant effort to put these capabilities in place. If Ligado never deploys, these resources will be out towards DOT's broader IDM initiative. In summary, when we think about IDM & PNT resiliency, the key metric is minimizing the duration from the time interference starts occurring to removing the source of interference (Slide 14). Because we may never prevent interference from occurring, we need to be prepared to detect, locate, and remove the source of interference as quickly as possible. Relying on user reports is inadequate. Although there are a lot of good reports, many may have been due to user equipment malfunction. Ms. Van Dyke told the Advisory Board that if any Members know of sources that can be used to integrate into the Common Operating Picture, the Defense Innovation Unit is interested, as they are looking to maximize one of the best sources to detect interference. The direct contribution of the source, as well as law enforcement, is critical to rapid mitigation.



Slides 13-14

Discussion:

ADM Allen thanked Ms. Van Dyke, then called on Mr. Goward for a question.

Mr. Goward asked, regarding the interference protection mitigation strategy, whether DOT has considered a legislative proposal to power state and local law enforcement to take action against illegal transmissions that interfere with GPS and GNSS?

Ms. Van Dyke stated, setting aside the legislative portion, that in conversations with DHS, who led the after-action reporting activity from Denver, CO, the question "what can we do better?" is always asked. It is important that we are able to harness

assets and equip them with the ability to detect interference. At the law enforcement level, we need to be aware that this is an issue and to look out for it.

Mr. Goward noted that, at the moment, even if they have the equipment and they find it, they don't really have the ability or the authority to do anything about it."

Ms. Van Dyke said that she is not sure in terms of their abilities, given that it is illegal to interfere with spectrum.

Mr. Goward asked that since the FCC has no enforcement responsibility, how are they playing into this interference detection mitigation?

Ms. Van Dyke responded that FCC has an enforcement bureau [which] is not as strong as it has been in the past, but they have been great partners with us when interference events occur. Their job is easier when we can point the finger at where we think the source of interference is coming from, and that is some of the changing dynamics of what we're facing. There's an increasing role in expectations for the DOT, and perhaps other departments and agencies, to do some of the upfront legwork of detecting where the interference source is coming from. The FCC, perhaps due to their cutbacks, do not have this capability.

Mr. Goward said he'd leave it to others to be less generous than Ms. Van Dyke in their assessment of the FCC's responsibility in that area. In his experience with government, when you have a strategy that means that you don't have any money. He gave his support to Ms. Van Dyke to get an interference detection mitigation system in place.

Ms. Van Dyke commented that DOT did get resources in our FY2022 budget request. In May of 2022, MITRE held a GPS interference situational awareness workshop where there was discussion on where to invest. The Defense Innovation Unit (DIU) is currently harnessing commercial capabilities that are attractive to DOT. DOT has sent money to DIU to leverage the capabilities that they have been working on for DoD. There is an opportunity for all of us to think about assets that we have that might be able to contribute"

Mr. Goward asked if there is anything in terms of an ongoing program for services or other things that would provide us that sort of common operation?

Ms. Van Dyke stated that needs to be embraced as we move forward because these interference instances are not going to go away. We have a "heat map" so we know where to send our assets, whether it's a flight check aircraft or assets on the ground. This needs to be a part of our collective approach going forward. This is not to say that we would move away from user reports or discourage users to report interference, but her goal is that [by the time] they report interference, we already know that something is happening. Then it becomes a matter of how quickly we can remove that interference source."

Mr. Shane stated that this was a great briefing, and asked whether there will there be an effort to socialize the findings that DOT has taken in this context with higher levels of government, such as the National Security Council (NSC), the Office of Science and Technology Policy (OSTP), and the Office of the President? This issue is a major issue attributable to an independent regulatory agency over which the Executive Branch has very limited power. It's not a mistake we should waste. How much of [this] is actually in DOT's thinking, and how much of it will go to other participants in the EXCOM?

Ms. Van Dyke thanked Mr. Shane and stated that is a great question. Ms. Caitlin Durkovich at NSC is very interested in the efforts and has been championing the Executive Order 13905. OSTP came out with a National R&D plan for PNT resiliency. While we never want an incident like what happened in Dallas last month to occur, we should use it as an opportunity to show what needs to be done to solve it. It is a problem that certainly received attention at the Secretary level. The Secretary of Transportation and FAA Administrator were shocked that we do not have an automated way to detect interference. So, this is an opportunity to say, that we absolutely need to have that. As Mr. Martin likes to say, resilience is not free and resources are needed to invest in that capability. Some of you may have seen the www.GPSjam.org that a Disney engineer created. During the Dallas incident, they probably got more clicks on that website than they had prior. Thus, there is recognition that the USG needs to have that capability."

Mr. Shane asked, if there any thought to a Legislative proposal where national security might be at stake through an independent regulatory agency's action of the sort.

Ms. Van Dyke said that she cannot speak to that.

ADM Allen said there are two things we might want to consider. First, I would look at the legislation that was created in the FAA Reauthorization Act regarding autonomous systems and how that got propagated across the interagency, and how command and control works for that. Secondly, during national special security events, like the Super Bowl. If you want to prototype or testbed this, and this is Ms. Durkovich's area where she can get involved, will be to take this capability and make it part of the overall response architecture for a national special security event. That would be the Super Bowl, the World Series, a national funeral, inauguration, and those types of things that actually enhance resiliency and mitigates risk. That's what's happening with unmanned systems now, especially drone operations around special national security events. I would suggest there's probably a way there. I would start with the FAA Reauthorization Act.

* * *

International Committee on GNSS (ICG) & Concise Update on International Traffic in Arms Regulations (View PDF)
Mr. Jeffery Auerbach, Acting Director, Office of Space Affairs, Department of State

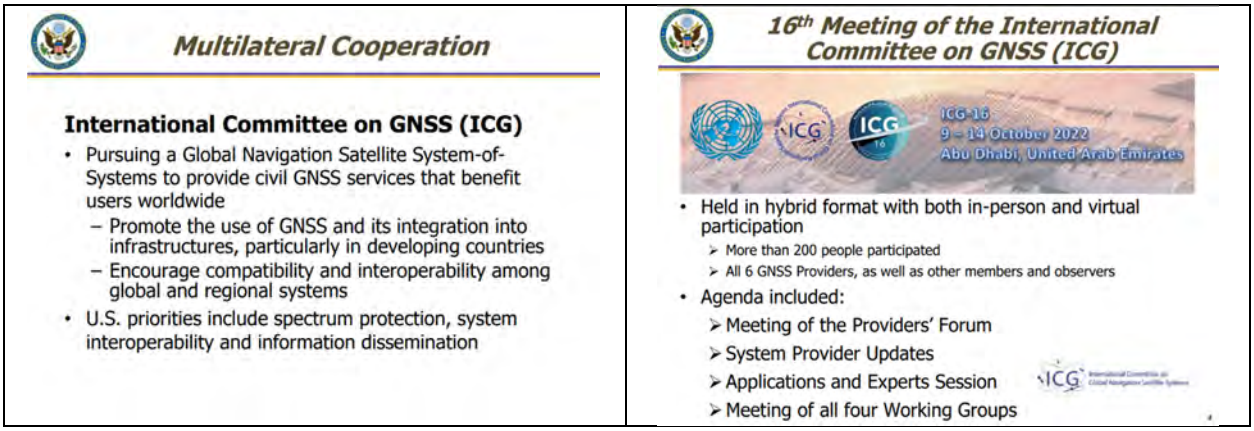
ADM Allen asked Mr. Auerbach to provide an update on the latest ICG meeting and ITAR.

Mr. Auerbach started by stating that he will give an update on the ICG-16 meeting that took place in Abu Dhabi, United Arab Emirates (UAE) in October of 2022. He is a cochair one of the WGs at the ICG, so he is very familiar with the issues. Additionally, although it is not his area of expertise, he will also give an update on ITAR (Slide 1).

Slide 1

International Committee on GNSS

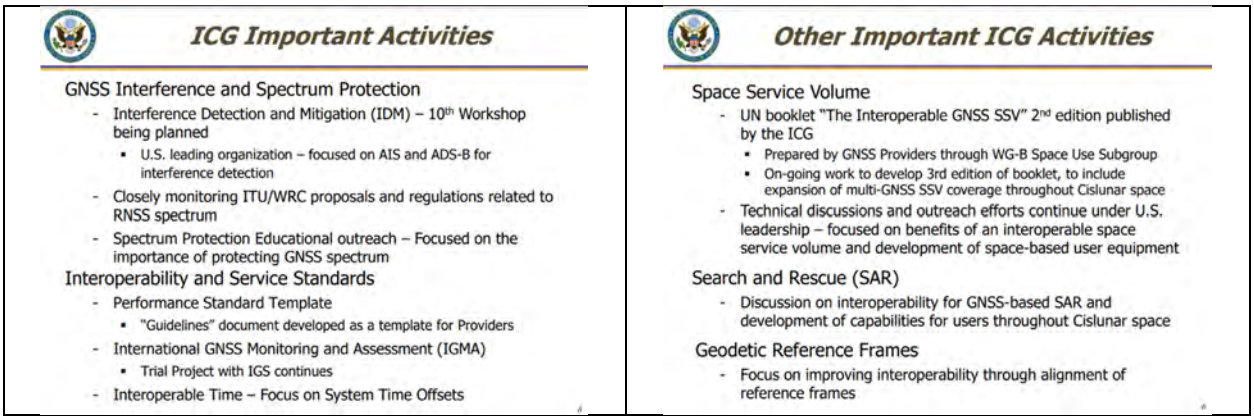
The ICG pursues a Global Navigation Satellite System of Systems to provide services the benefit users world-wide. Key topics include spectrum protection, interoperability, information dissemination, compatibility, etc. (Slide 2). The ICG-16 meeting was held in a hybrid format with over 200 participants from all six GNSS providers and other observers (Slide 3).



Slides 2-3

Some of the important activities included interference and spectrum protection (Slide 4). The ICG has conducted IDM workshops. The 10th workshop is currently being planned to take place in the summer of 2023 in Vienna, Austria in a hybrid format. Related to spectrum, we closely monitor the ITU, and World Radiocommunication Conferences (WRCs) related to Radionavigation Satellite Service (RNSS) spectrum. ICG has also done educational outreach, specifically focused on the importance of protecting GNSS spectrum. This is done by providing workshops targeted at spectrum regulators with a goal of highlighting the importance for all countries (not just GNSS providers) to be familiar with the concerns surrounding spectrum so situations such as the Ligado issue can be avoided. Regarding interoperability and service standards, the ICG is developing "guidelines" for providers to use as they develop performance standards. This is an issue that the U.S. has been pushing for in the ICG for more than 10 years, and it is finally getting traction. The U.S. has a trial project with the International GNSS Service (IGS) on international GNSS monitoring, which has been ongoing for the past seven to eight years. Although COVID-19 temporarily halted progress, this is still a topic that is being discussed in the ICG. Lastly, interoperable time has also been discussed for a number of years in the ICG.

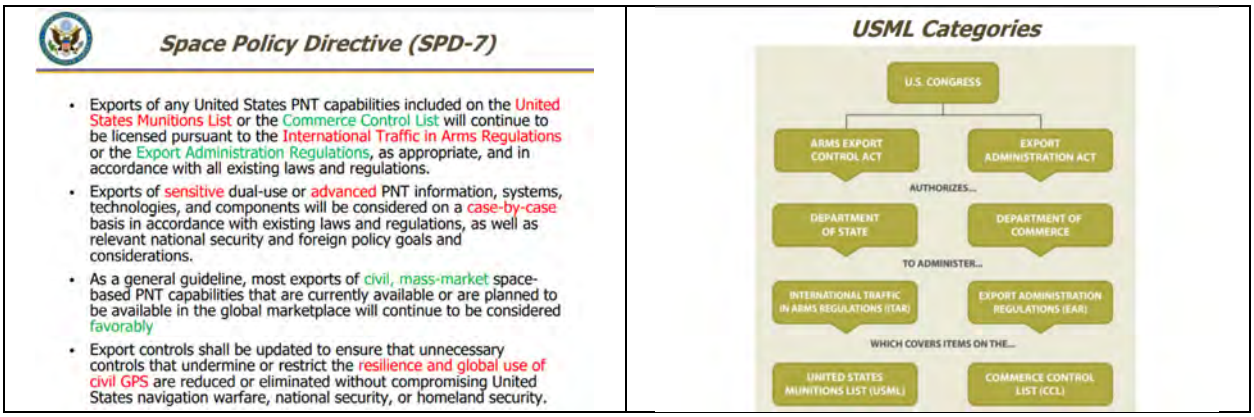
The Space Service Volume (SSV) is a big issue for NASA (Slide 5). ICG has published a couple of booklets (and is currently working on a third). Search and Rescue's (SAR) is discussed within the ICG with a focus on interoperability because we are moving toward a Lunar-based GNSS SAR system. There is also a working group focused on Geodetic Reference Frames. The LEO systems were introduced into the working group meetings for the first time this year. The ICG is considering having a workshop with the industry on this topic. Authentication is also something that the ICG may consider expanding on.



Slides 4-5

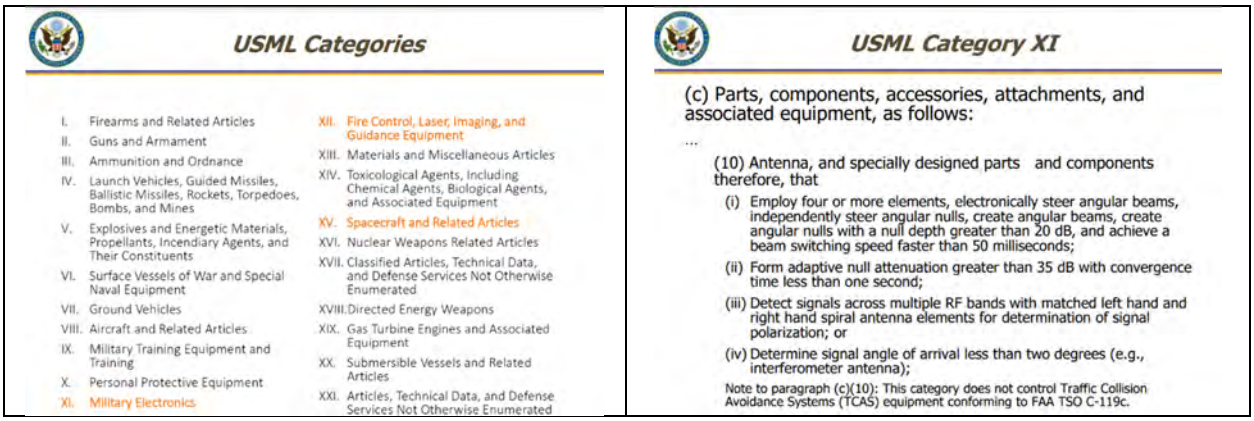
International Traffic in Arms Regulations

Mr. Auerbach reiterated that he is not an ITAR expert, as ITAR is handled by another office within DOS. He continued by stating that he will present this issue from a "process" perspective. Our current Space Policy Directive 7 highlights ITAR regulations, which means that it is managed by both the Department of State and Department of Commerce (Slide 6). There are two separate tracks that are completely independent from one another: ITAR (Slide 7, on the left) and Commerce Export Administration Regulations (EAR) process (Slide 7, on the right).



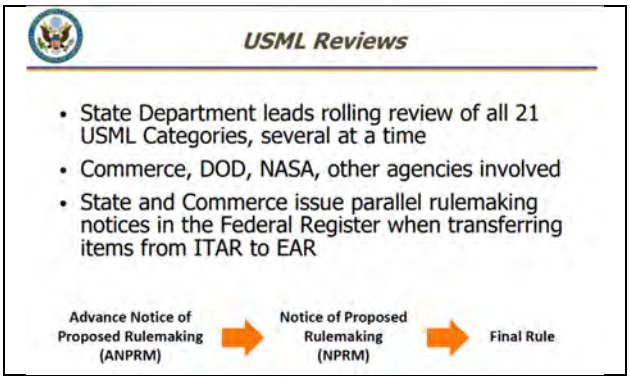
Slides 6-7

ITAR is the focus of this discussion, specifically Item XI, which is the Military Electronics Category (Slides 8-9).



Slides 8-9

DOS works very closely with DOC on the ITAR process but has final authority (Slide 10). The Category XI review, the Notice of Inquiry (NOI) went out and the comment period has closed, but there is opportunity to make additional comments.



Slide 10

Discussion:

ADM Allen asked, for clarification, if this is the proposed standard (referring to slide 9).

Mr. Auerbach stated that this is the existing standard. The second phase is notice of official rule making, which leads to making the final rule.

ADM Allen asked what is being proposed.

Mr. Auerbach answered that the proposal is to review the existing rules. There is going to be a review of the rules and the State and Commerce Departments have taken comments regarding this rule.

Admiral Thad Allen followed up, asking "if somebody wanted a standard other than [Slide 9], they would submit a comment on either advanced or proposed rulemaking?"

Mr. Auerbach stated that is correct. It is most valuable to hear about commercially available equipment. There is a lot of discussion about what companies are doing for the military, but it is more helpful to know what companies are doing at the commercial level.

Mr. Murphy asked if the information about the apparent effectiveness of current rules is interesting. He explained that is we may be able to show evidence that CRPAs are being deployed by Russia and China.

Mr. Auerbach replied, stating that would be helpful.

Mr. Goward asked Mr. Auerbach how someone could get involved in this federal process. He also asked if Mr. Auerbach is the point of contact at DOS.

Mr. Auerbach stated that the comments must be submitted through the official website and added that he could send out the link.

Dr, Parkinson noted he was appalled. It seems that by the time the government gets around to reviewing the rules, industry and other countries are going to be years ahead of the Unites States. Is there is somebody in this process that is pushing back on the tremendous built-in lags? Also, is this just for L-band or does the information on slide 12 apply more broadly (if it does, then it has already been violated).

Mr. Auerbach answered by stating that it would be helpful for Mr. Parkinson's concerns to be submitted as an official comment.

Dr. Parkinson reiterated his concern that there should be expertise at the national level, so we don't have to go through this process. If our government is making the rules, it is incumbent on them to know what the impacts are.

ADM Allen asked (referring to Title V) whether if there is a reason for it, can one go to an interim final rule on a particular topic? That's what the USG would do if this were an emergency.

Mr. Auerbach reiterated that he is not an expert and does not know how long to process takes or what the ins and outs of the approval process are. If they need to, our government could move quickly on these issues. DOS participated in meetings on this topic which implies that this is an important issue for them, and it is being addressed.

Dr. Penny Axelrad noted that spaceborne GPS receivers got moved to EAR. How did that happen?

Mr. Auerbach responded that when something gets removed from the ITAR list, it automatically goes to the EAR list. So, there was a review, and it was determined that foreign GPS space receivers are no longer part of ITAR. ITAR is the most restrictive and DOC is much less restrictive. Mr. Auerbach stated that he cannot comment on the details of how this transition happened, or how long it took.

Mr. Shane added to Dr. Parkinson's questioning that to make a change there has to be a case made, and so the comment process is the opportunity to make that case. Otherwise, it's not going to happen automatically. Mr. Shane then asked Mr. Parkinson if he's submitted comments.

Dr. Parkinson answered that he doesn't know what the process is. There are a lot of people that also do not know what this process is so, there should be someone involved in this process that is looking at the reasonableness of what they're doing. The process is too complicated and, in his view, is not helping our military. Dr. Parkinson said he is not likely to get involved in this process.

ADM Allen commented that Slide 10 illustrated that this is a periodic review by category, meaning that there was no demand to bring this up and evaluate it. Had that review not come up, when would this review have happened?

Mr. Auerbach stated that he doesn't know how often they do the periodic reviews, but he can try to find out specifically how the process works. Mr. Auerbach reiterated that there is an opportunity to address this issue right now, so we should take advantage of it if we can.

Dr. Powell asked if Mr. Auerbach could find out the time period of the review process.

Mr. Auerbach said he would inquire how often there is a review process.

Mr. Murphy added that the history of these review processes is not that old, only going back to around 2015. The issue is there since then, there has been a revolution surrounding electronics, and there wasn't a lot of commercial demand for this back when they had to be done with discreet phase shifters in an analog fashion. The advent for very powerful digital processing elements and software defined radios has lowered the cost of this so now it's a viability for civil applications. There would not have been a lot of comments in 2015 from companies that here chomping at the bit to do CRPAs for civil because their perception was that there was no market at the time. Now, evident by the fact that we have at least one US manufacturer that has gotten a Technical Standard Order (TSO) on a CRPAs for aviation applications, there is interest in civil applications. The problem is that company does not know how they are going to deal with ITAR. They built a product, but they can't export it. When you put an ITAR part on an airplane the airplane becomes ITAR, which is not something that a typical operator could deal with.

ADM Allen asked is anybody else had any statements.

Mr. Higgins asked, in fairness to Mr. Auerbach, whether the board should get an ITAR expert from DOS at the next meeting.

Mr. Auerbach stated that the experts are reluctant to participate.

ADM Allen stated that the Board can do more fact-finding on this issue.

Mr. Miller thanked Mr. Auerbach because it is not his area of expertise. He worked with Mr. Murphy and got DOS representatives to have an in-depth discussion. Mr. Miller stated that will continue to work with Mr. Auerbach to see if they can get DOS experts to attend the spring PNTAB meeting in Washington, DC.

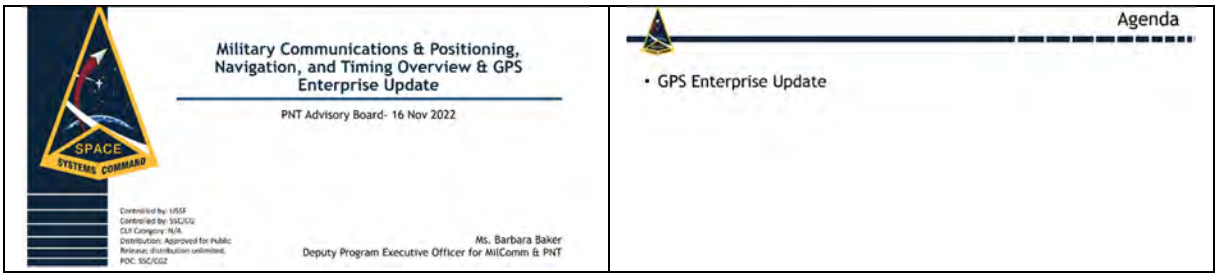
Mr. Auerbach added that there may be some progress between now and then on this process.

ADM Allen thanked Mr. Auerbach.

* * *

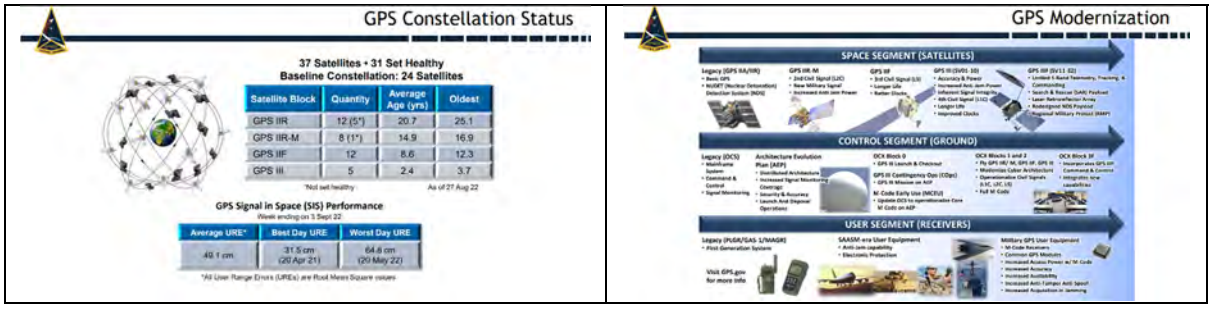
GPS Modernization Status: Enhancing Capabilities & Resilience (View PDF)
Ms. Barbara Baker, *Deputy Program Executive Officer for MilComm & PNT, Space Systems Command, U.S. Space Force*

Ms. Baker noted she would be speaking from the USSF's perspective regarding the latest PNT capabilities and status on the GPS Enterprise (Slides 1-2). Several agencies across the government that have a foot in PNT, but the question is who is at the head of decision making? The National Security Policy that was recently published is not 'loud'" regarding PNT, and this affects the decision-making process of where to allocate resources when civil interests are being weighed against warfronts.



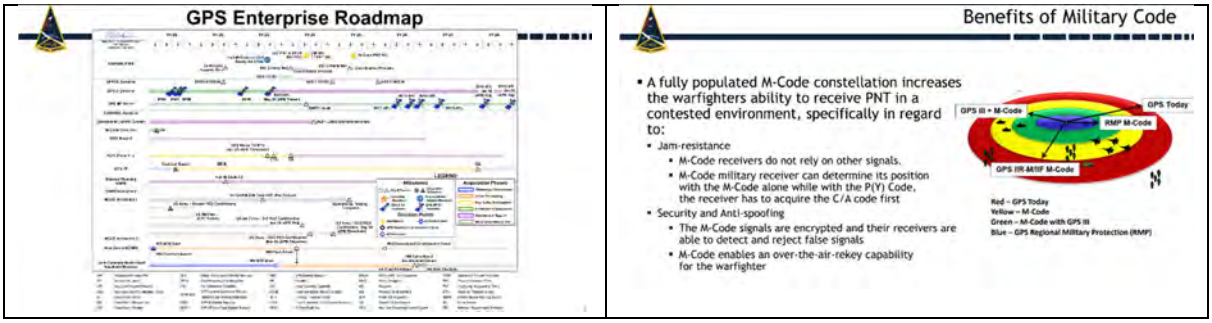
Slides 1-2

The USSF is responsible for operating GPS, and is now getting ready to launch the 6th GPS Block III space vehicle (SV) in the New Year. GPS Signal-in-Space (SiS) performance continues to be outstanding, and whenever she's seen a fault its often times due to user equipment (Slide 3). The USSF is about to complete production on the last GPS Block III space vehicle (SV 10), and are in the development phase for GPS Block IIIF. As shown on slide 4, with GPS blocks IIF and III comes higher anti-jam, higher accuracy, the 4th civil signal (L1C), longer vehicle life, etc. (Slide 4). GPS IIIF is also going to bring a Regional Military Protection (RMP) payload. Additionally, a Search and Rescue (SAR) repeater and laser retroflector array payloads will be added. The Next Generation Operational Control Segment (OCX) is getting ready for its final deliveries. The legacy system on the OCX was augmented as part of the Architecture Evolution Plan (AEP) and upgraded so the GPS III satellites can fly in the constellation using the legacy signals. The USSF flies OCX operationally via AEP through contingency operations. M-Code Early Use has also been brought online. AEP was augmented to monitor and mission task the M-code signal. With the launch of GPS III SV5, the U.S. has now full GPS constellation (24 satellites) of M-Code. Regarding the User Segment, USSF has built a user card that goes into user equipment. Testing is being completed for the aviation & maritime cards, and the ground cards are ready to be put on the market.



Slides 3-4

Slide 5 depicts the GPS Enterprise Roadmap. As new SVs come online, we are not only bringing on M-code but also the modernized civil signals. USSF has also engaged different services about starting to build user equipment with the ability to use M-code. We are developing higher anti-jam capabilities for our military signals (Slide 6). GPS III is coming online with boosted M-code, and GPS IIIF will be RMP-capable. Many folks working for USSF, including Dr. Tom Powell (PNTAB member) continue to work activities to address what we can do better regarding PNT resiliency.



Slides 5-6

Slide 7 details the benefits of improved civil signals. Regarding OCX, USSF has uncovered a few issues during the summer of 2022 that have caused a bit of a setback (Slide 8).

Slides 7-8

Development and operational testing for the Ground Segment is going to continue through 2023, with an operational acceptance target date in the First Quarter of 2024 (Slide 8). In the fall of 2023, USSF will transfer the constellation from a Legacy ground system onto OCX. Several GPS III SVs are currently in storage, and USSF is currently finishing development for SV10.

Slides 9-10

Regarding GPS IIIF, the first launch is forecasted for FY 2027 (Slide 11). Finally, the ground card for user equipment was certified earlier in 2022. Raytheon, the contractor charged with the aviation and maritime cards, delivered their last software drop that aimed to resolve requirement deficiencies. Additional testing with the Air Force B2 Spirit and the Navy Dog Arleigh Burke is required. MGUE Inc 2 has a smaller feature size (14 nanometer) and will be integrated into hand-held user equipment.

Slides 11-12

Discussion:

Gen Hamel asked what exactly is the Joint Program Office's role in addressing antennas to be used with user equipment overall?

Ms. Baker said that's not in their job jar. They're in in charge of building up the receiver card that gets integrated into different platforms. Who the user is and what platform they need is outside our responsibility.

Mr. Grossman noted that the Enterprise Roadmap Slide appeared to show that FY24 & FY25 did not have GPS launches.

Ms. Baker said the slides shows initial launch capability, so that's when the system is available to be launched but not the actual launch manifest date.

Mr. Grossman then asked is there is any discussion about speeding up that timeline as other nations are deploying their GNSS satellites at a faster rate.

Ms. Baker said that when you look at it from DoD's perspective, and who is doing national security launches, it's not just GPS that gets out prioritized. There are three main priorities in the National Security Policy: (1) Investing in people, education, and "the underlying sources of tools of American of power and influence; (2) Building a strong coalition to enhance our collective influence. "At Space Systems Command we have a huge presence of trying to get international partnerships going; (3) Modernizing and strengthening our military so it is equipped for the era of strategic competition with the major powers. Therefore, from a DoD perspective, missile warning, missile track, missile defense, are the priorities shown in the manifest. Because we have such a robust GPS constellation, it tends to not have as loud of a voice when prioritizing launches.

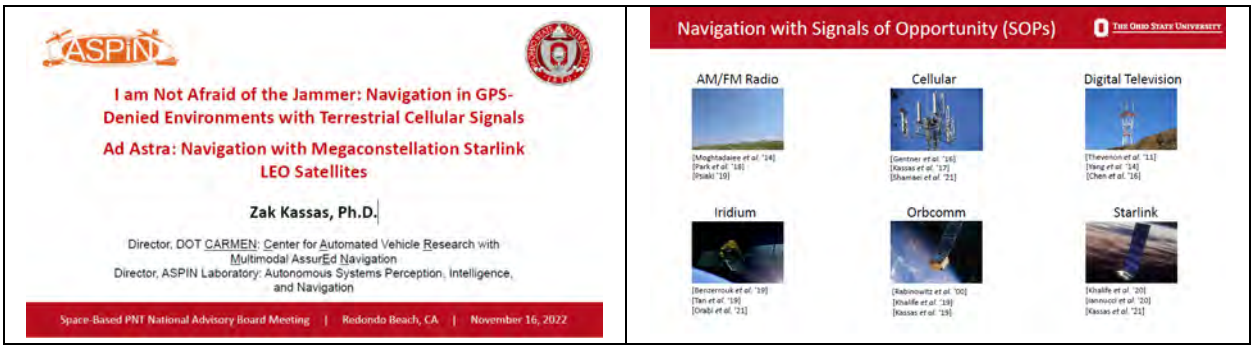
Mr. Miller commented that he really appreciated seeing the LRA and SAR payloads on the charts. While we take these for granted now, it took us seven years to get an approval for the LRAs and had to go three times through the PNT EXCOM Committee. Then, the DoD realized this was not civilian payload. Mr. Miller noted that in the future he'd like to also see the importance of the GPS Space Service Volume (SSV) reflected in these charts. Gen Thompson has been our champion over many years. SPD-7 explicitly mentions the development of a Cislunar Service Volume, and that means extending the current SSV beyond GEO and taking it up to Lunar orbit. Everything we do at NASA is not just to benefit us, but also all our agency partners and the commercial sector. Are there any SSV enhancements planned?

Ms. Baker responded that nothing is being planned beyond what is already being provided. There are no new additional requirements planned. At this time, the priorities for Space Systems Command are: (1) Missile warning and defense, (2). Space data transport layer, and (3) NAVWAR force design.

LEO Constellations for Navigation (View PDF)

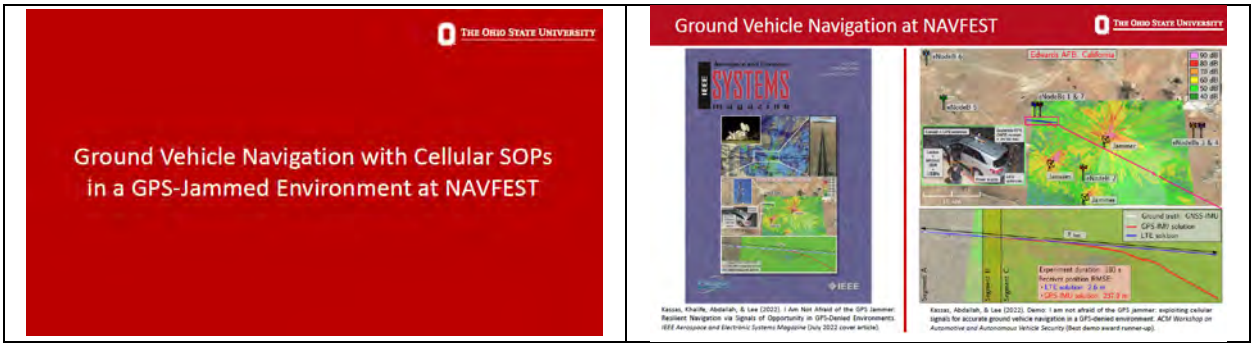
Dr. Zak Kassas, *Director, DOT Center for Automated Vehicles Research with Multimodal AssurEd Navigation (CARMEN), The Ohio State University*

Dr. Kassas introduced himself and noted he would discuss how to navigate with Starlink (Slide 1). We live in a frequency rich world where there are signals that we can leverage and explore opportunistically for navigation, ranging from terrestrial (AM/FM radio, cellular, and digital television) or coming from space (Iridium, Orbcomm, Starlink) (Slide 2).



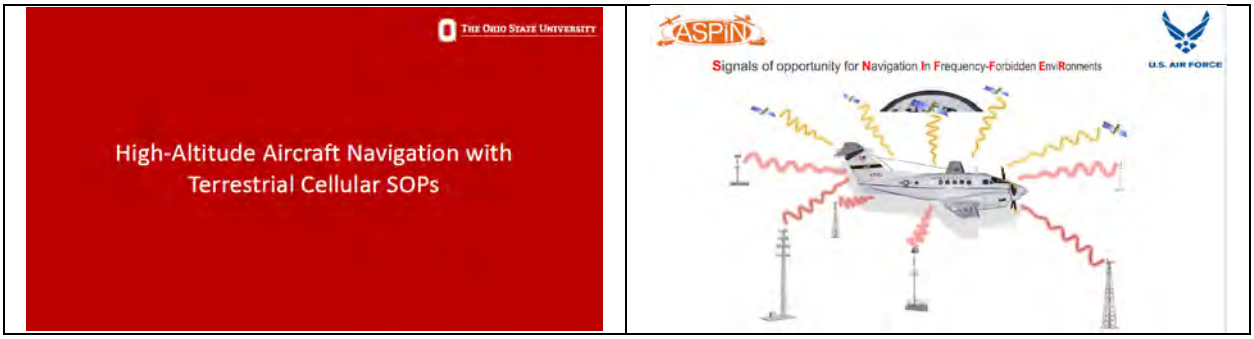
Slides 1-2

First let's review the results of some experiments we conducted at NAVFEST, where we had a successful demonstration (we believe it was the first one) of high accuracy navigation in a GPS-jammed environment by listening to cellular signals of opportunity (SOPs) (Slide 3). This work was released in July 2022 and featured in the Institute of Electrical and Electronics Engineers (IEEE) Aerospace and Electronic Systems Magazine (Slide 4). At NAVFEST we successfully navigated our vehicle through a jammed environment that could be as high as a signal-to-jamming radio of 90 dB. We did this by using LTE from towers over 30 km away were able to navigated to an accuracy of approximately 2.6 m over a distance of 3.5 km [Ed Note: See demonstration video in 4:50:35-4:52:18 of the meeting recording at: https://www.youtube.com/watch?v=RzOAg5HCuGo].



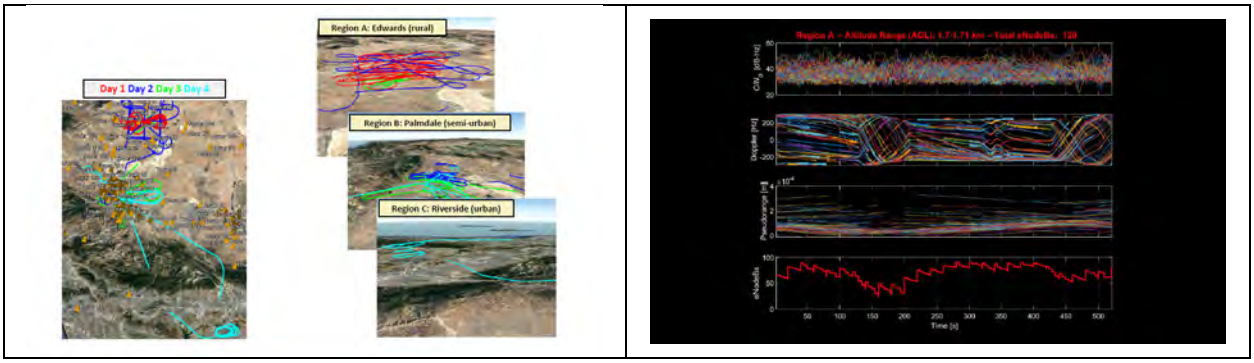
Slides 3-4

The issue is whether it is possible to navigation high-altitude aircraft with terrestrial cellular SOPs (Slide 5). We are not the first to look at LTE, but to date we are the ones that have achieved the most accurate results. We were able to navigate an aircraft submeter level accuracy just by listening to LTE. We collaborated with the Air Force on the 'Sniffer' mission to determine how high and usable can LTE signals go (Slides 6-8). [See demonstration video in 4:53:04-5:05:06 segment of the meeting recording available at: https://www.youtube.com/watch?v=RzOAg5HCuGo].



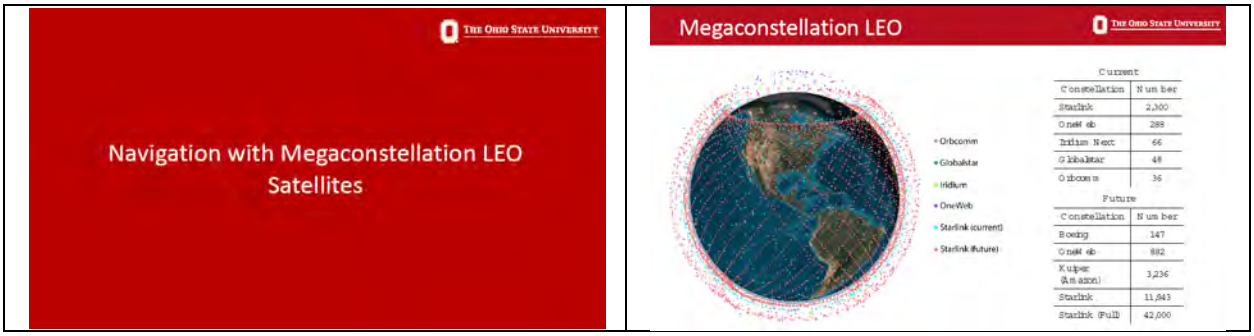
Slides 5-6

The test was conducted right before the COVID-19 outbreak, and we were only able to conduct four days of testing prior to its cancellation. Slide 7 depicts the trajectories that were followed by the UAV over a rural region, a semi-urban region, and an urban region, and slides 8-12 show the number of LTE towers (nodes) being tracked, the pseudorange accuracy, Doppler, and C/N_0 during these flights. For example, slide 8 depicts a portion of a flight over the rural region at an altitude of 1.7 km. During these tests we flew the airplane up to an altitude of 23,000 ft and were still able to track LTE towers even at a distance of 100 km.



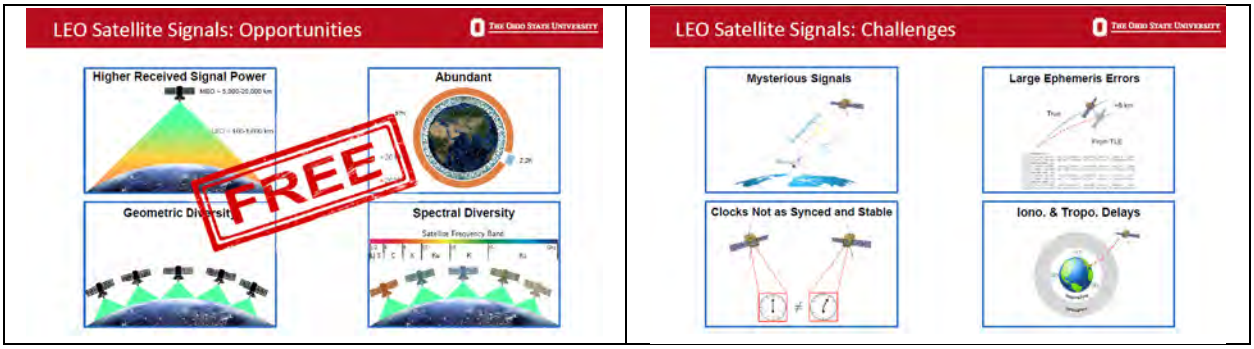
Slides 7-8

The next topic discussed was navigation with a Megaconstellation of LEO Satellites (Slide 9-10).



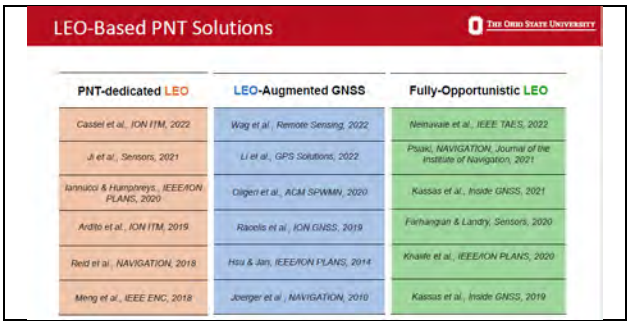
Slides 9-10

The opportunities in using LEOs, as compared to GNSS, is that they are much closer to Earth and have higher received signal power, there are abundant satellites, their positions are geometrically diverse, they transmit in a wide range of frequencies, and the approach being used is opportunistic/free (Slide 11). There are also challenges such as a need to build cognitive receivers that can decipher which signals we want to use, the LEO constellations don't necessarily transmit their ephemerides (so we could be talking about several km in satellite position errors), their clocks are not as synchronized and stable, and the ionospheric and atmospheric delays are going to be different since they are transmitting over a large swath of the spectrum (Slide 12).



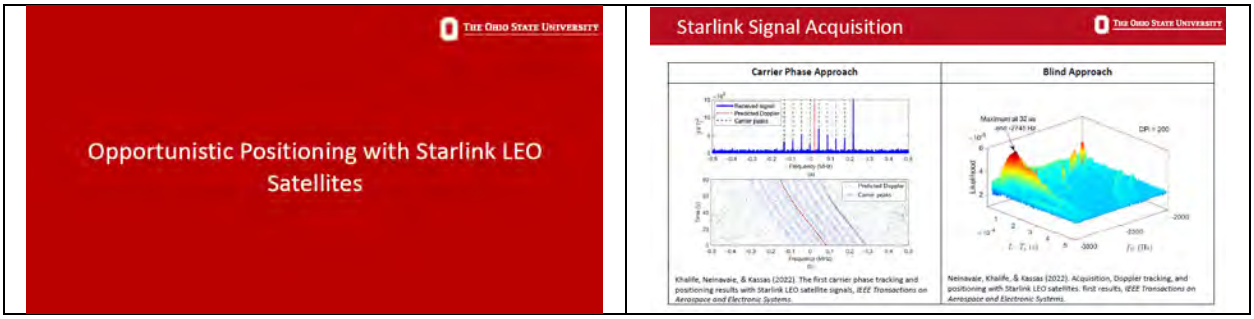
Slides 11-12

We are not the only people looking at using LEO constellations for PNT, and there are three schools of thought on how to approach this (Slide 13). These include: (1) using PNT-dedicated LEO satellites, (2) augmenting GNSS with LEO satellites to get the best of both worlds, and (3) fully opportunistic use of LEO constellations as we are doing.



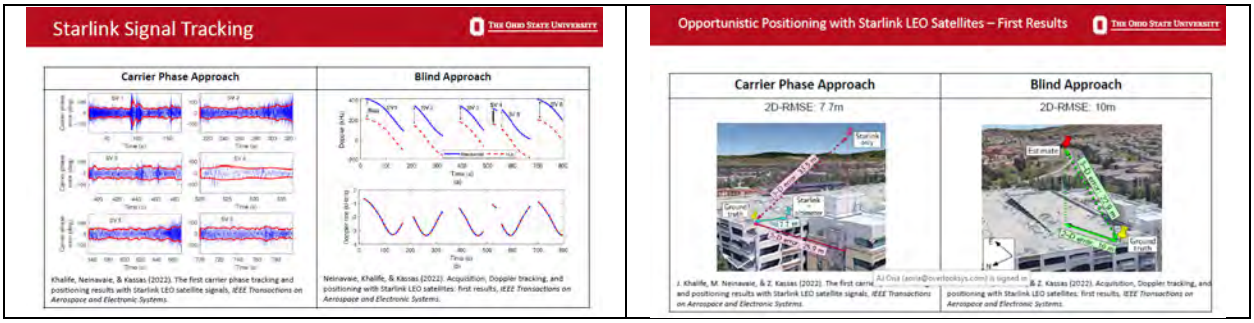
Slide 13

The next topic we're going to discuss is opportunistic positioning using Starlink LEO satellites (Slide 14). Essentially, we developed two approaches (Slide 15) for signal acquisition. The first one looks at the carrier phase, and the second one is a blind Doppler estimation. The trick to get these results was that we determined the code (code length, etc.) on our own.



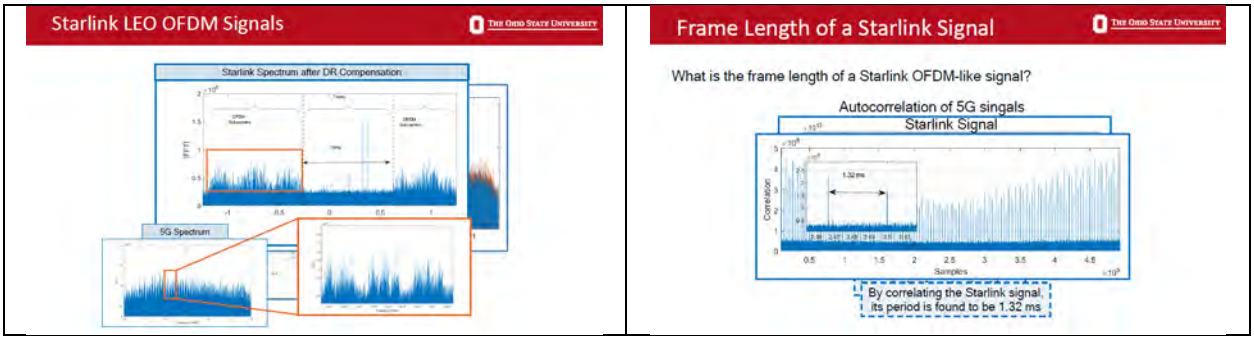
Slides 14-15

Slide 16 depicts the tracking using both approaches: the carrier phase approach and the blind Doppler approach. Initial result show that for a stationary receiver, the carrier phase approach gave us a 7.7 m 2D (two dimensional) error, and the blind Doppler approach gave us a 10 m 2D error (Slide 17).



Slides 16-17

Next, we improved the algorithm in our cognitive opportunistic receiver to track Orthogonal Frequency Division Multiplexing (OFDM) signals (Slides 18-19). This approach allows us to estimate the OFDM frame, and then we can start navigating. For Starlink, the frame length is 1.2 milliseconds.

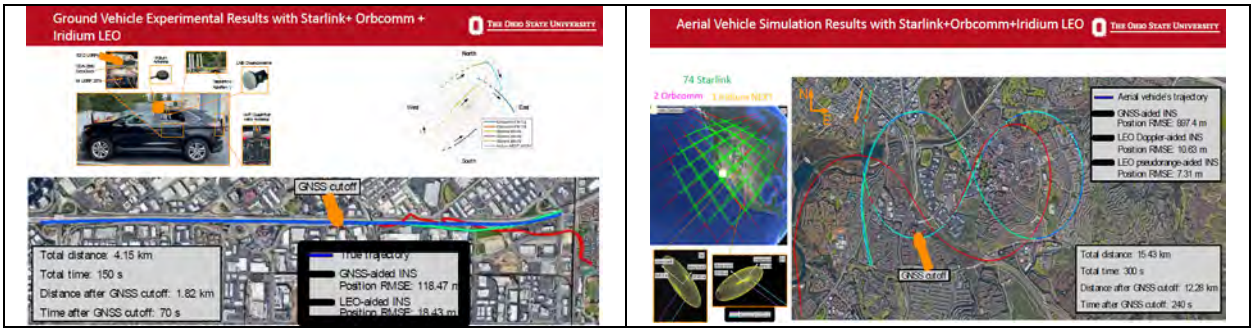


Slides 18-19

Unlike in other approaches, we did not reverse engineer the signal. We have developed a theory that can be successfully applied to Starlink, Orbcomm, Globalstar, GPS, and 5G that enables us to reconstruct what different providers are transmitting. The following video shows six Starlink satellites we tracked and determined which were transmitting OFDM and which were only transmitting the pilot signal [Ed. Note: see 5:06:14-5:07:03 segment in https://www.youtube.com/watch?v=RzOAg5HCuGo]. We ran this data through our new receiver and were able to reduce the error from 10 m down to 6.5 m since we were dealing with a larger bandwidth (Slide 20). Next, we are going to discuss how to do this on a mobile platform (Slide 21).

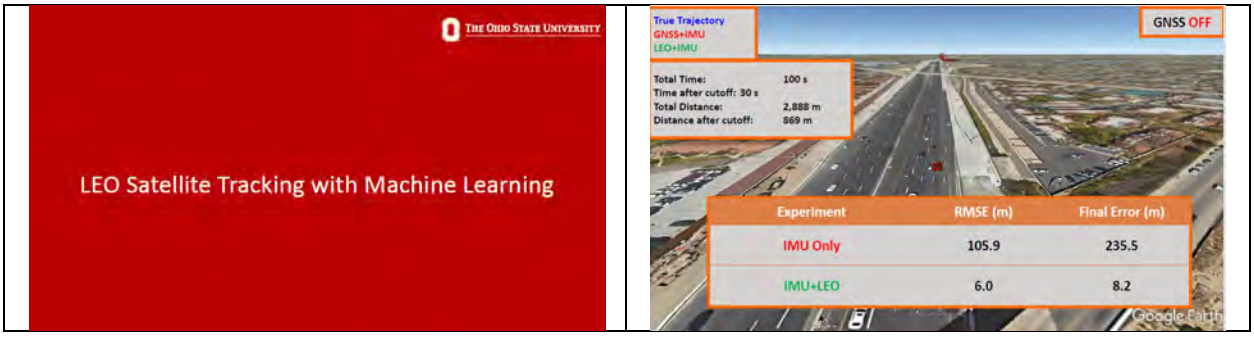
Slides 20-21

Slide 22 depicts an example of using our cognitive receiver to track two Orbcomm, one Iridium, and three Starlink satellites when traveling 4.15 km by car. At the 2.33 km mark we cut off GNSS. The green line shows the position estimated using LEO-aided INS. Slide 23 shows the results of an aerial simulation of what happens should we assume all planned Starlink satellites are in operation, which results in 74 Starlink satellites over area we conducted our tests. Following the GNSS cutoff, when using Doppler only we achieved 10.63 m RMS accuracy, and when using pseudorange we obtained 7.31 m RMS accuracy over a travel distance of 12.28 km.



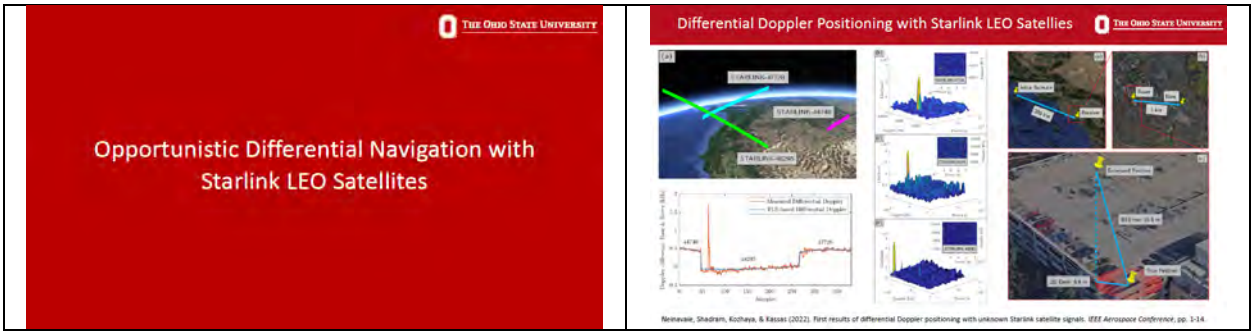
Slides 22-23

Machine learning is showing tremendous promise in the form of improving our ephemerides estimation for tracking LEO satellites (Slide 24). Using a machine-learning estimated ephemeris, following GNSS cutoff we were able to reduce the final error to 8.2 m over a distance travelled of 2.9 km when using Inertial Measurement Unit (IMU) + LEO measurements (Slide 25) [Also see demon video in 5:11:46-5:12:42 segment of the meeting recording available at: https://www.youtube.com/watch?v=RzOAg5HCuGo].



Slides 24-25

The last topic is opportunistic differential navigation with Starlink (Slide 26). This is another way to compensate for the large ephemerides error. We set up a base and rover separated by 1 km, both listening to the same Starlink satellites (Slide 27). The base would then send the differential corrections to the rover, without doing any machine learning or fancy ephemerides correction. We started with an initial estimate 200 km away, but ultimately we brought it down to 5.6 m by tracking just three Starlink satelites.



Slides 26-27

When running an aerial simulation with 44 Starlink satellites in view, we can predict submeter level accuracy (Slide 28). With that, Dr. Kassas thanked the board for the opportunity to present his results and what he hopes can be achieved and acknowledged the agencies that have provided funding to this work (Slide 29).

Slides 28-29

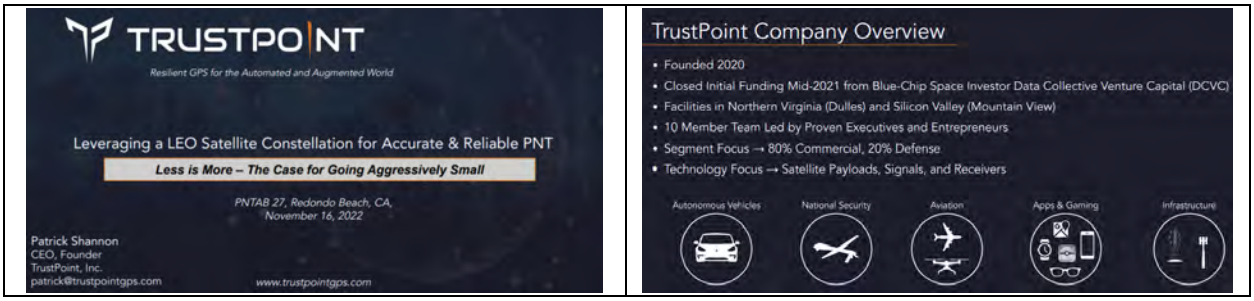
Discussion:

> Prof. Moore asked a two-part question. First, during these tests the data was recorded and then postprocessed? Second, if so, the process looks very intensive in computation, so how can it be moved to real-time?
>
> Dr. Kassas said that that for the cellular tracking, for the tests at Edwards Air Force Base (AFB) the data was recorded for the first pass and then postprocessed for the first pass. However, for LEO satellite tracking he believes this could potentially be turned into a real-time system.
>
> Dr. Filjar asked about the computational capacity required, especially for the perspective of mass markets. Is it possible to distribute the position estimation process so that only essential calculations are done at, say, one's smartphone?
>
> Dr. Kassas said that would be fantastic if we had that capability. However, one of the biggest challenges to put this on a smartphone are the antennas.

* * *

Leveraging a LEO Satellite Constellation for Accurate & Reliable PNT (View PDF)
Mr. Patrick Shannon, *Founder & CEO, TrustPoint, Inc.*

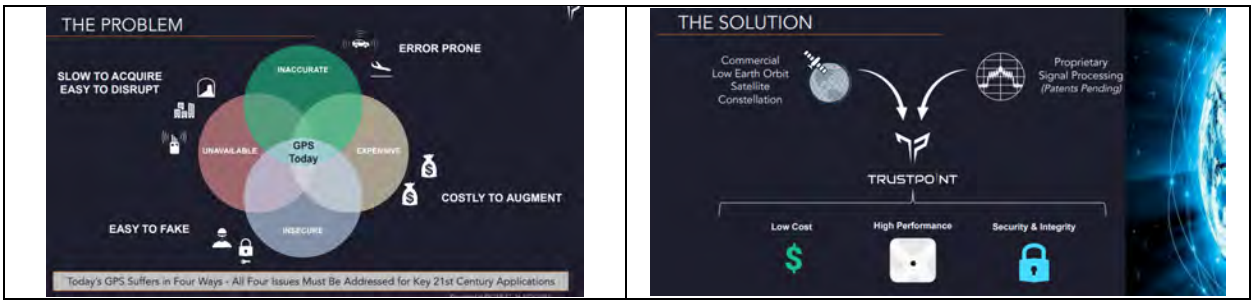
Mr. Shannon introduced himself. He is one of the founders of TrustPoint, Inc. This briefing is titled, "Leveraging a LEO Satellite Constellation for Accurate & Reliable PNT," but a more specific subtitle would be, "Less is More – The Case for Going Aggressively Small." (Slide 1). Slide 2 provides a company overview.



Slides 1-2

The Problem and the Solution

Slide 3 depicts some of the problems across GPS that TrustPoint is trying to solve. In TrustPoint's opinion, the solution is to innovate in the space infrastructure area with commercial satellites, specifically microsatellites, and in the signal layer (Slide 4). This brings us to defining the goal, specifically what we are trying to do that we haven't already done.

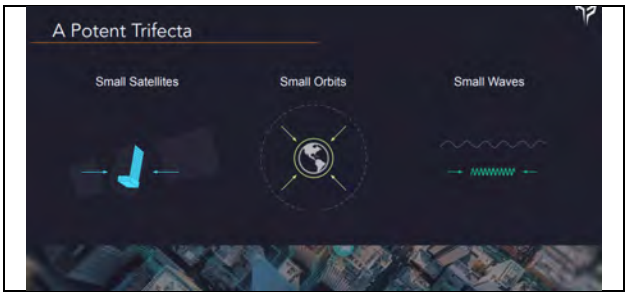


Slides 3-4

This comes down to four primary things (Slides 5-6). The first one is the general performance of the service, which can be accuracy, availability, and many other things. It also needs to be scalable. People often see this as a feature in commercial systems, but that's only accessible as a feature if what you are proposing is scalable. Scalable means a first small bite, something that is manageable and easy at first but also logically extensible. There also need to be some plateaus before getting to the full system. And, finally, when you get to your end state it should be affordable. The two other things are resilience and future proofing. LEOs are in a good place to support these. On the resilience side we are breaking this into three parts: graceful degradation, flexibility, and responsiveness. As for future proofing, there are things we cannot predict maybe ten years out. Therefore, we need a baked-in capability to be flexible, and to do that we need to build an architecture capable to support that.

Slides 5-6

With that said, if those are the goals how do we get there? This is where a potent trifecta comes in the form of small satellites, small orbits, and small waves. (Slide 7). It's not one of these providing incremental value to the others, but rather there being synergy between all three.



Slide 7

Small Satellites

Let's describe the 'small satellites' component (Slides 8-10). Small satellites usually start around 100 kg in mass, but we are going to take this a lot smaller than that and in the order of 6-unit CubeSats, which typically have up to 50 W of power available to the payload (Slide 8). This approach is generally low-cost. TrustPoint has gone out an engaged the known platform providers (Slide 9). It's also worth noting that the 'Pack Leaders' are relatively new platforms. The "Middle Majority" is where CubeSats have been over the past 10-15 years. The main take-away is that we now have high performing precision pointing CubeSats on the order of $200K, and potentially less than that at scale. When we are talking about proliferated LEO architectures, it becomes very affordable. It enables having many nodes and is also more resilient as losing a few satellites is just a small percentage of the whole system.

Slides 8-9

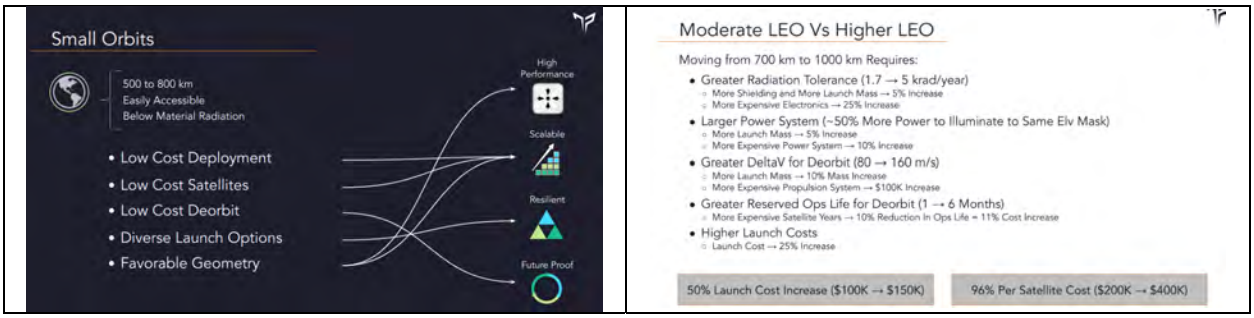
This approach is also important for evolutionary design and development (Slide 10). Short build schedules facilitate iteratively design and development, as we've seen with the development of cellphones/smartphones and order of magnitude in the improvement of services they provide.

Slide 10

Small Orbits

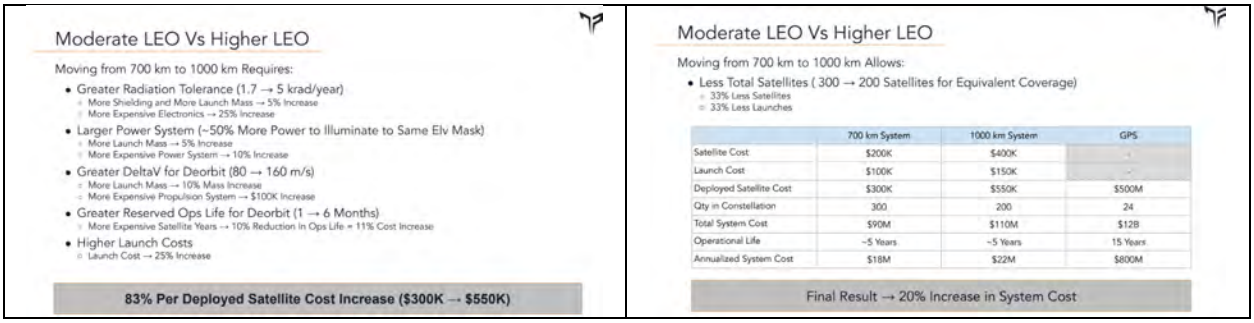
Next, let's discuss 'small orbits' (Slides 11-14). We are focusing on a subset of LEO, which we can call "Moderate LEO" covering 500-800 km altitude (Slide 11). It's good for two reasons: it's easy to access those orbits and the radiation environment is relatively mild. Those orbits allow for low-cost deployment, including ride-share opportunities. They also allow for simple spacecraft and keeps the satellite-cost down, and they also have low-cost to deorbit which is very important (per the latest FCC guidance to deorbit within 5 years after mission completion).

To illustrate this further, let's compare a satellite system operating at 700 km altitude vs. a system operating at 1,000 km (Slide 12). There are a lot of factors that weigh in, such as radiation tolerance, size of the power system, delta-v required for deorbit, reserved operational life to support deorbiting maneuvers, and launch costs.



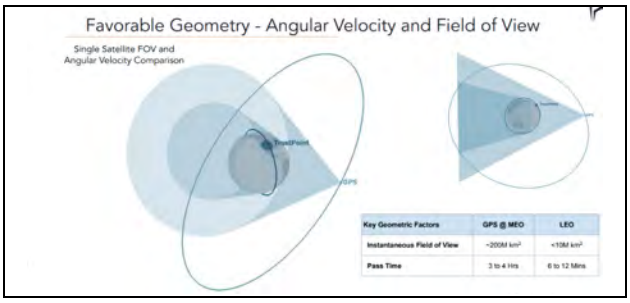
Slides 11-12

When staking all these factors together, we're looking at an 83% increase in deployed satellite cost when operating at 1000 km compared to what would have been at 700 km altitude (Slide 13). We can also compare this from a standpoint of the number of spacecrafts you need at 1000 km compared to 400 km (Slide 14), which translates to an additional 20% increase in system cost. Another thing worth noting is that propulsion and power systems for a 1000 km system are not yet available, which results in additional R&D costs and schedule delays. A notional 12-month schedule delta for a 1000 km system would result in tens of millions in lost opportunity costs.



Slides 13-14

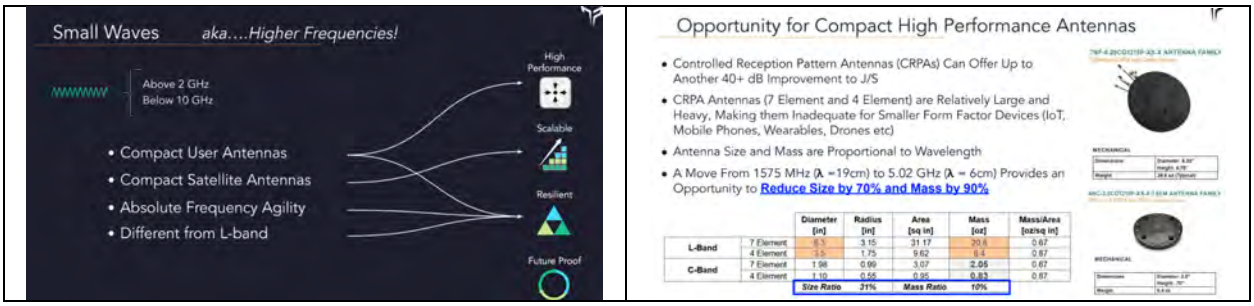
There is a more diverse market for launch options to LEO compared to other orbits. There is also a favorable geometry aspect in LEO (Slide 15). In LEO you are looking at a much small surface area on Earth, which allows you to 'cellularize' the service and change the change the modulation scheme, encryption scheme, frequencies, transmit power, etc., to serve the specific needs of a customer. This enables a scalable business model.



Slide 15

Small Signals

The last category is 'small signals', that is, shorter wavelengths or higher frequencies (Slides 16-17). While there are many detractors to our proposed approach, a key advantage is that higher frequencies enable using compact user antennas. The size of the antenna is directly to the wavelength/frequency it's been designed to receive. Moving from 1.575 GHz (L-Band) to 5.0 GHz (C-Band), which corresponds to reducing the wavelength by about 2/3, would provide an opportunity to reduce the receiver size by 70% and the mass by 90%. The antenna size and weight are as important to the commercial sector as they are to national security. Mobile phones, Internet of Things (IoT) devices, and wearables have extreme size, weight, and power (SWaP) limitations. There are also more opportunities for spectrum-sharing in C-band. There is also a corollary where higher frequencies also mean smaller satellite transmit antennas. There is also absolute frequency agility. A standard antenna has approximately a 10% bandwidth off its center frequency, which means that there are 500 MHz in RF front-end frequency agility at C-band compared to approximately 150 MHz in L-Band. So, you end you having greater flexibility. Finally, using C-band in addition to L-band provides frequency diversity.

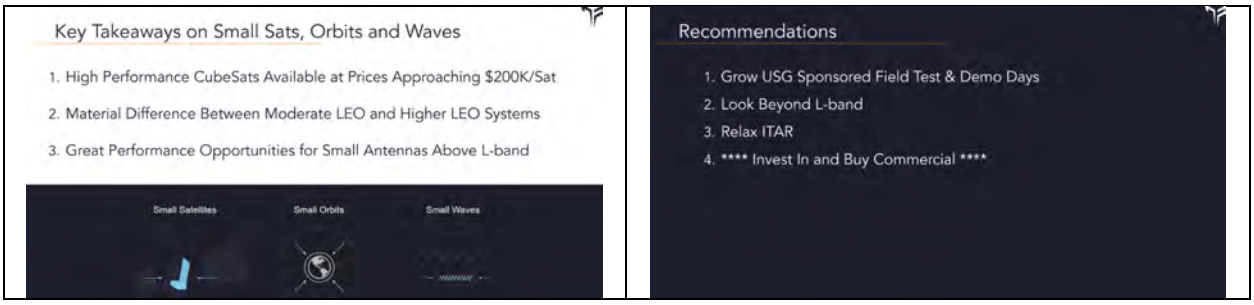


Slides 16-17

Wrap-Up

In summary, there are three key take aways (Slide 18): (1) high performance CubeSats are available at prices about $200K per satellite; (2) there is a substantial difference in costs when operating in 'moderate LEO' vs. 'higher LEO'; (3) there are great performance opportunities to use small antennas in higher frequencies.

Mr. Shannon wrapped-up the briefing with a few recommendations (Slide 19), including: (1) as a commercial company we'd like to see more USG-sponsored field test & demo days; (2) consider looking beyond just using L-band for navigation; (3) revise ITAR restrictions; and (4) invest and use commercial systems.



Slides 18-19

Discussion:

Dr. Powell noted that Mr. Shannon had mentioned the ITU, and then asked him if there are any RNSS allocations in 2-10 GHz.

Mr. Shannon said yes, there are. There is allocation in S-Band at 2.483-2.5 GHz and another one at 5-5.03 GHz.

Dr. Filjar asked if TrustPoint has considered any Intellectual Property (IPR) issues for your idea in the current regulatory and standardization environment?

Mr. Shannon said, yes. The 900-lb gorilla around the corner is 5G, which is looking to gobble some heritage systems and underused spectrum. I think we should reserve some of that spectrum for non-5G purposes. The process at the ITU is very descriptive, but at the national level it can be very difficult. For example, in the U.S. with the FCC one has to come up with a 'bond', which can get as high as $5M, which is intractable for a startup. Other places, such as Europe, aren't as bad.

Mr. Higgins noted the Australian PNT Roadmap is being built around the possibility to use LEOs. Following on Dr. Powell's question, having frequency diversity is good but that can also cause equipage problems since most equipment at this time is for L-Band. He asked Mr. Shannon if he has a feel whether that's an issue or not.

Mr. Shannon noted that his approach is to look at what users in the higher frequencies are doing, such as the 5G community working on the mid-band sector or the mid-ISM (Industrial, Scientific, and Medical) community that has been proficiently working at 5.8 GHz and 2.4 GHz for over 30 years. There is a lot of piece-part selection under 10 GHz we can work from to find cheap components.

Mr. Murphy asked why not above 10 GHz?

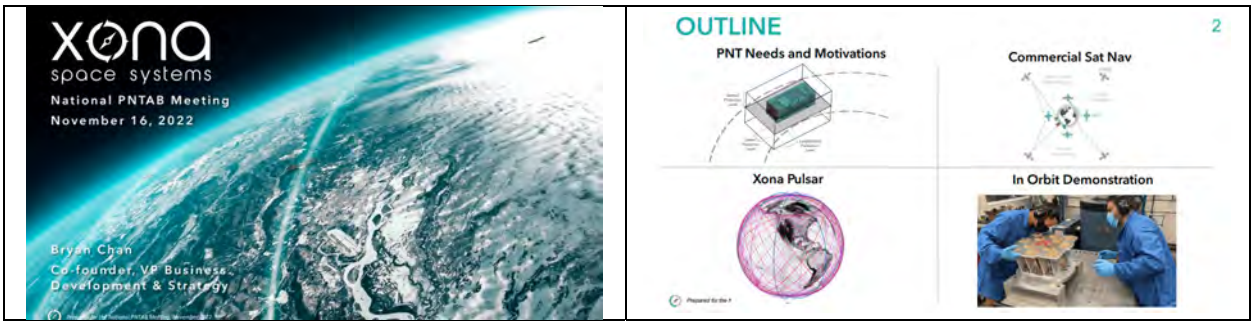
Mr. Shannon responded that there are two primary concerns there. Your efficiency in power-amps becomes more material, and you also start to have some issues in small form factors, for high powers with multi-paction the spacecraft becomes more difficult to design and develop. You'll also start to have atmospheric effects that can become material for a signal like PNT.

* * *

LEO PNT Constellation Progress & Technology Roadmap Xona Space Briefing (View PDF)
Mr. Bryan Chan, *Co-Founder and VP of Business Development & Strategy, Xona Space Systems*

<Dr. Todd Walter recused himself from the Xona Space Systems briefing>

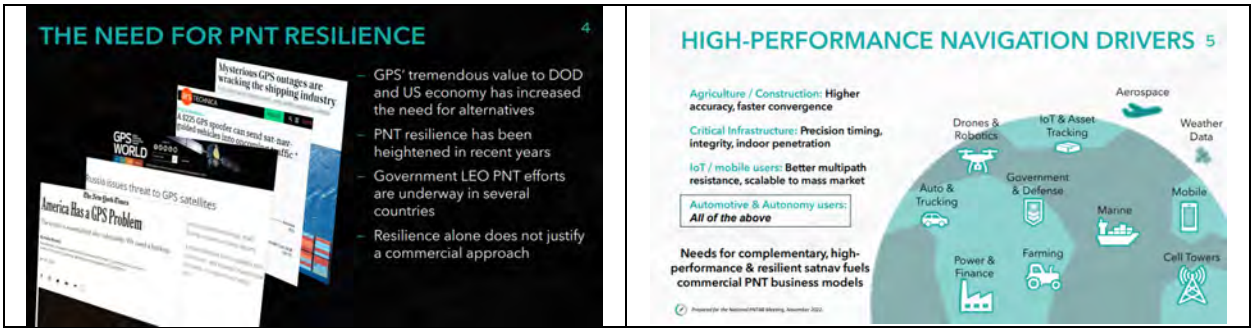
Mr. Chan introduced himself. He is the co-cofounder and Vice President of Business Development and Strategy at Xona Space Systems (Slide 1). This briefing begins by setting up the stage with how Xona Space Systems sees PNT needs and the motivation behind them, followed with how commercial sat nav feeds into meeting some of these requirements, and then describes what Xona's Pulsar service and its progress (Slide 2).



Slides 1-2

PNT Needs and Motivation

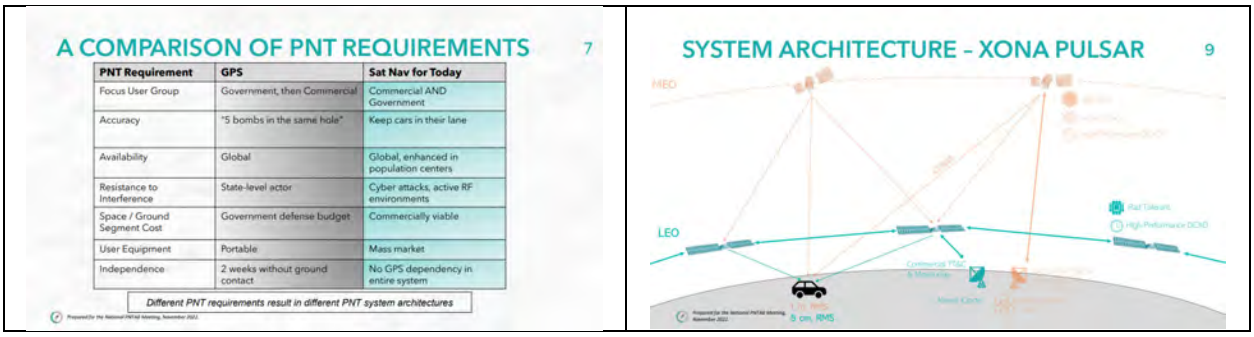
The need for PNT resilience is not a new topic (Slide 5). GPS has tremendous value to not only the DoD but also to civilian users across the U.S. and the world. The more value GPS provides, the louder are the calls for alternatives should GPS not be available. There really has not been a single comprehensive response to address users everywhere. Recently there have been some government LEO PNT efforts that. In China a couple LEO PNT demos have been conducted, and in both Europe and the United Arab Emirates they're also looking into conducting their own demos. From Mr. Chan's perspective, resilience alone does not justify a commercial approach, and it is just one of many factors. For the past three years, Mr. Chan has been engaging with end users of GPS to understand what performance they are looking for and what they are willing to pay for. Slide 4 is a high-level summary chart of the high-performance navigation drivers. Depending on specific industry, there are different priorities, features they're looking for, and price points. At a high level, automotive and autonomy users are the ones that have the most stringent requirements. They want higher accuracy, they want it to converge very quickly, they want their accuracy in very challenging environments like urban canyons and downtown centers, and they want all these features rolled up into low-cost devices that can be produces in high volumes.



Slides 3-4

Commercial Sat Nav

Let's compare PNT requirements for GPS with those of current commercial systems (Slide 5). In his view, GPS requirements were originally primarily focused on government users and the military, whereas today there is]a much stronger emphasis on commercial users. Commercial requirements have also tightened from just knowing where you are along a road to knowing which lane one is on. The interference environment has changed, increasing both in the number of events as well as their sophistication. Finally, the market has increased from millions to billions of users. The takeaway is that given these different sets of PNT requirements, this results in different PNT system architectures. Key advantages in a LEO system architecture (Xona Pulsar) vs. Medium Earth Orbit, or MEO (GPS, etc.), include quicker convergence times since the satellites are moving much faster and higher receive power (Slide 6). There are also disadvantages. Current atomic clocks are high SWaP (Size, Weight/Mass, and Power), and they don't make much commercial sense give the high number that would be required for a LEO constellation. The way to overcome this is by offloading this kind of long-term stability to a network across the satellite constellation and ultimately back down to the surface.



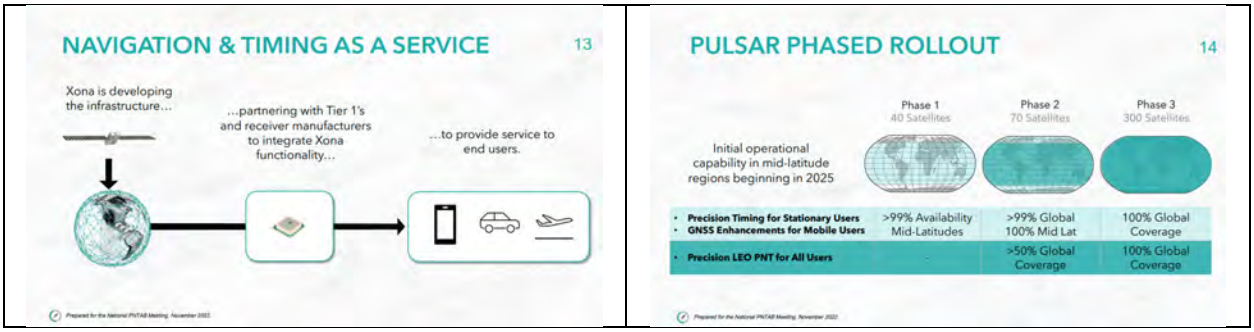
Slides 5-6

Xona Pulsar

Xona's mission is to enable modern technologies to operate safely in any environment, and is supported by a great team with backing from Lockheed Martin and Toyota Ventures. (Slide 7). Ley aspects of the Xona Pulsar system, including providing complementary GPS data, resilience and accuracy, and security (Slide 8). Regarding < 10 cm level accuracy, Xona Satellites require GPS as an initial input. Without GPS, the accuracy delivered would be at the 1-2 m level.

Slides 7-8

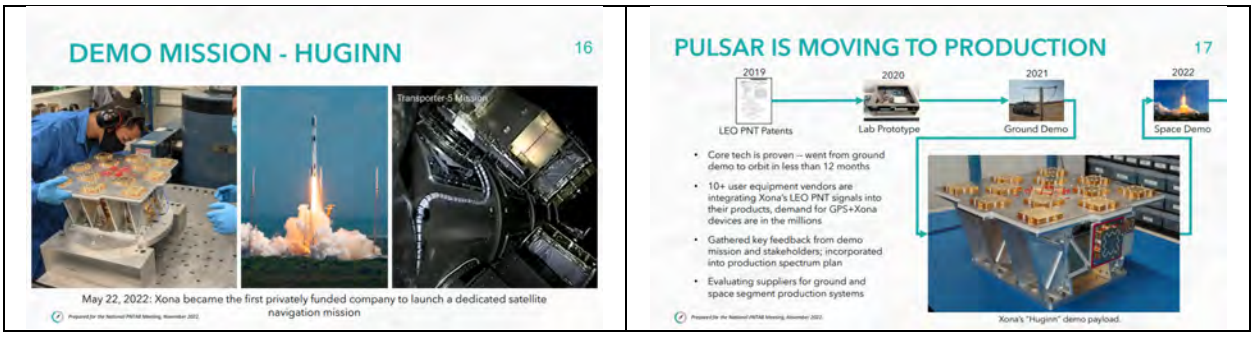
How does this work as a business? Xona is developing the ground and space segment to deliver the signal to users, and partners with Tier 1's (Top-tier suppliers that provide parts or services directly to an OEM) and receiver manufacturers to integrate the Xona functionality (Slide 9). Slide 10 depicts the phase rollout plan for Pulsar. Phase 1 allows for at least one satellite in view across mid latitudes by 2025. As the constellation is further populated (Phases 2 and 3), the service features and coverage improve.



Slides 9-10

In Orbit Demonstration

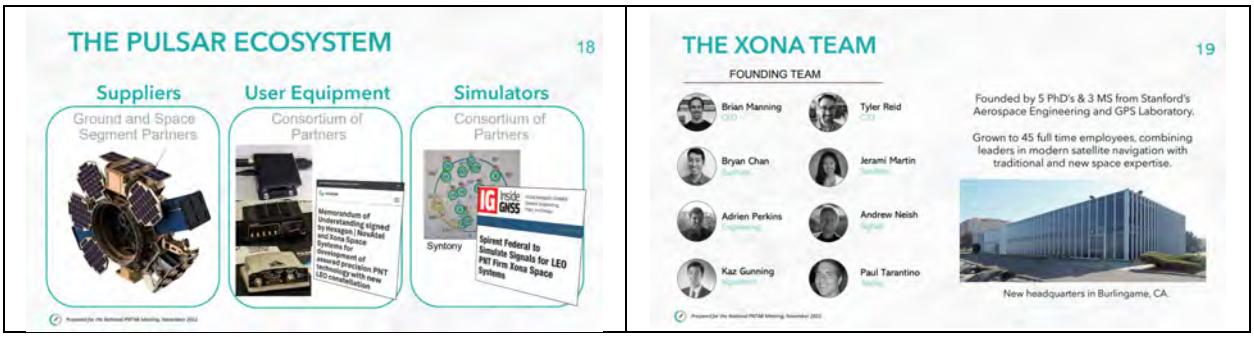
The 'Huggin' demo smallsat was launched in May 2022, becoming the first privately funded company to launch a dedicated navigation satellite (Slide 11). In Slide 11, the picture on the left depicts the navigation payload. It is designed to broadcast in both L-band and C-band. Xona is moving quickly and has started to move into production (Slide 12). Huggin has already successfully completed some firmware uploads, and in 2023 we expect to open it up to end-to-end tests with our third-party manufacturers. Xona is currently working with a dozen or so equipment manufacturers. Some of them are investigating whether with a firmware change only they can also pick up Xona, and we are seeing some promising results. On the spectrum side, we've also received good feedback from spectrum regulators, government folks, and equipment manufacturers as we try to make the integration of Xona as easy as possible while working to protect GPS. A second demonstration mission is coming up next year, and we are already evaluating suppliers for the ground and space segment.



Slides 11-12

Wrap-Up

Xona is part of a broad ecosystem of ground and space segment equipment suppliers, user equipment suppliers, and simulators (Slide 13). When it comes to simulators, we have a partnership with Spirent Federal for a Xona+GPS simulator. We believe we have a strong technical staff and very well steeped in GPS, vehicle autonomy, civil aviation, and space systems (Slide 14).



Slides 13-14

Discussion:

Prof. TMoore asked whether in Slide 11 the antenna on the side is for satellite-to-satellite tracking.

Mr. Chan responded yes.

Mr. Shields asked what kind of pricing Xona will have for cars. Senior folks working on automated car driving are looking at 10 cm level relative accuracy within a lane and working to use multiple cameras on cars (a multi-stereo approach) to do be able to do the precise positioning, and costs comparable to just adding some software to the car to do the job. What would be your cost?

Mr. Chan noted that expensive equipment may be required to reach a reliability level of five nines. Thus, Xona's approach is to offload the need for expensive equipment (LIDAR, cameras, etc.) and be left with a low-cost chipset that picks up GPS and Xona.

Mr. Shields said that we should expect in the next 6-7 years consumer costs under $5000 for automated driving in cars.

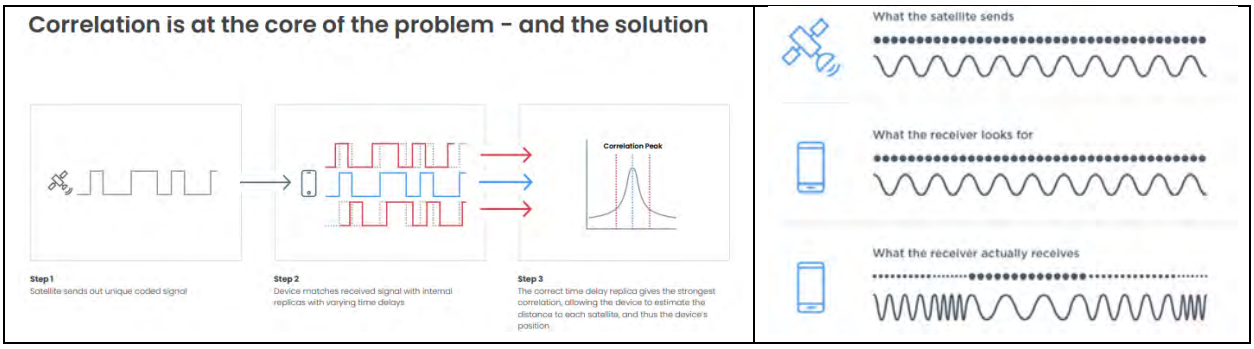
* * *

Supercorrelation: Software Upgrade to Toughen GNSS Receivers from Jamming & Spoofing (View PDF)
Dr. Ramsey Faragher, CEO & CTO, Focal Point Positioning, Ltd.

Dr. Faragher introduced himself and noted that GNSS performs poorly in urban environments because signals are blocked and/or reflected from buildings, also known as non-line-of-sight (NLOS) signals, which interfere with true line-of-sight (LOS signals) (Slides 1-2). Receivers cannot rely just on signal power level to distinguish between LOS and NLOS signals, and sometimes the LOS signals may not even be visible to the users. This is the problem that supercorrelation fixes.

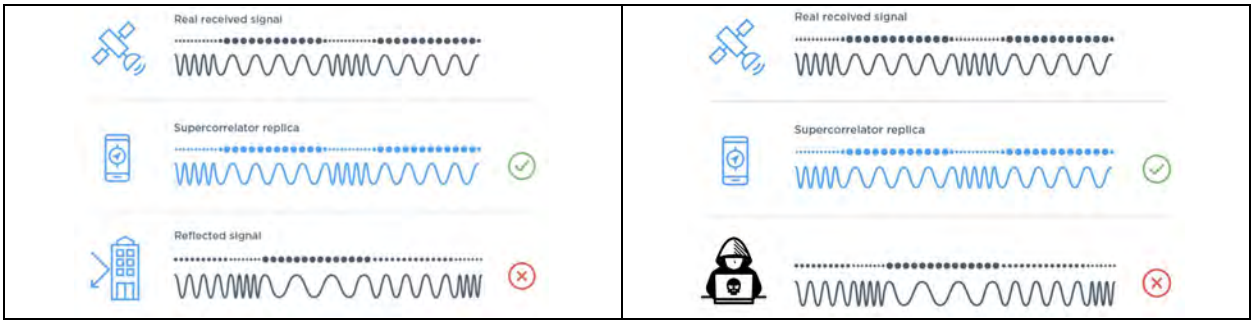
Slides 1-2

Correlation matches the received signal with internal replicas (stored in the receiver) with varying time delays, and the correct time delay replica gives the strongest correlation (Slide 3). This allows the receiver to estimate the distance to each satellite, and thus its position. So, how do we do this? The correlation codewords repeat over and over, as represented by the dots in the carrier signal transmitted by the satellite (Slide 4, top). This is then matched to what the receiver is looking for. This would work perfectly if the receiver were static and had a very good clock. However, one is likely to be moving, and the clock is likely to be a relatively low-quality oscillator. What this means is that when the receiver samples a signal, that sample and pattern does not look like what is being transmitted (Slide 4, bottom). Thus, the user is getting a distorted view of both the code words and the carrier frequency, which the receiver then tries to match to what's in the middle (Slide 4, middle).



Slides 3-4

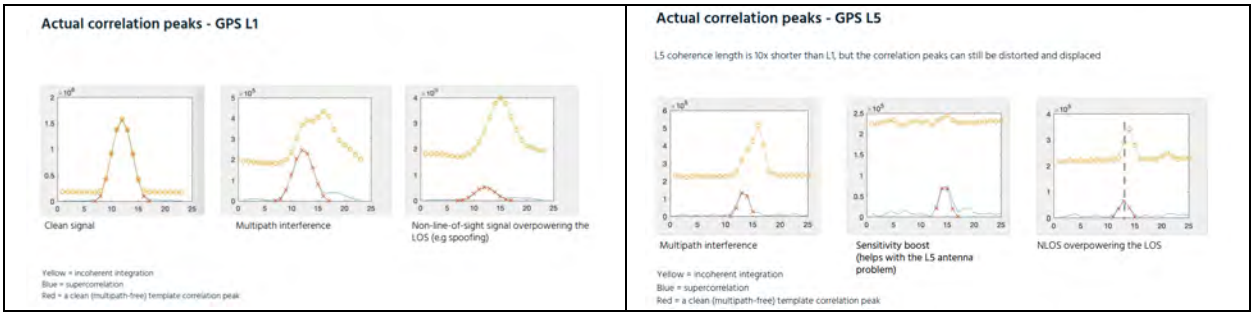
In supercorrelation, we reconstruct the motion of the antenna through space and use that to motion-compensate the correlation sequence, and model what the oscillator is doing (Slide 5). We do this over long timescales, about one second. The longest we've done is 5 seconds, which gave us a 10 dB gain. This provides true discrimination between the LOS and NLOS signals, and are separated by their angle of arrival. In addition, a spoofer cannot replicate your motion and what your oscillator is doing (Slide 6).



Slides 5-6

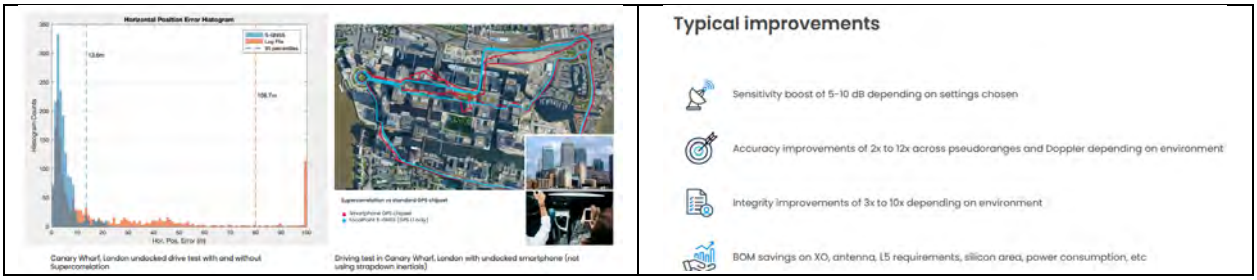
Slides 7-8 depict some actual correlation peaks for both GPS L1 and GPS L5. The yellow lines depict incoherent integration of the correlation beacon (what's coming into the receiver), the blue lines depict the supercorrelation peak, and red lines depict the

clean (multipath free) template correlation peak. In slide 7, the picture on the left shows a GPS L1 signal where normal processing is clean, the picture on the center shows data from an urban canyon (note how the yellow line is distorted, and how the blue supercorrelation peak is clean), and the picture on the right shows what looks like a clean signal but is actually NLOS overpowering LOS. For the latter, a simple algorithm running inside the receiver could be easily fooled into trusting it, but supercorrelation was still successful in detecting the earlier weaker signal. In this example, the signal was coming through a building. Slide 8 depicts what happens to the GPS L5 signal. On the picture on the center, we see how despite the L5 coherence length being ten times shorter than L1, the correlation peaks were still distorted and displaced. Finally, the picture on the right shows what happens NLOS overpowers LOS, but once again supercorrelation was successful in detecting the earlier weaker signal.



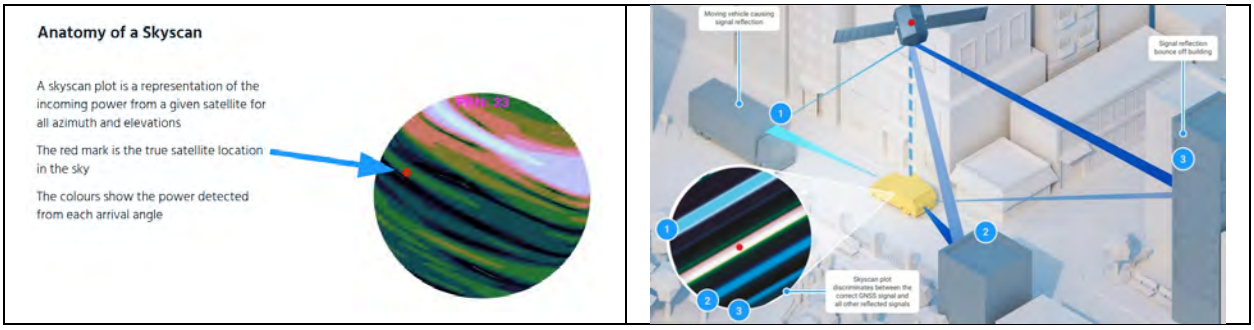
Slides 7-8

Slide 9 shows the results from a GPS L1-only driving test through the Canary Warf district in London. Supercorrelation was used to clean up the observables (pseudorange & Doppler) and pass them to a Kalman filter. Inertials were not used, which is why traditional processing (red lines on the picture in the right) is bad. The error histrograms during the drive are shown on the left. Slide 10 summarizes the typical improvements across a wide range of trials with many smartphones (BOM = build of materials).



Slides 9-10

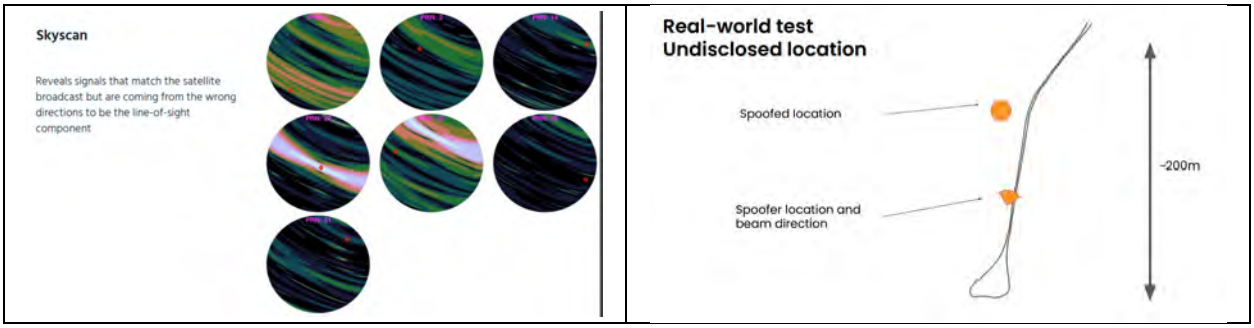
Slide 11 depicts what FocalPoint calls Skyscan, a plot representation of the incoming power from a given satellite as seen from all azimuth and elevations. The red dot indicates the true location of the satellite. The picture depicts GPS PRN 23, and the colors indicate the power detected coming from each direction. Lighter colors indicate a stronger signal. White indicates strong power and black indicates no power detected. Note the disparity between the power level around the red dot (the direction along which the GPS satellite is located) and the lighter colors at higher elevation. This is what multipath looks like. In this case, the difference in power level between LOS and NLOS is about 100x less power since at that moment as because most of the power in GPS PRN 23 LOS was eclipsed behind a building. Slide 12 is a cartoon representation of how Skyscan is plotted for a car that's moving through an urban environment with various reflected signals. If moving in a straight line, the resulting power level would look like a band.



Slides 11-12

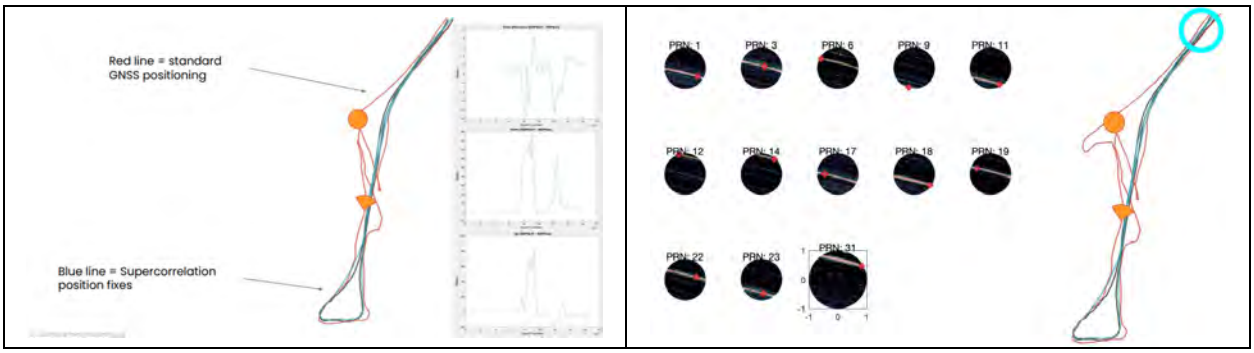
Slide 13 depicts the plots for seven GPS satellites as seen while driving through an urban canyon, which can result in vastly different patterns.

Next, we are going to review the results of a real-world trial that, unfortunately, we are not allowed to disclose (Slide 14-20). We drove past a spoofer (which was essentially meaconing, it was rebroadcasting the sky) for about 200 m and turned back (Slide 14). The spoofer was set to give an offset a little bit north of us. This is one of the worst kinds of attack because all the encryption is in the rebroadcast.



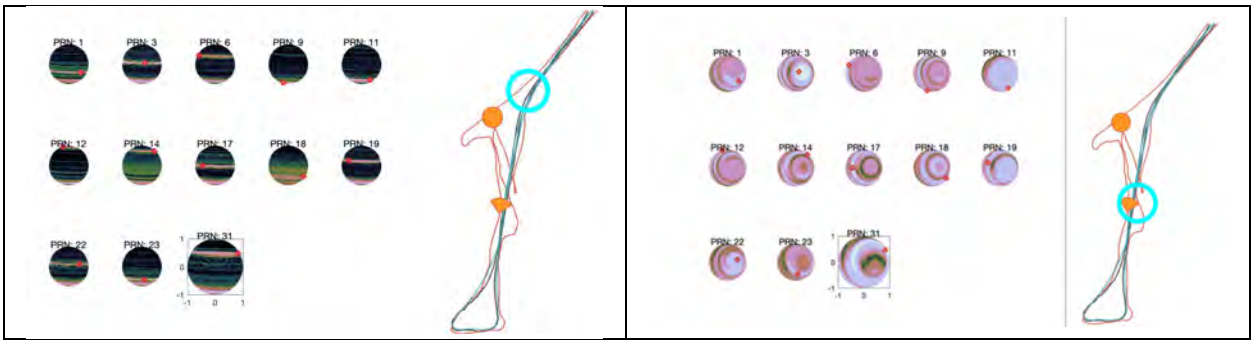
Slides 13-14

In the graphs on slide 15, the red line shows normal GPS processing, the blue line shows supercorrelation processing, and the black line is the truth. The plots show the north, east, and up errors. As we can see, for normal GPS processing the position was driven north by about 100 meters during both passes (Note: on these plots North is shows downwards). Slide 16 shows the skyscan plot of various GPS satellites at the moment we started driving (light blue circle).



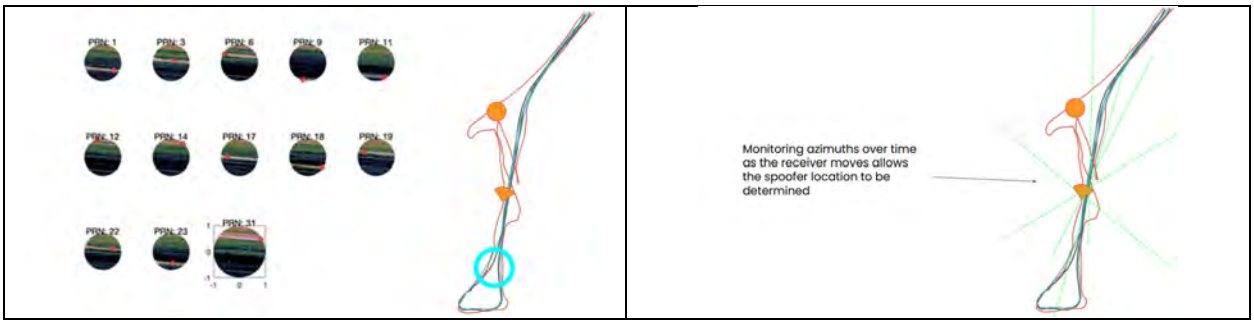
Slides 15-16

Slide 17 shows the skyscan plots as we move past the spoofed location. Note how the normal GPS positioning is being driven off towards the spoofer's location. The band of power is moving across the red dot across all plots. Slide 18 shows the skyscan plots as we drive right past the spoofer.



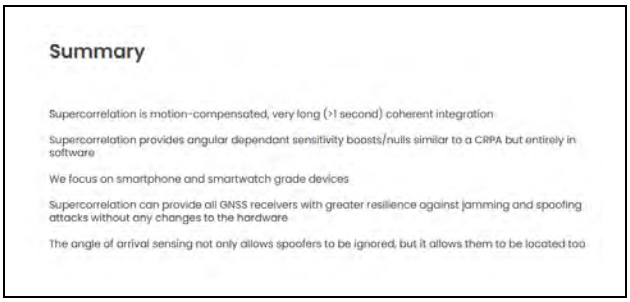
Slides 17-18

Finally, slide 19 shows the skyscan plots when we've moved past the spoofer and traditional GPS processing once again working. Because skyscan is a directional technology, you can effectively take an azimuth at each location and locate where the spoofer is (Slide 20).



Slides 19-20

In summary, supercorrelation can provide all GNSS receivers greater resilience against jamming and spoofing, and also allows to locate where the spoofers are (Slide 21). This can be done without expensive antennas. We've focused on smartphones and smartwatches, and are working with all the major brands. We've licensed our technology to U-blox (that's the only company we're allowed to name at this time), and have recently received a GBP 23 million funding round with an undisclosed major automotive firm.



Slides 21

Discussion:

Dr. Parkinson asked if they're using a running fix concept to get the azimuth and elevation measurements.

Dr. Faragher said they rely on motion and are synthesizing an aperture. For smartphones, a human usually moves one meter over one second, so in essence they're dragging one meter of antenna elements and effectively steering a beam.

Dr. Parkinson noted that when driving in a straight line, there will be one direction with bad measurements.

Dr. Faragher said that when moving in a straight line, the sensitivity is the surface of a cone.

Mr. Diamond asked the impact on the system processor that their software would add.

Dr. Faragher responded that it's a few MIPS (million instructions per second) of extra processing. It depends on the receiver design, how bad the oscillator is, and other things like that. The impact is approximately tens of kilobytes of extra memory, which is essentially meaningless for a smartphone.

Mr. Diamond asked whether the software is an app, or if it's integrated into the operating system.

Dr. Faragher said it's at the level of an Android standard app.

Mr. Diamond then asked if the software needs to go through a discovery process to understand the antenna, or whether there is some kind of menu from which to select?

Dr. Faragher noted that each receiver they work with is subtly different. When going through the trial phase, we learn if there is any particular interesting thing about their receiver that we have to compensate for.

Prof. Moore asked how long it will be until this appears in consumer electronics.

Dr. Faragher said his conservative statement is that it will be within a couple of years.

Dr. Powell asked what the source is for the supercorrelation replica.

Dr. Faragher said they collect 200 correlations over one second and monitor the inertials. From that they build a set of complex corrections for the supercorrelation phasor.

* * *

Broadcast Positioning System Using ATSC 3.0 TV Signals (View PDF)

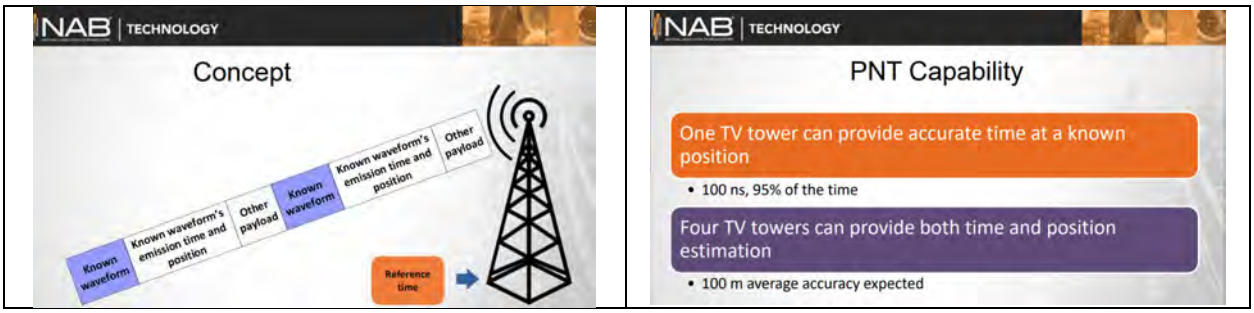
Mr. Sam Matheny, *Exec. VP & CTO, National Association of Broadcasters (NAB)*
Mr. Tariq Mondal, *VP of Advanced Tech., NAB*

Mr. Matheny introduced himself and noted that Mr. Mondal would explain how the Broadcast Positioning System (BPS) works and what it does, and then Mr. Matheny would come back and explain how BPS could fit into a system of systems (Slide 1).

Mr. Mondal said that BPS is a system and method of estimating time and position using over-the-air television signals (Slide 2). BPS is fully compliant with the Next Generation TV technology standard, which is referred to as the Advanced Television Systems Committee (ATSC) 3.0. BPS is also fully independent of GPS, the internet, and cellular connectivity.

Slides 1-2

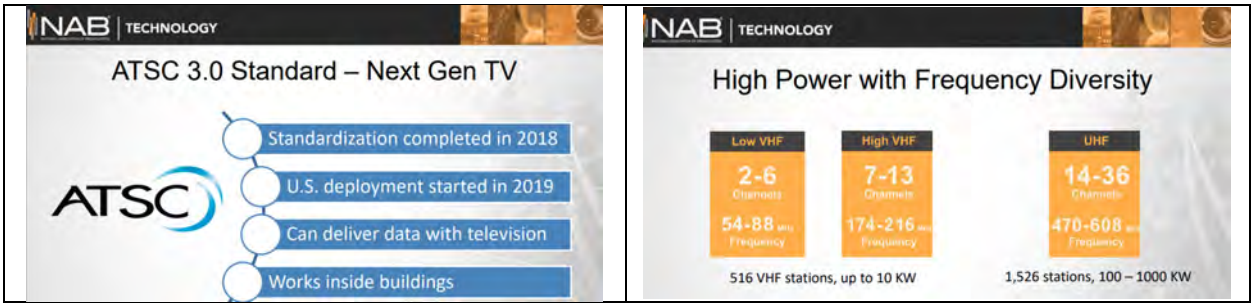
The concept is a waveform transmitted from a tower followed by the transmission of that waveform's emission time and position [of the tower]. When stationary, time be determined with just one tower, and when moving the position and time can be determined with four towers (Slide 4). They applied this concept to the television broadcast system. They believe that when using one tower, a good timing reference, and not too much multi-path, that a 100-nanosecond (95% of the time) level accuracy can be achieved. For the multi-lateral solution technique, a 100-meter average accuracy may be possible. This approach is also non-line-of-sight.



Slides 3-4

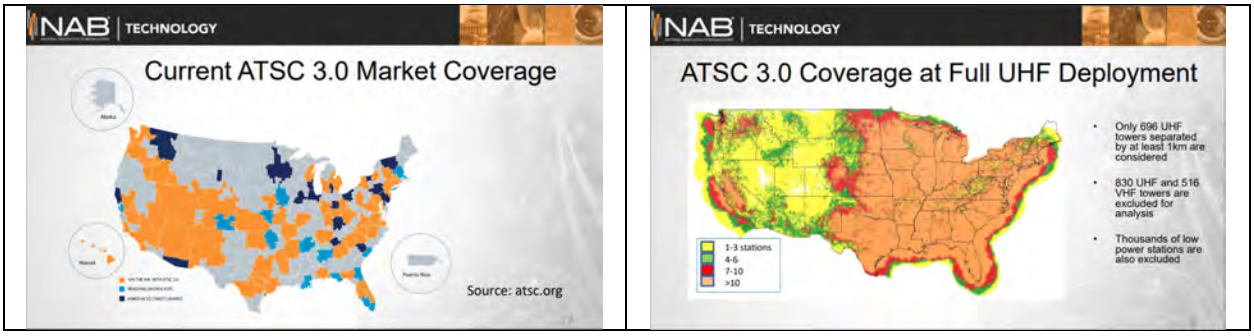
Discussions on the ATSC 3.0 standard began in 2010 and involved a lot of big companies, such as Sony, Samsung, LG, and Qualcomm, and it was completed in 2018 (Slide 5). In 2018 it was first deployed in South Korea, and U.S. deployment began in 2019. ATSC can deliver data along with the television signal and works inside buildings much better compared to previous generation television signals (the signal-to-noise ratio is 20 dB better) and can be received by mobile devices.

Let's discuss television signals (Slide 6). Terrestrial television currently operates through 35 channels, each one six MHz wide. Within these channels there are a number of assigned frequencies. There are over 500 VHS stations operating at a power level up to 10 kW, and over 1,500 UHF stations operating between 100-1000 kW.



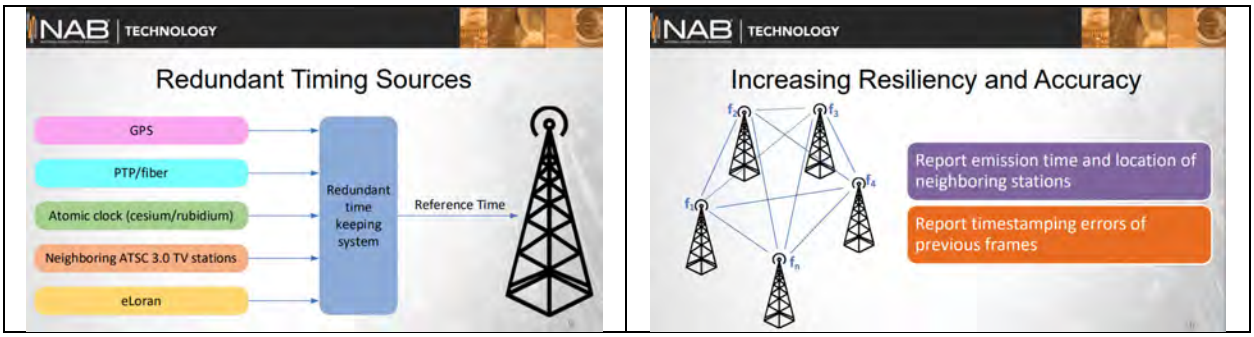
Slides 5-6

ATSC has been deployed in 65 markets across the U.S. (Slide 7). Within the orange area shown on the map, signals from 1-2 stations can be tracked. Slide 8 depicts the ATSC coverage at full UHF deployment. While there are more than 1500 channels deployed, they only considered 696 towers due to their geographical separation, which is at least one km. Over half of the U.S. will be covered by over 10 UHF channels/towers being available. Within the yellow area on the map, they did not consider UHF as there are many VHF channels/towers that can be used instead.



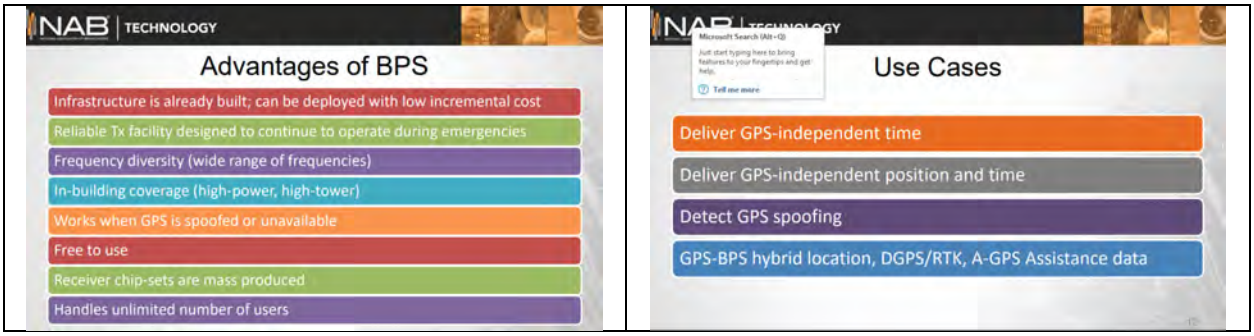
Slides 7-8

It is important to have multiple sources of timing to ensure redundancy (Slide 9). GPS can be tracked at all the towers locations, and neighboring ATSC TV stations can also provide an additional timing reference. To increase resiliency and accuracy, they recommend that all stations listen to each other and report the position and time of all neighboring stations (Slide 10). With that, a receiver can easily detect if a signal is being spoofed. If there are signals that are good enough for time of arrival detection but is not strong enough for demodulation (to get the emission time and position of the tower), it can get the assistance data from other towers and computer the fix. This system will also be reporting the timestamping errors of previous frames. Thus, one can actually take that measurement error and apply it to past fixes to get a more accurate location estimate.



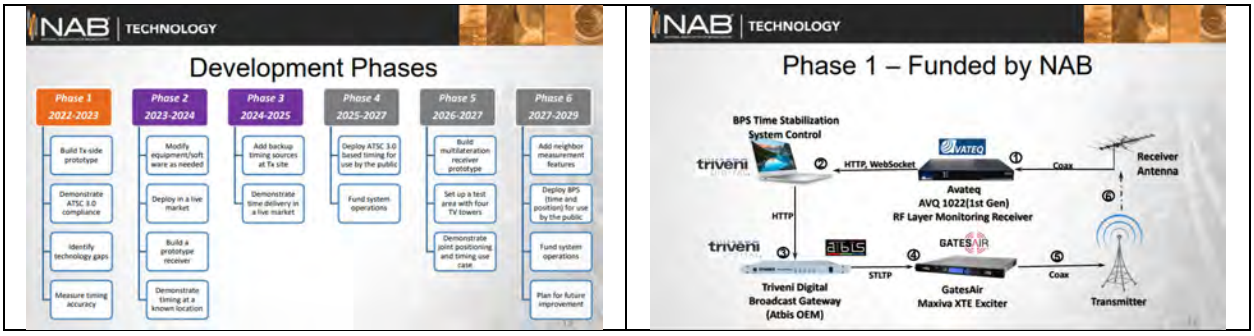
Slides 9-10

Mr. Matheny took over from Mr. Mondal and described the many important and inherent advantages to a BPS-type system (Slide 11). It's low-cost, reliable, can be received indoors, and designed to operate 24/7, even in times of disaster or emergency. The receivers are already being mass produced. The Consumer Technology Association (CTA) estimates that over five million NextGen television sets will be sold this year, and will grow to 20 sets being sold by 2025. So, what are the potential use cases for GPS (Slide 12)? BPS can deliver GPS-independent position and time, can detect GPS spoofing, and can be used in combination with GPS and to support GPS (DGPS/RTK applications, Assisted GPS, etc.). Earlier this year, at a tradeshow in Las Vegas, NV, they had a demonstration where an ATSC transmission of RTK data was received by a drone and combined with GPS data.



Slides 11-12

Slide 13 describes the development phases. At this time, they're in Phase 1 and focused on the transmission side. The data scheme has been detailed, and they're beginning to work with commercial vendors to get it integrated. Following this, they'll get it back to the NAB lab to finish it out. Phases 2 & 3 are about developing a prototype receiver, and moving towards deployment in a live market. Phase 4 is about deploying a timing service, and Phases 5 & 6 are about building towers and implementing the positioning use case. Slide 14 shows what NAB is working on today, which they believe will be completed early in 2023.



Slides 13-14

There is precedent in establishing a partnership between a television broadcaster and the government. Primary Entry Point (PEP) stations are part of the emergency alert system (Slide 15). These stations have additional hardening to remain fully operational over extended periods of time. ATSC supports the Emergency Alert System (EAS). NAB needs help working on phases 2&3 (Slide 16), as they don't want to pursue this without knowing all the PNT use cases, requirements, etc.

Slides 15-16

Discussion:

Dr. Powell asked what kind of antenna is required, and at what distance can they close the link.

Mr. Mondal said that the UHF system works with smartphones, which have small antennas. The system works beyond the range of television signals. The system can be configured so that data can be received at -5 dB signal-to-noise ratio.

Dr. Parkinson asked whether they can their accuracy numbers in terms of range from a typical tower.

Mr. Mondal said he didn't have specific data, but noted that television signals can go up to a distance of 50 miles or so.

Mr. Matheny added that towers can be up to 2,000 feet tall, and operated up to 1 MW.

Dr. Powell asked if they have to consider something equivalent to Dilution of Precision (DOP). In Los Angeles all transmitters are on Mt. Wilson, so you can't get good geometric diversity.

Mr. Matheny said that, yes, they took out any tower that was less than one km from another. Also, there are thousands of low power stations that were not included in their model.

Dr. Parkinson noted that in terms of positioning, this is similar to LORAN. An absolute time reference will be needed, and it could be an issue across the U.S. since towers are leapfrogging. He is also worried about the antenna size.

Mr. Matheny said that the antenna size depends on the use case. In any case, this is the type of feedback they're looking for.

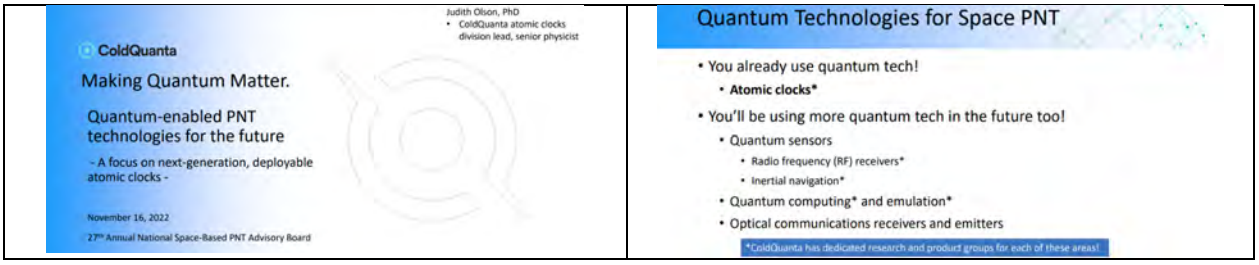
Mr. Goward noted that a few years ago a National Timing Architecture paper was published that addressed some of the concerns raised by Dr. Parkinson.

ADM Allen asked the PNTAB subcommittee chairs to establish virtual relationships with the briefers and provide updates on how BPS development is progressing.

* * *

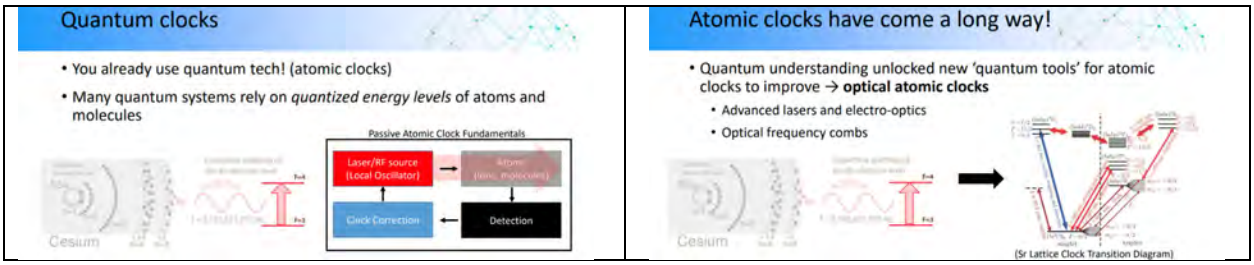
Quantum-Enabled PNT Technologies for the Future (View PDF)
Dr. Judith Olson, *Senior Physicist, Head of Atomic Clocks Group, Cold Quanta*

Dr. Olson introduced herself (Slide 1) and noted that term 'quantum' has been used a lot these days. Much money has been invested in 'quantum' technology, but its payout hasn't been realized. ColdQuanta is structured around the near-term benefits in this technology, whereas concepts such as "Quantum Computer" may take decades to come to fruition. The briefing focuses on atomic clocks, which fundamentally are the oldest quantum technology in existence (Slide 2). There are other near term quantum technologies that can also be used for space-based PNT, such as RF receivers where we use the quantum properties of atoms to have energy, rather than wavelength, be the coupling factor. This would significantly decrease in the size of receivers. Other areas ColdQuanta is involved in include inertial navigation, computing & emulation, and optical communication receivers & emitters.



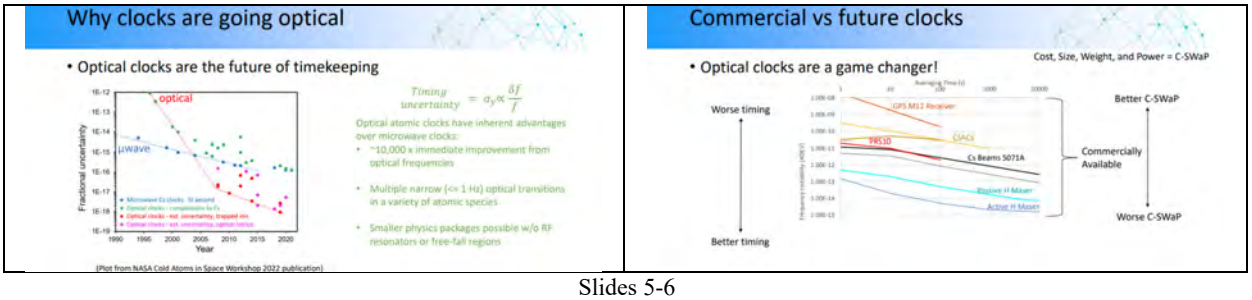
Slides 1-2

Atomic clocks are defined by the quantized energy levels of atoms (Slide 3). Atoms are in discrete states, and if you poke them with just the right amount of energy they change state. In the simplest form, we can pretend an atom has two levels, and if you send the right amount of energy with the right frequency the atom will change level. Ultimately, this tells you the frequency of the radiation. A passive atomic clock works like this, where you have an initial source (laser or RF signal), also called the 'local oscillator', that interacts with ions/molecules to change their state. The change can be detected (for example, with fluorescence detection), and a clock correction is generated. The cycle repeats consistently. This is how you get the 'quantum information' out of these atoms. Applying it is not as easy as it seems. For example, slide 4 depicts the clock transition structure we have to worry about when designing a Strontium optical lattice clock. Current atomic clocks are based on RF level transitions in the atoms even if they're using lasers to incite the change in state. The local oscillator itself is not in the optical regime. Quantum understanding will unlock new levels of performance. This technology has become viable over the past 20 years thanks to the development of advanced lasers & electro-optics because when building a complicated clock, you may need 6 or 7 lasers. The other break has been optical frequency combs [Ed. Note: In optics, a frequency comb is a laser source whose spectrum consists of a series of discrete, equally spaced frequency lines], which allows to take optical frequencies down to RF signals that can be used by electronics.



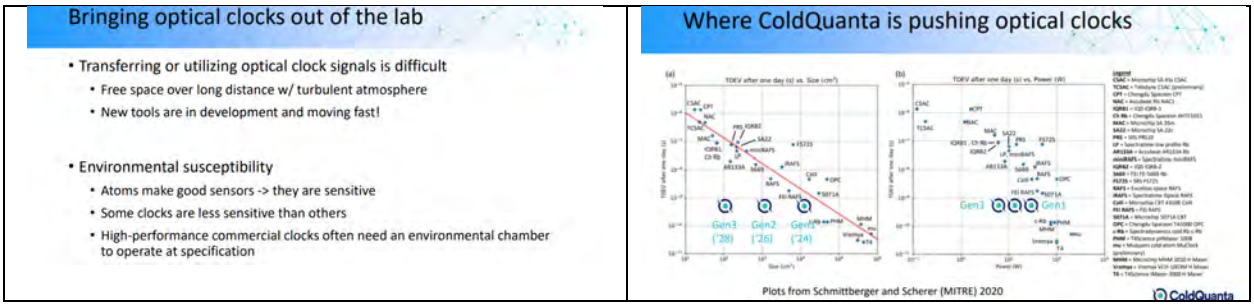
Slides 3-4

Slide 5 the plot shows the limit in using microwave systems, and how much better optical clocks are. In fact, there are clocks that can tell time better than time is even defined in terms of the SI second (Ed. Note: SI is the International System of Units). Optical clocks are good because of the timing uncertainty. The better you can measure frequency, the better you can measure time. Optical atomic clocks have inherent advantages over microwave clocks. Slide 6 shows what is currently commercially available. In terms of cost, size, weight, and power (C-SWaP), generally speaking the worst timing performance has a better C-SWaP.



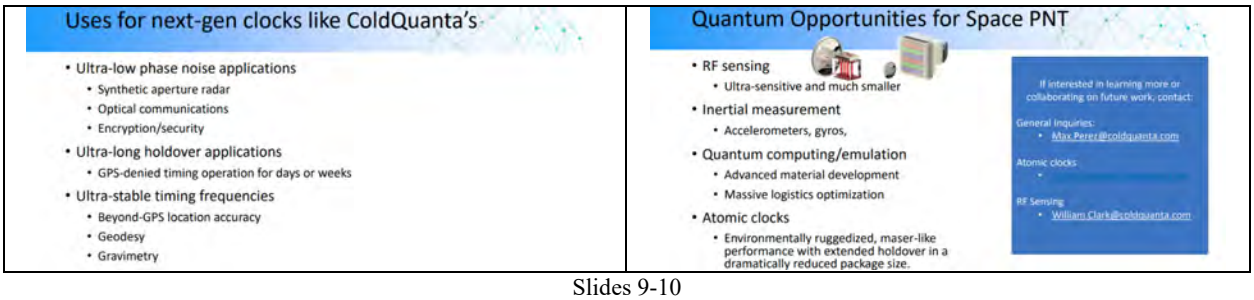
Slides 5-6

Currently there are many problems in getting optical clocks out of the lab (Slide 7). It comes down to two general things. First, it is difficult to transfer through free space optical clock signals. Second, optical clocks are very sensitive to the environment. In order to make optical sensors only sensitive to your laser, and nothing else, a lot of solid engineering is required. These are the tenets that are built into ColdQuanta's atomic clock commercialization efforts. Slide 8 depicts where the commercial clocks space lines up. The plot on the left is the time deviation after one day vs. clock size, and the plot on the right shows the time deviation after one day vs. the required power. The plots show the general trend wherefor higher performance requires larger clocks and larger power consumption. The ColdQuanta's Gen 1, 2, and 3 are depicted in light blue. ColdQuanta's Gen 1 clock is due for release in 2024, with a size of approximately 15 liters. The objective for Gen 1 is to show how good optical clocks are, and the objective of subsequent generations will reduce the clock down to pocket size.



Slides 7-8

The clocks ColdQuanta is working on could, in theory, do better than active lasers. Potential uses of ColdQuanta's clocks are described in Slide 9. Slide 10 summarizes the opportunities their technology has for PNT. Note the images of ColdQuanta's two ultra-sensitive RF sensors, which are about the size of a quarter. They have a tunable range of 40 GHz and could be adjusted to go higher than that. The goal of the atomic clocks Dr. Olson is working on is to provide environmentally ruggedized, maser-like performance with extended holdover in a very small device. The contact information for ColdQuanta is shown on the slide.



Slides 9-10

Discussion:

Mr. Pat Diamond asked if Dr. Olson is aware of NASA's Deep Space Atomic Clock (DSAC).

Dr. Olson said yes. DSAC is good for many reasons, one being that it does not use lasers and therefore can have a lifetime over 10 years. They also have a very long holdover. ColdQuanta's clocks are note geared for DSAC's application space and is focusing instead on short-term clock holdover.

Dr. Powell brought up the comment made by Dr. Olson regarding clocks becoming more accurate than the current definition of time. Does this mean that what's being used for TAI (International Atomic Time) is obsolete and should be replaced?

Dr. Olson responded that she's participated in discussions at the BIPM (International Bureau of Weights and Measures) question, and the biggest barrier she sees is that these clocks are hard to build and maintain, and there are few. Before the SI second can be redefined, several of these clocks need to be at every metrology institute

Dr. Parkinson noted that historically GPS tends to look at a 10^5 second Allan variance. The nifty thing about what Dr. Olson presented is that on the phase noise lower frequencies, there are many reasons why GPS (particularly for jam resistance and long averaging times) really want that low base noise. This reinforces her market need message.

Dr. Olson agreed, and noted that an accurate clock is the best way to know if GPS is being spoofed.

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ADM Allen adjourned the Wednesday, May 16 session at 6:00pm.

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Session of Thursday, November 17, 2022

PNTAB Leadership Observations from Day 1 & Member Feedback

ADM Allen thanked everybody for the informal communications that he has gotten in the last 24 hours. He feels positive about where the board is going. We have a lot of work to do, but this is by far the most productive meeting [and] the most engaged meeting we've had. We still have some things to do, but we've gotten a lot better at a lot of things. This morning we are going to try to figure out how we convert the great work that the subcommittees have done into actual lists of recommendations, fact sheets, working papers, and so forth. One of the things that we need to report out of here is, there is a specific topic that we have a recommendation for, but we need to do more work on it. Admiral Allen said that some have contacted him asking how they continue that work under the Advisory Board's guidelines. There are Designated Federal Officials (DFOs) for subcommittees.

The goal should be to create institutionalized relationships with the different parts of government and industry that the Board represents, and mature and evolve it at each meeting. Out competency is very significant right now, but as you know it is very diverse. He is always pleased when people give the board compliments for being who we are, where we've been, and what we know. Going forward, we are going to have to learn how to develop more political acumen and bring effect to the things we believe need to be done in our recommendations. Doing that is going to require is to hold two things in tension: our dismissive view of the government's structure, and our need to work within it and use it.

Clearly, if you're not in the security strategy, you're not in the pecking order. So, we have to figure out what to get into the Tablets of Moses to pass down to these folks for funding. That happens when we develop greater relevancy, competency, and intellectual political weight and we're starting to do that with where we're going right now. We're not there yet but continue to be a work in progress.

Regarding the structure of the meetings, we're moving towards the thematic structure people have talked about. We'll be better at that at the next one. Hopefully this will be the last meeting where we have a briefing and discussion on Ligado. It's sucking all the oxygen out of the room. Our goal is to redirect attention and then redirect resources.

ADM Allen noted that he spent a great deal of his time in the USCG not dealing with crisis but managing money and appropriations. His watch phrase was that you don't make policy, you spend money. Our goal should be to make them want to spend money moving forward.

Before we leave here today, we need a list of recommendations. He'd like to make sure we have absolute clarity about the work that needs to continue and how that's going to be organized, structured, and reported. Board members have the degree of freedom to do what they need to do to continue the terrific work they've started thus far.

ADM Allen asked Vice Chair Dr. Parkinson, and Mr. Miller if either of them have any comments. They did not.

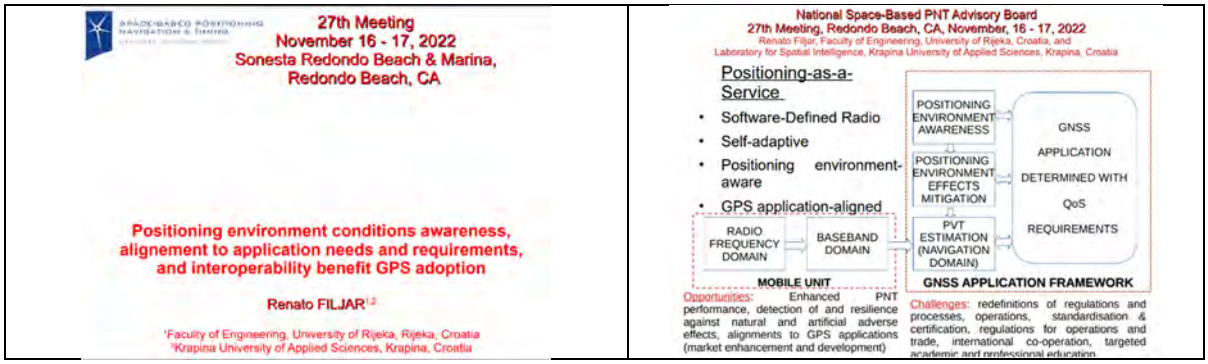
ADM Allen called upon the Board's various representatives to give their updates.

***

Updates from International Members & Representatives:

1) Croatia, Dr. Renato Filjar

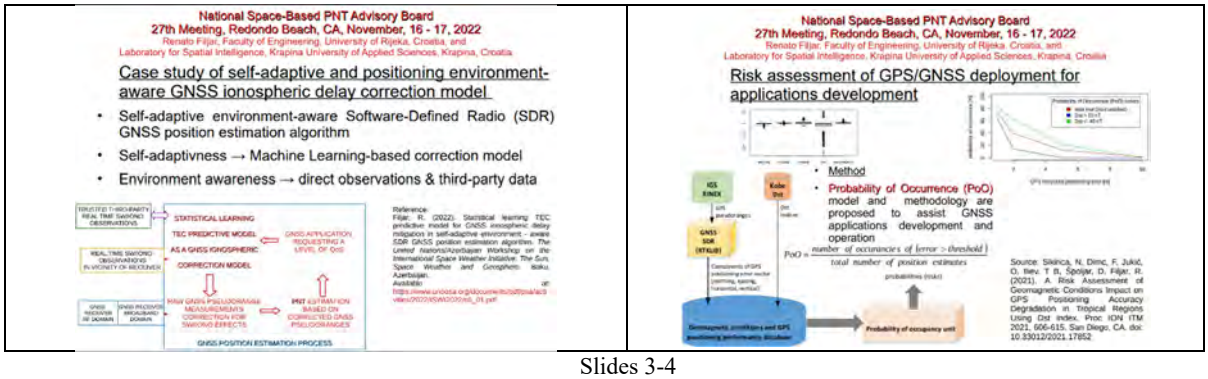
Dr. Filjar thanked the Admiral for the opportunity to present. He represents the University of Rijeka and the Krapina University of Applied Sciences in Croatia (Slide 1). He advocates using the so-called Positioning-as-a-Service Approach to satellite navigation (Slide 2). Traditionally. GNSS receivers are seen as a black box used by users that can fill other GPS-based applications with estimates of position, velocity, and time (PVT). This allows for the wide range of applications, making modern society strong and efficient. Satellite navigation drives the telecommunications financial sector, but also the Internet and mobile networks as well. Recent developments in the field of telecommunications, computer science, and statistics allow for new developments and utilization of GNSS spectrum and GNSS signals. This approach is utilized by technology such as software-defined radio. Taking the information perspective of various information sources makes GPS more resilient and more adaptive to the GNSS-based applications. The needs and requirements of GNSS applications is important to utilize the satellite navigation's initial framework, and not only opens the improved services that are already existing, but also a huge new market of GPS developments. There are opportunities and challenges regarding the utilization of Positioning-as-a-Service. For example, there are questions surrounding the regulation standardization, operations, and legal liability of such a service. The Positioning-as-a-Service has a huge advantage, and the positioning estimation can be aligned with the needs are requirements of the GNSS applications.



Slides 1-2

Several case studies have recently been conducted in order to provide self-adaptiveness to the GPS positioning estimation process (Slide 3). Dr. Filjar's team considered utilization of the direct observation of the immediate positioning in order to facilitate better understanding and awareness of positioning environment. This self-adaptiveness can be made using the machine learning-based correction models. This model has been developed for the fast-developing and short-term geomagnetic storms, which is a challenge for the standard global ionospheric correction model.

To align with the needs of GNSS applications, we need to develop the methodology for risk assessment of GPS deployment for applications development (Slide 4). This means that applications developers and operators need robust methodology to assess what is the consequence of GPS quality deteriorations. Dr. Filjar's team has developed a methodology and presented it in a paper at the Institute of Navigation (ION) conference on the means of a simple risk assessment for the GPS-based application operation in order to address the opportunity and risk for getting temporary restrictions on the GPS positioning performance.



Slides 3-4

Turning to development in Europe, the European Union Navigation Plan (ERNP) was recently completed and adopted (Slide 5). Dr. Filjar will distribute the document when it becomes available. Additionally, the European Connectivity Initiative would allow for the integration of GNSS capabilities into communication services, especially in SAR operations. Dr. Filjar's organization has also worked to align university study programs in order to recognize what is important for the

telecommunication, computer science, or transport engineers to know and understand about satellite navigation technology. This is done so engineers understand the framework of the underlying technology and not make a fundamental mistake. Dr. Filjar congratulated Prof. Terry Moore on the first UK satellite orbital launch by Virgin Orbit. The UK has recognized PNT as an important subject that should be addressed at the government level. PNT plays a part in the infrastructure that enables other services and systems and should be considered on the national level as such. Prof. Terry Moore will be able to speak much more about the UK-based RIN Advisory Group because he was the most recent President of the RIN.

Horizon Europe is the major framework for the funding of research in the European Union (Slide 6). There are two flagship programs currently in the EU: Galileo and Copernicus. Slide 6 outlines the most important projects funded by the 2nd Horizon Europe Call.

Slides 5-6

Dr. Filjar closed by inviting the members to the Baska Spatial Information Fusion Meetings in Baska, Krk Island, Croatia (Slide 7). These meetings will address satellite navigation as a source of spatial information as well as the opportunity to use satellite navigation for spatial data collection, aggregation, and analysis. The development of the predictive models is going to bring people from all around the world from different disciplines, from computer science to aeronautics and engineering to Baska on the Island of Krk."

Slide 7

Discussion: None.

2) *Australia, Mr. Matt Higgins (**View PDF**)*

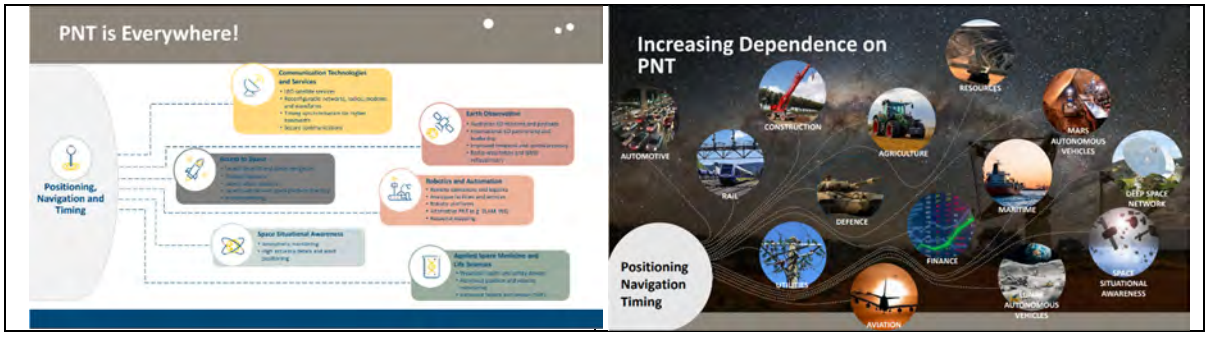
Mr. Higgins noted he would be giving the Australian Update and that he has two official government presentations, one on PNT Roadmap for Australia and one on SouthPAN, the Southern Positioning Augmentation Network (Slides 1-2). Within the Australian Space Agency, we are developing the PNT Roadmap for Australia. The agency also just got AUD 1.18B over the next 19 years for a Space-Based Augmentation System (SBAS) SouthPAN. This project will be done jointly with the government of New Zealand.

Slides 1-2

Slides 3-5, regarding the PNT Roadmap for Australia, were recently presented a conference. At the last Advisory Board meeting he talked about the civil space strategy. Under this strategy, there are certain priority areas, and for each of those priority areas, they are doing roadmaps. So far, they have published the roadmaps on communications, robotics and automation, and earth observation. The Australian Space Agency recently received AUD 4B in funding to launch earth observation satellites. Other roadmaps are Leapfrog R&D (which regards applied space medicine), access to space, space situational awareness and debris mitigation, and PNT.

Slides 3-4

Slide 5 illustrates how the other six priorities in space rely on PNT. In Australia, there is also an increasing need on precise positioning and critical infrastructure (Slide 6). The right side of the diagram on slide 6 shows the increasing interest of PNT in space, as opposed to PNT from space.



Slides 5-6

Part of the process of doing the roadmap is to evaluate the state of Australia, and his agency has conducted several in-depth discussions with various agencies around the country (Slide 7). Mr. Higgins stated that he cannot comment on where they are in those discussions because the roadmaps would need to be approved by the Minister and published, so hopefully by the next PNTAB meeting he can give an update. In terms of dependence and vulnerability, Australia is hearing all of the same concerns as the United States. A significant thing that Australia needs to achieve with their roadmaps is to have more resilient PNT. The center of slide 7 depicts things that Australia is good at.

Australia has also commissioned a study from KPMG about the market for PNT in space (Slide 8). Slide 8 shows the potential market for PNT in space. At the moment, Australia has a very small share of the global market because they have not launched many PNT payloads. Part of the roadmap is to grow the market for Australia.

Slides 7-8

Slide 9 shows the cooperation that needs to take place. At the top left of slide, "Australian Space Agency" is shown in a bubble. It is important to note that "Defense" and "Home Affairs" are included in the top left corner as well. Many of the concerns within Australian defense are also with critical infrastructure, and a tax on critical infrastructure is considered a threat. Home Affairs is concerned with the vulnerability of critical infrastructure.

The Australian Space Agency has also collaborated with international partners, including major space agencies, international universities, and international industry leaders. The agency has communicated with Australian industry. For example, SkyKraft is a company that is launching a constellation of LEO satellites to do ADS-B from space. Their first round of satellites is scheduled to launch through SpaceX in December. A big focus is the Australian research community. Australia has always been strong in GNSS research. The Australian Academy for Science Decadal Plan for Science and Space has a PNT portion to it.

Slide 9

Discussion:

Dr. Parkinson commented that he is very impressed, and that Mr. Higgins is a "major catalyst" in Australia. Are there activities that also involve New Zealand?

Mr. Higgins said that SouthPAN is joint project between Australia and New Zealand.

Dr. Powell said that one of the charts mentioned spoofing and jamming detection and geolocation. He asked Mr. Higgins to expand on that."

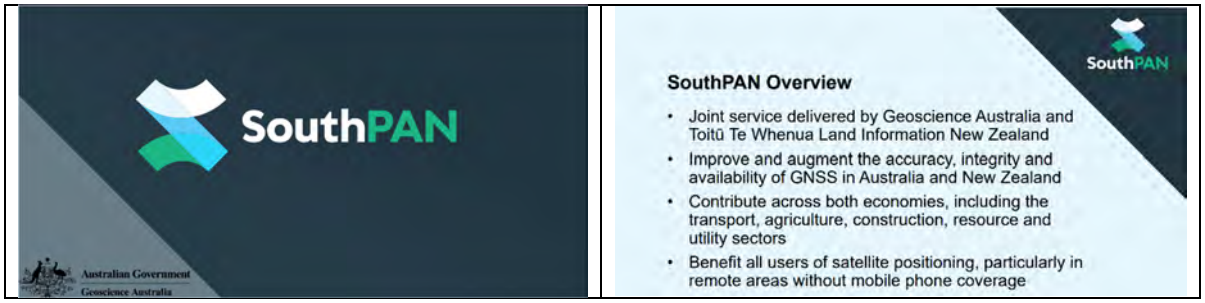
Mr. Higgins said that there is a company, GPSat Systems in Melbourne, Australia, who have been doing work for Australian defense, and have developed a Griffin System, which has been developed for defense but is looking to go into more commercial and civilian applications. He believes it also has anti-spoofing capabilities. At the moment, it's a system based on towers, but they have interest in expanding that to, for example, drones. That is a project that's been going on with Australian Defense for a while."

Dr. Powell asked if it consists of sensors on cellular towers.

Mr. Higgins noted he believes one has to put up their own towers. In his view it is very good technology. It's been in defense for a while and is now coming into the civilian side. There are brochures on the website he can point you to."

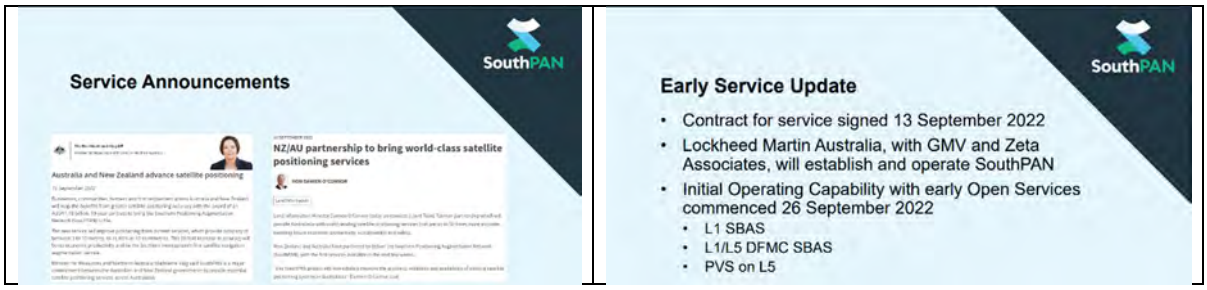
SouthPAN is a joint service delivered by Geoscience Australia and Land Information New Zealand (Slides 10-11). It will improve and augment the accuracy, integrity, and availability in both countries, and contribute to the key industries and critical

infrastructure surrounding PNT. Australia is a large country (the size of the U.S. lower 48 states, and with about a tenth of the population) that does not currently have complete mobile coverage. Delivery by satellite is an important part of SouthPAN.



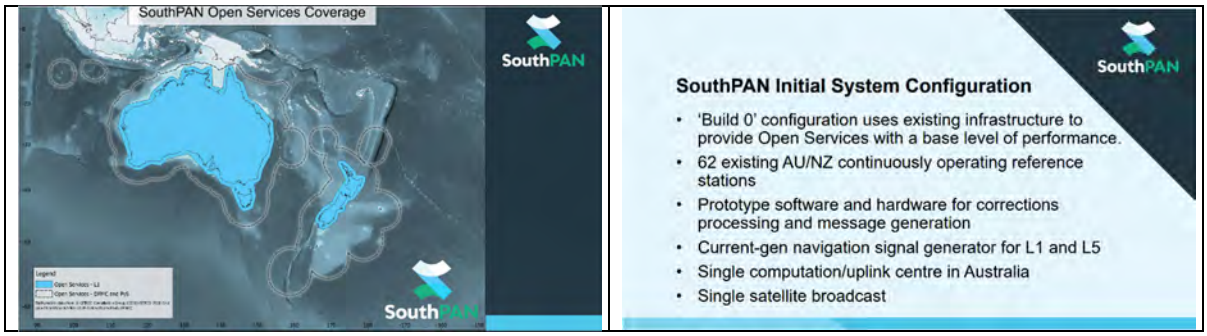
Slides 10-11

Slide 12 shows an article describing SouthPAN's 19-year contact. The contract was signed in September and involved Lockheed Martin Australia, along with GMV and Zeta Associates. SouthPAN will operate as a service (Slide 13).



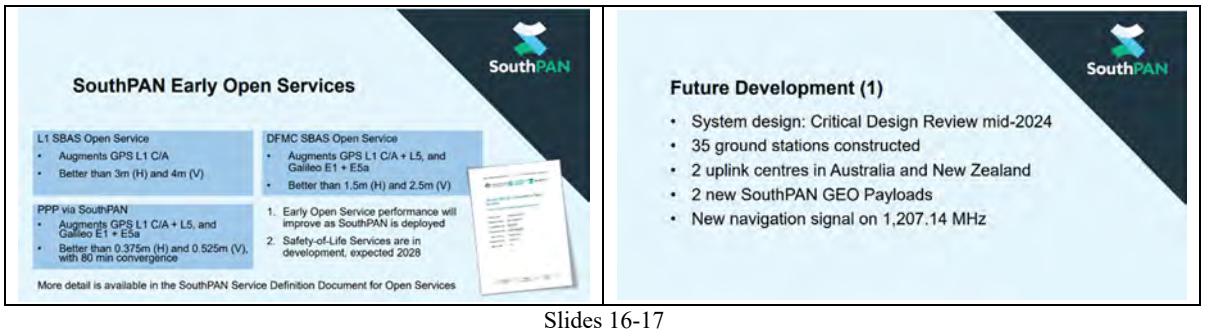
Slides 12-13

The initial operating capability, or Open Services, is effectively just turning back on the test bed that was in place for a number of years to build the business case for SouthPAN (Slides 14-15). It will offer L1 SBAS, next generation SBAS (which is L1/L5 Galileo and GPS), and Precise Point Positioning (PPP) via SouthPAN (PVS service) on L5. As depicted on slide 14, L1 services are limited to the land mass, but the DFMC services go out to territorial land masses for both countries.



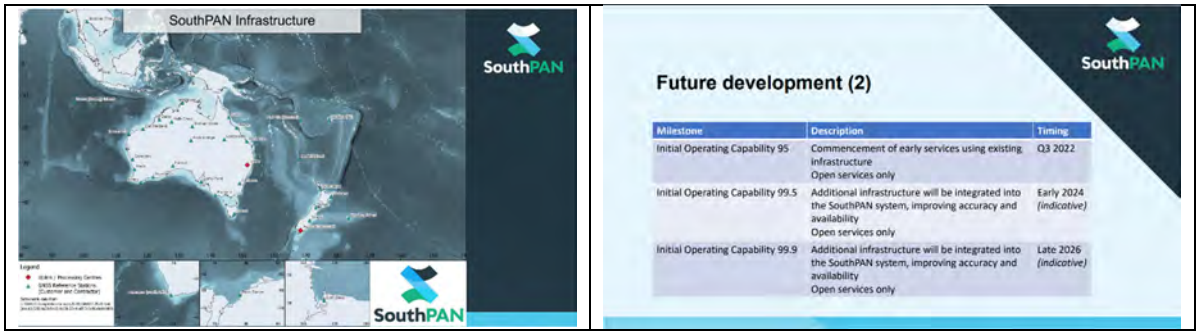
Slides 14-15

The initial configuration is to use the existing CORS network, prototype software, and current signal generator. Slide 16 shows the accuracies for SouthPAN's three different services and coverage. This document is available on both the Geoscience Australia and Land Information New Zealand websites.



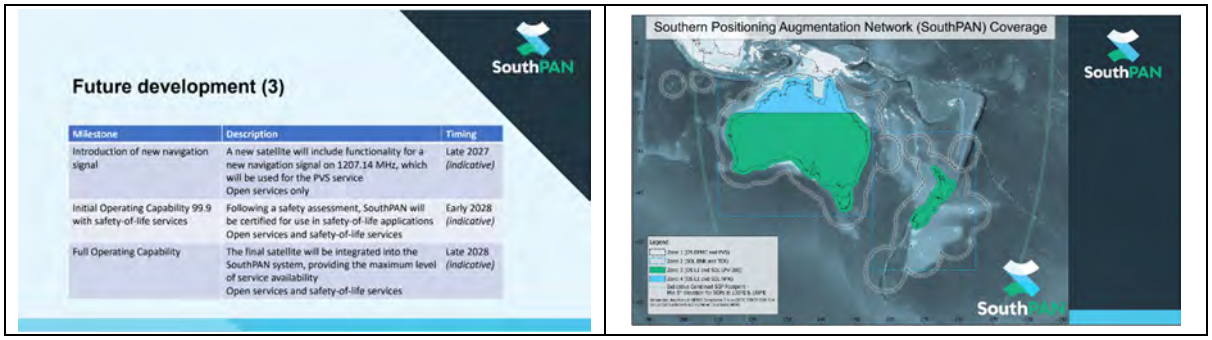
Slides 16-17

Moving to the operations system, 35 ground stations will be constructed, there will be uplink centers in Australia and New Zealand, and two new GEO payloads on two different satellites (Slides 17-18).



Slides 18-19

Slides 19-20 show the schedule moving forward. Some services are not yet certified for safety of life. By late 2028, Australia and New Zealand are expecting full operating capability of SouthPAN. Slide 21 shows SouthPAN's coverage for its four services. The green area (zone 3) covers most of Australia's capital cities. The goal is to move this coverage closet to the equator, which is being discussed with partners in the Pacific.



Slides 20-21

Mr. Higgins finished with a mention of the upcoming IGNSS (International GNSS) conference in Sydney, Australia in December 2022 (Slides 22-23).

Slides 22-23

Discussion:

Mr. Thompson asked if the 62 CORS are new or existing.

Mr. Higgins stated that they were existing.

ADM Allen thanked Mr. Higgins for his presentation.

3) *United Kingdom, Prof. Terry Moore (View PDF)*

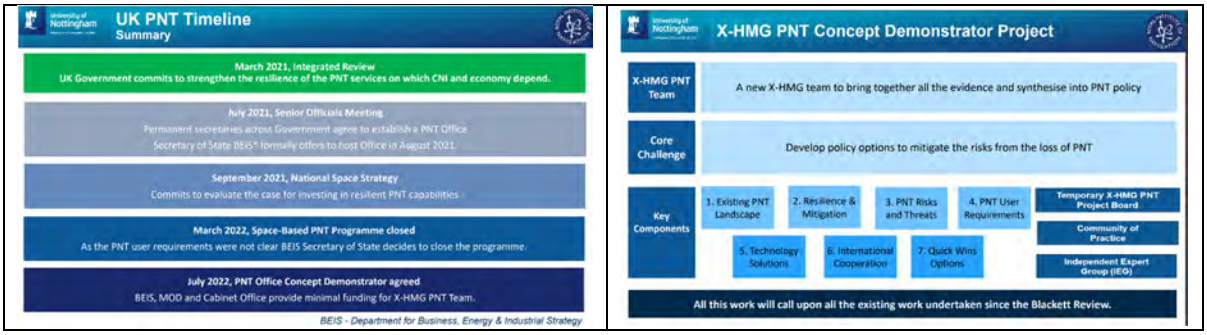
Professor Moore introduced himself and stated that he would be presenting PNT updates in the UK (Slide 1). Also, Prof. Moore will be speaking independently from the University of Nottingham and UK RIN. Slides 2-4 were approved by the UK government.

There is a lot of sensitivity regarding the skills, education, and training in the PNT sector. Since Brexit, it has been an interesting time in the UK to get things done. Before the Blackett Review was published in 2018, there was a London Economics Study that came out in 2017 (Slide 2). This study looked at the impact of disruption to GNSS and found that it would cost approximately GBP 5.2B for a five-day loss of GNSS. This stimulated the Cabinet Office to set up a review process, titled Blackett Review, which looked at the impact, vulnerability, and risks of GNSS. By August of 2018, the UK announced that there would be an 18-month investigation to look at the prospect of a UK GNSS system. At around the same time, the UK was in the final stages of Brexit, so the UK Prime Minister at the time announced that the UK would not be using the Galileo Publicly Regulated Service (PRS) for defense or critical national infrastructure.

Slides 1-2

The draft PNT Strategy was sponsored by Cabinet Office and delivered in 2021 (Slide 3). The National GNSS program evolved into The National Space-Based PNT Program, which was launched in 2020. It looked at the options of a space based PNT system in the UK. There was still a sense of inaction within the UK government, so there was an Integrated Review which strengthened the commitment of resilient PNT services for the Critical National Infrastructure (CNI) and economic purposes. The Department of Business, Energy, and Industrial Strategy (BEIS) Secretary of State hosted meetings of Senior Officials for the first time, and the UK got the first sense of leadership appearing within government. For clarification, the Secretary of State in the UK is not a single person, it is each Senior Minister in charge of every major department in the UK government. In September of 2021, the National Space Strategy was published and approved by the government. This highlighted the importance of PNT capabilities and provided a stimulus for more activities to take place. By March of 2022, the Space-Based PNT Board closed because, as stated by the BEIS Secretary of State, the PNT user requirements were not clear and not well made. In July of 2022, a prototype office for PNT was agreed upon as a demonstrator office to look at the feasibility of how a permanent office would be set up and operate, and provide a full business case to take a PNT strategy further forward. This effort is currently being led by BEIS, UK Ministry of Defence (MOD), and the Cabinet Office with representation of all 13 departments across the UK government that have identified a need for critical national infrastructure.

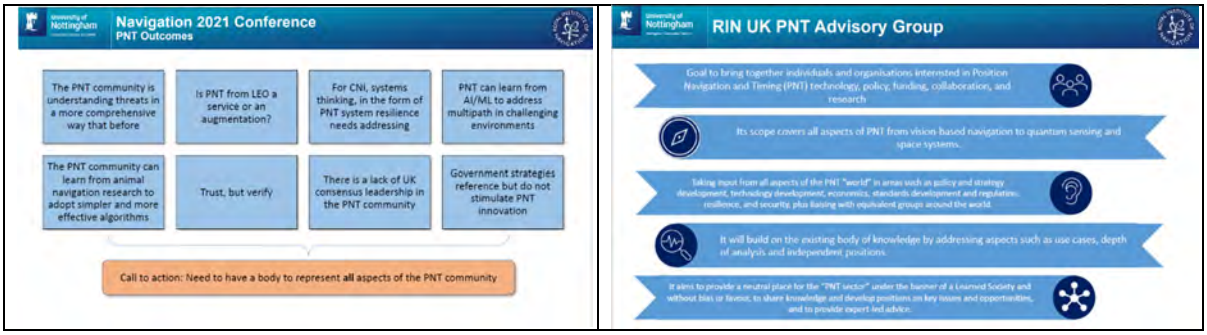
The X-HMG PNT Concept Demonstrator Project is the official title of the prototype office, which has now been established (Slide 4). This is a team, not within a single department, but across government to try to bring together all of the evidence including the Blackett Review and London Economics Study to produce a unified PNT policy. The main core challenge is to develop policy options to mitigate the risk from the loss of PNT. The key components are: (1) Review the existing PNT landscape, (2) Focus on resilience and mitigation, (3) Identify PNT risks and threats, (4) Look at user requirements, (5) Technology solutions, (6) The aspects of international collaboration, and (7) Quick wins, an independent export group, which includes academic leaders, provides expert guidance to the X-HMG Team.



Slides 3-4

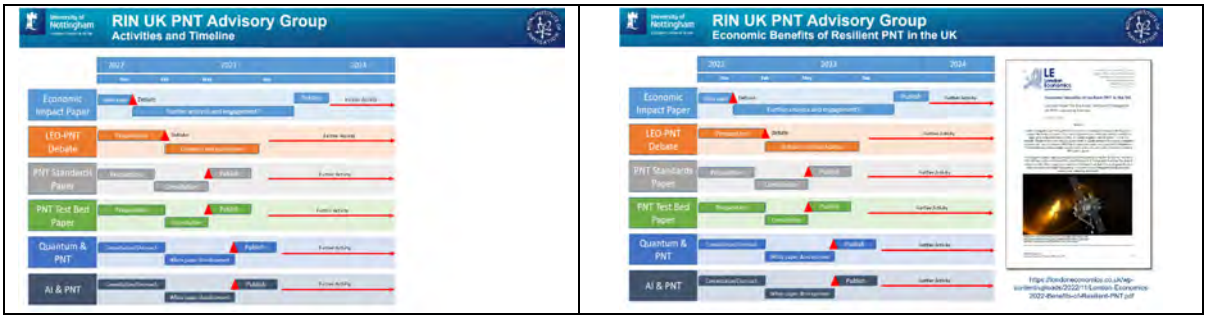
In November of 2021, the RIN hosted a Navigation 2021 Conference, which was a combination of the National Navigation Conference and the European Navigation Conference (Slide 5). Throughout this conference, there was an increasing understanding of the risks and threats, as well as a frustration about the lack of progress. The decision of the conference was that somebody needed to do something, and it was suggested that the RIN could take that independent leading role.

Within the RIN, a UK PNT Advisory Group was established (Slide 6). Fundamentally, this group brings together individuals and organizations that are involved in PNT technology, policy, funding, collaboration, and research to provide an independent focus and forum discussion.



Slides 5-6

Slides 7-8 show the RIN UK PNT Advisory Group's timeline of activities. The first piece of work that the Advisory Board has been working on with London Economics is an updated Economic Impact Paper. This paper will not only look at the impact of a loss of PNT, but also the economic benefits of resilient PNT. This paper has been completed and published. The second White Paper will be focused on LEO PNT and the meeting for that will take place in January or February of 2023. PNT Standards, PNT Test Beds, Quantum, and AI are also among the ongoing work of the Advisory Board. All papers will be delivered within the next year.



Slides 7-8

Discussion:

ADM Allen asked Prof. Moore who is hosting the UK for the meeting in December.

Prof. Moore said that Mr. Auerbach was speaking with the Department of State, and he does not know what the latest update are regarding that.

ADM Allen thanked Prof. Moore for his presentation.

4) Resilient Navigation and Timing (RNT) Foundation, Mr. Dana Goward (Note: There were no slides for this presentation)

Mr. Goward noted that in the beginning, there was GPS, and it was good. The people acclaimed it a great joy and they prospered. Yet slowly, serpents of darkness crept into this Eden and here and there began to sew chaos. The year was 2013, and he had just left the government, having served as the maritime navigation authority for the United States. Former Assistant Secretary of the Air Force, Mr. Martin Faga, and he shared concerns that the federal government had not taken the steps it articulated as necessary to protect GPS services and users. At the time, most receivers in use were relatively simple devices that could be easily jammed or spoofed, or otherwise interfered with. Also at the time, the FCC had a pending action to allow Lightsquared to broadcast on the only satellite frequency band, and there was overwhelming concern within the Executive Branch and industry deny or degrade service for many GPS users. Also, protecting GPS frequencies on a day-to-day basis was difficult because the nation has little ability to detect, locate, and terminate interference. And despite a 2004 Presidential Directive to establish a complementary service for GPS, and a 2008 press release by DHS saying a technology had been selected and an effort was underway, there was no real prospect of that every happening. Ignoring virtually every engineer and technologist in the government familiar with the issue, the Office of Management and Budget (OMB) had eliminated the funding that had been in place for 50 years that was to be used to establish the new system."

Mr. Faga and he were concerned that talk about resilient PNT within the federal government had essentially stopped, so they created the Resilient Navigation Timing (RNT) Foundation to keep that discussion alive. It would advocate for policy and systems to protect GNSS and GPS satellites, signals, and users. Basically, protect, toughen, and augment. The foundation is a 501(c)(3) scientific and educational charity, and we have individual and corporate members. Its corporate supporters include satellite companies, simulation & testing companies, terrestrial broadcast companies, clock manufacturers, folks involved with quantum technology, device manufacturers, local PNT system providers, and network folks.

By law, as a 501(c)(3), it is prohibited from giving our members any substantial direct benefit. Individuals and companies joined the RNT foundation because they believe in a support our efforts. We really appreciate that, so thanks to all of the members who are here and online for all of your ongoing support. To keep our memberships accessible, we keep our dues fairly low. We like to say that 'we put the 'non' in 'nonprofit'' at the RNT Foundation."

Efforts of RNT and the PNTAB to protect GPS frequencies suffered when the FCC decided for Ligado. By the way, Ligado complained to us that the RNT Foundation has had more filings to the FCC against their proposal than any other organization. Yet, despite a huge coalition of organization also submitting similar filings, the decision went the other way. If there is any bright spot in this at all, it's that the FCC has not yet figured out how to answer our petition for reconsideration of that decision, nor those from six other organizations.

Today, protecting GPS frequencies on a day-to-day basis is still as difficult as it was before as the nation has little ability to detect, locate, and determine interference. See Dallas and Denver, as we talked about yesterday. A lot of work has been done in the last 10 years to enable and build tougher receivers to better resist interference. Not a lot of headway has been made, though, getting that equipment in the hands of users. Ramsay [Faragher]'s presentation yesterday was a hopeful note. The discussion about ITAR was not such a hopeful note. At the same time, in the last 10 years, we've seen jamming, spoofing, meaconing, and accidental interference greatly increase. For the moment, the environment has gotten much worse, and most users are unchanged and therefore much more at risk.

Augmenting signals always seems to be the most controversial of the PTA triad. Some diehard 'GPSers' seem to think the suggestion for complementary services is calling their baby ugly. On the other hand, you can see this as recognizing that the GPS baby is actually quite beautiful and precious and invaluable and in need of protection. In 2008 the Bush Administration committed to establish a complementary system. In 2015, the Obama Administration promised Congress that it would do the same thing. By the way, this Board, for those of you who are new, has recommended complementary capability on three separate occasions, most recently in 2018. Congress has long been concerned and has always held hearing in this process, often in the DoD area, but also under DOC and DOT. In 2018, despite the Obama Administration's promises, no action had been taken and they passed the National Timing, Resilience, and Security Act requiring the Secretary of Transportation to establish at least one complementary timing system to complement GPS, based on the availability of funds. Unfortunately, the last two Administrations have vigorously opposed any funding, and the current Administration has twice recommended repealing that act.

In the last 10 years, China has greatly advanced its own PNT architecture to provide multiple space-based and terrestrial complementary systems. Russia, Iran, South Korea, and Saudi Arabia have kept and improved their complementary PNT. This puts the U.S. in an awkward position relative to some of our most vociferous advisories.

Again, the PNT environment has changed drastically over the last 10 year. In troubling ways, the U.S. has failed to adapt to these changes. He mentioned earlier that we at the RNT Foundation advocate for policy and systems to protect GNSS and GPS satellites, signals, and users. The PNTAB has made it clear that there are plenty of systems available to for PTA. However, technology in and of itself is not going to save us. Our challenge is having the leadership and the policies that will get these technologies implemented. In his opinion, this is where the board needs to focus its efforts.

Discussion: None

5) Consumer Technology Association (CTA), Mr. J. David Grossman (Note: There were no slides for this presentation)

Mr. Grossman noted he would be discussing the recent Midterm Election, the change in the makeup of Congress, and potentially new Chairs on committees of jurisdiction as it relates to the FCC.

Congressman Mike Doyle of Pennsylvania will retire that the end of this Session. He has served as the Chairman of the House Energy and Commerce Subcommittee on Communications and Technology. There will be a new Democratic Ranking Member in the 118th Congress. Congresswoman Doris Matsui of California is among the names being discussed to fill that role. On the Senate side, although the Chamber is not changing parties, it's expected that Senator Ted Cruz of Texas will take over as Vice Chair of the Senate Commerce Committee. Although this Advisory Board does not lobby or advocate, it is important to know who the new players are going to be regarding the issues that will impact this industry.

Additionally, there is still an open Commissioner position at the FCC. Gigi Sohn's (nominated by President Biden over a year ago) nomination remains pending. It is very much in play, with the current lame duck session, that there may be a vote in December after the Georgia election.

Spectrum policy and cybersecurity are both tangential issues to the PNT and GPS world. There was an NOI at the FCC that was voted on and approved on a bipartisan basis regarding the 12.7 GHz band. This is a 500 MHz swath of spectrum between 12.7 and 13.25 that the FCC is pitching for next-generation wireless services, 5G and beyond. Comments are due for the NOI on November 28, 2022. CTA will be filing comments expressing support. There are several questions in the NOI regarding adjacent band compatibility and the standard of interference.

There are two updates regarding cybersecurity. The first involves the way that the FCC's equipment authorization process takes place. All wireless devices must receive FCC authorization. Last year, Congress passed, and the President signed into law, the Secure Equipment Act. This Law requires the FCC to adopt rules that prevent entities from obtaining FCC authorization for covered list equipment. This list is very similar to the DOC's Entity List. I n the case of the FCC, there are currently ten companies, primarily China-based. The Secure Equipment Act requires close the loophole so equipment that is still on the covered list could never retain FCC authorization. That order has been adopted but not yet released. FCC Chairwoman Rosenworcel stated that the release of that order will be imminent. It is Mr. Grossman's understanding that it will only apply to completed devices, not individual components within a device.

The second cybersecurity item involves the White House NSC. Last month, NSC held a strategic discussion around cybersecurity labeling of IoT connected devices. Mr. Grossman and a colleague of his participated in the meeting on behalf of CTA. This is a program that the White House planned to launch by the Spring of 2023. There are a lot of questions surrounding what a label would look like, what federal agency would oversee it, and what would the criteria be. It is an all-of-government approach. The Chairwoman of the FCC, the Chairwoman of Consumer product Safety Commission, the Director of the National Institute of Standards and Technology (NIST), senior leaders from the OSTP, and other leaders from around the government were involved in this meeting. There are a lot of policy issues that may be at play around liability protection for companies who adopt such a labeling scheme. Cybersecurity is not a static issue; it is constantly evolving. Explaining to consumers what a label means is going to require some resources.

At the prior PNTAB meeting, Mr. Grossman discussed the FCC NOI on receiver performance. CTA filed comments in the Summer of 2022 which the FCC is still reviewing. CTA does not think that regulation by the FCC is the right approach. They have questions about legal authority, impact to innovation, and the sheer volume of receivers in the market. If the goal is setting some type of receiver performance, and there are billions of devices in the market, with GPS for example, spectrum efficiency will not be improved.

Discussion:

ADM Allen said that was very helpful and if Mr. Grossman could plan on doing that every time, the Board would appreciate it. Admiral Allen then asked Mr. Tim Murphy if he could briefly update the Board on Ligado's Canadian filing.

Mr. Murphy said he was reminded by an email this morning that Ligado Networks filed an application with the Canadian spectrum regulator for operations in Canada. He will provide a link to interested parties. Unlike the FCC order, which limits the power to 9.8 dBW, Ligado is asking for 28.9 dBW for operations in Canada. They're also asking for relaxations for the limits of out-of-band emissions. Mr. Murphy noted that there is a comment period which on the following day. Interested parties may wish to comment. There are already letters from the Office of Management and Budget (ALPA) and Canadian Business Aviation Association.

Mr. Goward commented that the subset of folks that oppose the Ligado decision is the U.S. have turned their attention towards Canada, and those that have interest [in] Canada are attempting to do a similar thing to what was done here in the U.S., hopefully with greater affect."

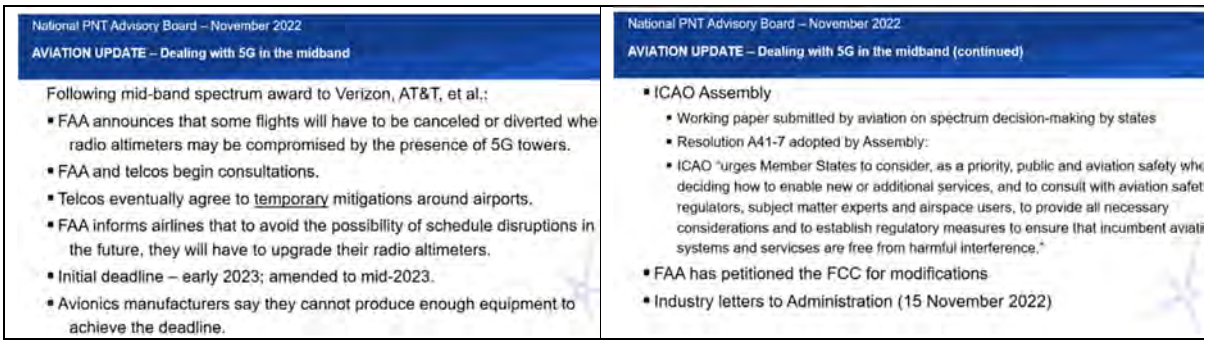
ADM Allen commented that the issue here is that it'll drive equipment manufacturers to move to the higher level, which gives them leverage in the United States.

6) International Air Transport Association (IATA), Hon. Jeff Shane

Mr. Shane opened by stating that he would not going too much into the background of aviation. This presentation focuses on one issue: FCC's award of spectrum to several 5G providers though an auction that was completed in early 2021 (Slides 1-2). The FAA and the aviation industry participated in the proceedings, pleading with the FCC to protect aviation. There may be a problem with interference, particularly with the radio altimeters that are in all commercial and noncommercial aircraft. The FCC and NTIA disagreed with the FAA's technical analysis. Only the FAA has the authority to regulate the safety of aviation and by disagreeing with the FAA, the FCC and NTIA were effectively taking on aviation safety responsibility. The award was made "over the dead body of the FAA," and the FAA immediately started cancelling flights where there was low visibility because interference via 5G would compromise the performance of the radio altimeter, of which the crew relies on for a safe landing. The radio altimeter supports several avionics within the airplane. So, the function of the radio altimeter is critical to safe operation of an aircraft.

The FAA immediately tried to engage with winners of the auction regarding what mitigations might be possible at airports in order to protect aviation. It is important to keep in mind that the FAA would not allow a flight to occur if it were unsafe. When facing interference, the FAA would cancel or divert a flight, so we're talking about disruption. We are not talking about putting people's lives in jeopardy. The telephone companies (telcos) eventually agreed to temporary mitigations around airports. However, these companies paid greater than $60B for the spectrum, and wanted to get maximum value, so they agreed to leave the mitigations in place for a year. The FAA told the airlines that if they want to avoid disruptions when the mitigations were taken down, they will have to upgrade their radio altimeters. The deadline to do this is July of 2023. However, the manufacturers of the radio altimeters claim that they cannot produce enough equipment by that deadline.

In late September/early October of 2022, the International Civil Aviation Organization (ICAO), which is the UN specialized agency that handles aviation internationally, had an assembly, which are held one every three years. They released a working paper on spectrum decision-making, and as a result, a resolution was adopted by the assembly (made up of 193 countries). Following the paper, the FAA formally petitioned the FCC for modifications to its order making it possible for telcos to broadcast 5G signals in and around airports. Additionally, avionics manufacturers, aircraft manufacturers, and foreign airlines have written to the Director of the National Economic Council, Secretary of Commerce, and Secretary of Transportation pleading with them to facilitate some sort of mitigation or modification to FCC's award (Slide 3). These companies highlighted that they cannot produce enough equipment to retrofit the fleet by the July 2023 deadline. The FAA has also stated that if the fleets are not retrofitted by the deadline, by February of 2024, you will not be able to fly to the United States. You will not be able to operate to airports that are affected by 5G."



Slides 1-2

Slide 3

Fifty-four foreign airlines who fly to and from the U.S. are also being told by the FAA that they must retrofit their fleets in order to continue to operate in the United States. These foreign airlines stated in a letter, dated November 15, 2022, that they cannot do this. First, the FAA has not certified all of the equipment that the airlines would need, and second, supply chain issues would prevent the manufacturers from predicting the necessary equipment. The U.S. has international obligations to foreign airlines, and therefore, we are not supposed to write unilateral rules that are inconsistent with international standards. When one country decides to impose on airlines a standard that is different from the ones that are in their own country, that are in every other country, it causes a real issue. If we do not have the mitigation that the industry is looking for, there will be lots of bilateral and multilateral consultations. Mr. Shane stated that he has called this nothing less than "an institutional administrative cockup of galactic proportions.

Discussion:

Dr. Parkinson noted that this presentation greaves him egregiously, and it represents a total disfunction of our government. He asked if each airline is expected to pay for this or is there some liability to either the FCC or proprietors of 5G. The cost of the impacts should be borne onto them. [Are] there any lawsuits or a court order or anything to bring this to a screeching halt?

Mr. Shane answered that the airlines are expected to pay for it.

Dr. Parkinson asked if any logic can be traced in that.

Mr. Shane stated that we have an administrative law system which says that the FCC has statutory authority to award spectrum, and they do that after a long proceeding: lots of notice, lots of comment, lots of deliberation. So therefore, after the dust finally settles, you have winners, like AT&T, Verizon, T-Mobile, and so forth. They are operating legally. They are doing exactly what they are asked to do, and they have been given permission by the government to do it. An environment has been created for which the airlines, in order to continue to operate the way they want to, are going to have to upgrade their avionics."

Dr. Parkinson asked if there's a taking clause, or something, that [states] value has been taken now from the airlines that somebody in government seems to be responsible for.

Mr. Shane said he doesn't think the taking clause envisioned an award by the FCC to telcos which require some accommodation by airlines. It may well be that it's time to upgrade altimeters. Airlines aren't quarreling about the idea of upgrading their equipment. The filters on those altimeters probably are inefficient for today's world as spectrum gets more and more crowded. We're talking now about out-of-band interference. They are not sitting on the band that is reserved for the altimeters. So that's not the issue. The issue is that its physically impossible to comply with what the FAA has told the industry to do. So, something has got to give. It's been no gift to the telcos to have this disruption. They paid a huge amount of money for the right to broadcast 5G, and people want it. It's not a bad thing to try to advance technology in that way. We're just talking about a conflict right now that for physical reasons and other reasons, and maybe some economic reasons, is very difficult to overcome."

ADM Allen added that he's been involved in regulatory issues in the maritime environment probably as long as Jeff [Shane] has. The basic premise is if there's a public good to be served, and you go through the processes under Title V, the Administrative Procedures Act, you could mandate a 'carriage requirement.' As a condition of operation, you have to do certain things whether it's an aircraft or a ship, and the cost of that is born by implementing the regulation that should be passed onto a consumer. Basically, taking an externality and internalizing it to the price of goods to be barred by the consumer and what they pay for. That's the basis for these 'carriage requirements' when you see them."

Mr. Murphy noted that the picture is even darker than you've outlined here because even though we have to do this upgrade by the middle of next year, it's not guaranteed to be the end because there's another rulemaking coming for the upper band above 4 GHz. There's no consensus about how hard the receivers need to be on a global scale. The thing that we're being forced to hurry is likely to be a temporary Band-Aid and we'll end up doing it again in a few years. It's also very frustrating that industry made it extremely clear to the FAA that this was not a reasonably period of time to do this. When TCAS was mandated, it took us seven years to get that in the fleet, and that was just about as fast as the industry could move on something like this. It's not surprising that now there's a lot of push back. The other thing is that all the mitigations at the FAA has done only apply to 83 airports. T here's a whole lot of airports where large airplanes with radio altimeters operate into today that are not going to be necessarily protected by the levels of interference rejection that is being mandated by the middle of next year. So, we're still likely to see some operation restrictions even after that at some of the smaller airports. The tragedy of all of this is that it's burdensome to the aviation industry and everybody's working some of this problem, and we only have so many people. Also, people that are working this are not working other things such as GPS interference or improvements to GPS. It's just a massive drain on the resources of my company and the avionics manufacturers, and the FAA has resource constrain issues. They only have so many people and they're off working this issue right now."

Mr. Shane said we were reminded by Ms. Van Dyke of how much work is being done to head off potential for disrupting GPS by another award of the FCC. And as he watched that briefing, his heart was breaking because so much productive

activity was being diverted away from actual progress to playing defense. That's exactly what's happening within the FAA and within the aviation industry right now and it's because, ladies and gentlemen, our spectrum decision-making in the U.S. is being made by a so-called independent regulatory agency. It's not that the decisions are inherently bad, it's that there isn't the give and take, there isn't the deliberation, there isn't the holistic approach given to these decisions that there ought to be."

Mr. Mike Hamel asked whether given the FAA's authority over national airspace, does this then also obtain to all military aircraft operations within the US? Is this getting the light of day through NTIA, or is DoD standing up and speaking?

Mr. Shane replied that he really doesn't know the answer to that. To the extent that military aircraft are operating in and out of military airbases, of course it is up to the military to decide what's necessary and whether 5G can be deployed and so forth. It's got much more control than the FAA does over civilian airports. So, if a military aircraft lands at a civilian airport without the requisite radio altimeter and there's 5G there and there's low visibility, he believes that in the interest of safety, that aircraft would be warned not to land."

Gen Hamel noted that given Mr. Murphy's comment that there are only 8] airports in the country operating under this mitigation, this could be very impactful to military that may not even be subject to mitigation."

ADM Allen asked Mr. Stormy Martin if the board could get a quick answer through the EXCOM on this.

Mr. Martin stated that he would ask DoD.

Mr. Van Dyke commented that DoD has been working with NTIA through the Institute of Telecommunications and Sciences in Boulder, Colorado. They have been conducting a lot of testing to better understand the impact to military aircraft. NTIA just released a report on the results of the testing, so DoD has taken that into consideration."

Gen Hamel said that whatever position the board takes, it will want to somehow acknowledge whatever agency in the government that may likewise express concern about this. This is not just a commercial issue.

ADM Allen said that makes sense.

Mr. Shane commented that 5G is being deployed around the world, even at airports. It's just at airports everywhere else require the signal be mitigated or to be further away from the frequencies of which radio altimeters rely upon. So, when you hear from the telcos that 5G is available everywhere, the response should be that in every other country they've been smarter about how they deploy 5G. It hasn't been a problem for aviation anywhere else except for the United States.

Mr. Winfree commented that he is interested in having a sense of the board on whether it needs to consider the fact that this is becoming a pattern in practice with FCC. It's an unrelated issue, but the 5.9 GHz safety band that DOT had invested in a global enterprise for communications technologies for vehicles was overridden by FCC when they granted the spectrum to wireless interests. So, there were the same kinds of 'treaty obligations' that were completely disregarded. The priorities of another executive agency were disregarded by FCC. So, this is becoming a pattern with the FCC.

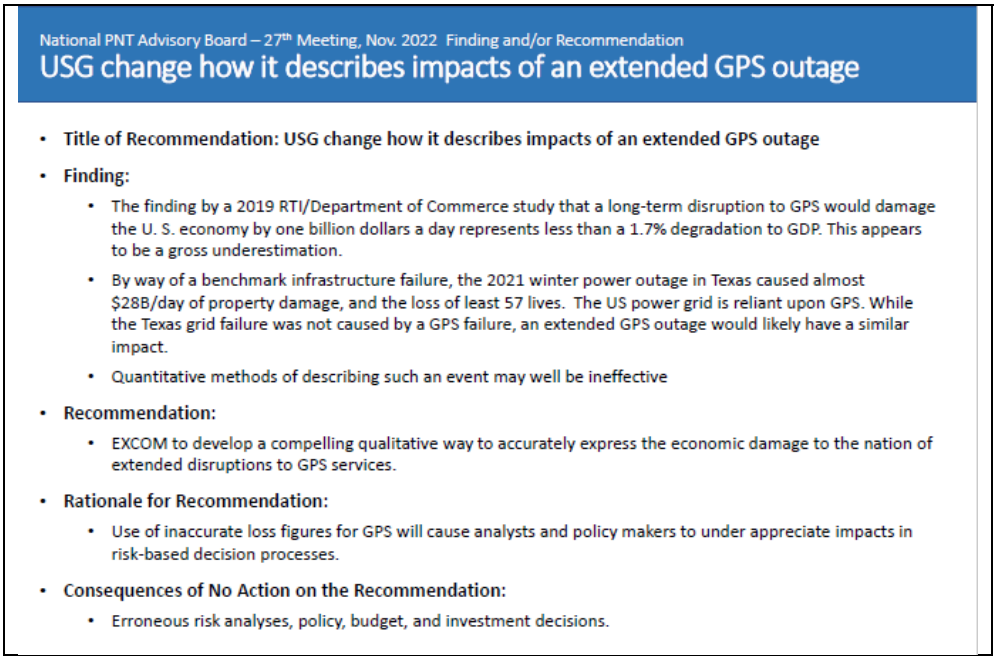
* * *

Roundtable Recommendation Presentation & Adoption

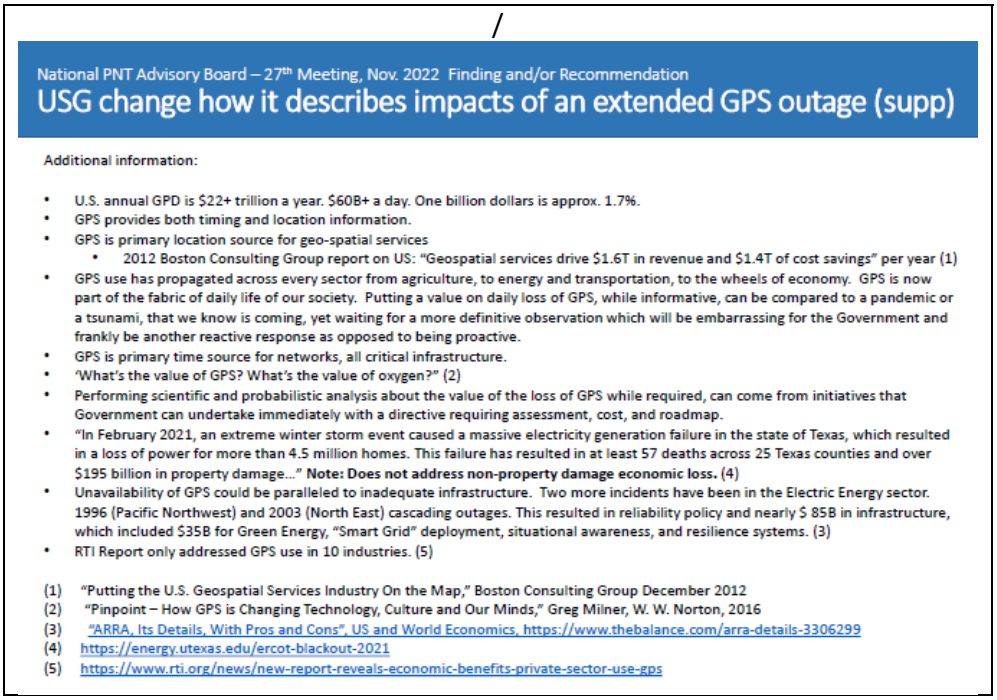
ADM Allen opened the floor for subcommittee chairs to propose recommendations for deliberation by the full board.

1) Communications & External Relations (CER) Subcommittee

Mr. Goward (CER Subcommittee Chair) presented three proposed recommendations. The first recommendation calls for the USG to develop compelling qualitative process to accurate express the economic damage to the nation of extended disruptions to GPS Services (Slides 1-2).

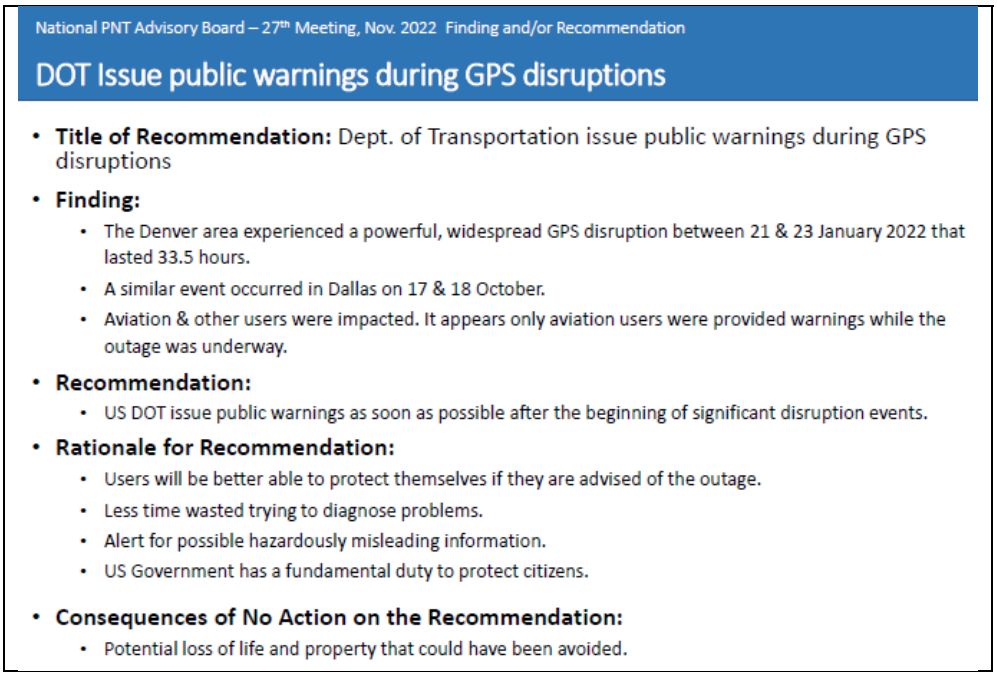


Slide 1

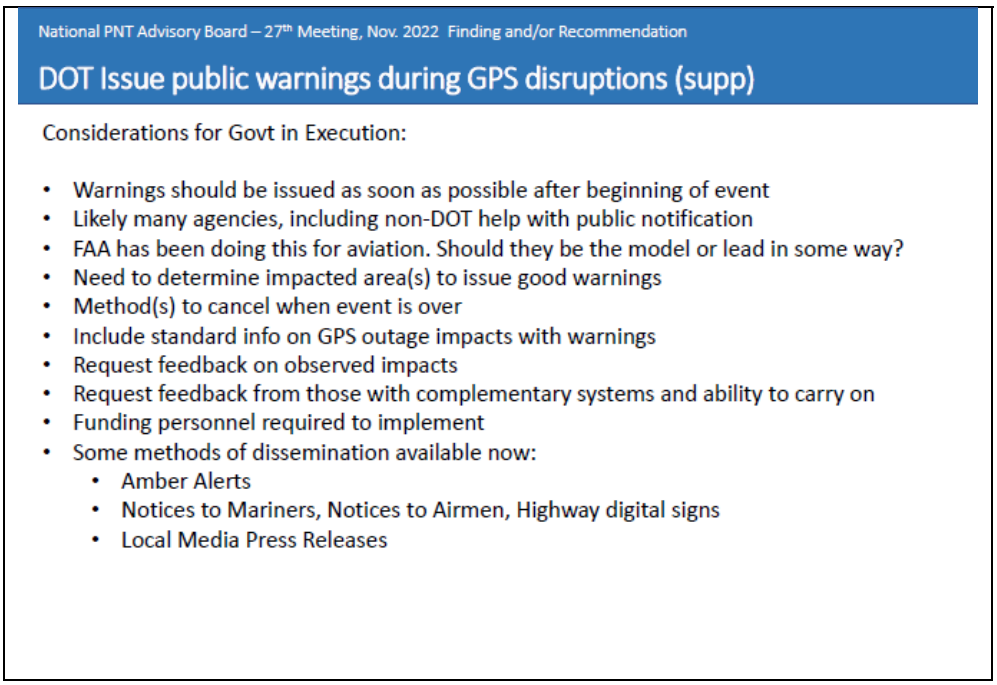


Slide 2

The second recommendation is for the DOT to issue public warnings during GPS disruptions (Slide 3). Slide 4 describes additional considerations for the USG when executing this recommendation.

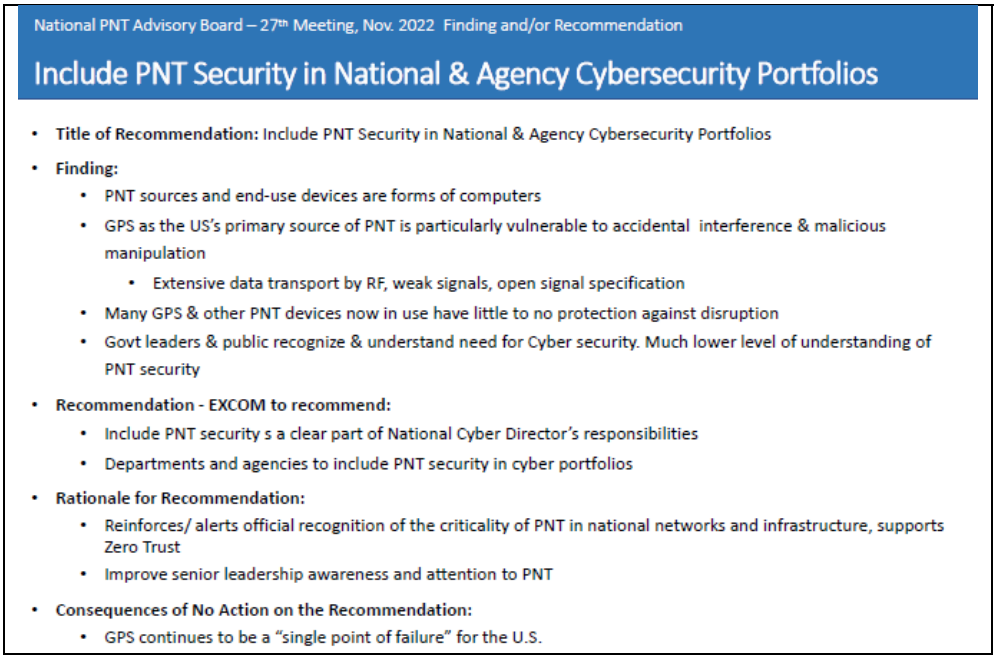


Slide 3



Slide 4

The third recommendation is to include PNT security as a clear part of National Cyber Director responsibilities, and for agencies to include PNT security in cyber portfolios (Slide 5).



Slide 5

Discussion:

ADM Allen asked Ms. Van Dyke if she had comments on the 2nd recommendation, as it pertains to DOT.

Ms. Van Dyke noted DOT needs to do some thinking about what such broad notice would entail compared to, for example, specific ones such as the Notices to Air Mission (formerly Notice to Airmen), or NOTAM, issued by the FAA or the Notices to Mariners issues by the USCG. As indicated on the previous day, DOT's view is that such notice should be used for situational awareness and perhaps include a graphical representation of the area affected by interference to inform users where GPS is being disrupted. This notice could also be linked to gps.gov and distributed through e-mail list. We'll take an action at DOT to think more about this.

ADM Allen added that he would like to include a GPS outage disruption as part of a national exercise coordinated between Federal Emergency Management Agency (FEMA) and the (NSC, and have the effects of the outage be a goal of this exercise. The outcome of the exercise would be how to achieve adequate warning. Perhaps we should talk about this with Ms. Caitlin Durkovich (DHS Advisor for Resilience and Response, NSC), and have them come up with the best recommendation on issuing a national-level warning of GPS disruption. Adm Allen also agreed that DOT has the best authority to issue such warning.

Mr. Martin noted that five or six years ago the NCO submitted a recommendation for a national level exercise. To do that, a town would be recreated somewhere, along with infrastructure that is dependent on GPS, and use that to assess in a controlled environment the effects of different levels of jamming & spoofing. Unfortunately, this proposal was out prioritized by a national level exercise of susceptibility of the electric grid to solar storms. We would support Adm Allen's recommendation, and if it comes from the PNTAB.

Mr. Goward agreed, and noted that the intent for this recommendation is to have a minimal level of USG responsibility to address what should have happened during the last two events (Dallas Fort Worth & Denver) to warn in some way the larger population beyond just aviation. One would hate for something to go wrong, perhaps with casualties, and then people in the broader community say they would have acted differently had they known.

Dr Powell asked Ms. Van Dyke whether the warning would include a 'heat map' (a visualization of interference power levels and its geographic extend).

Ms. VanDyke noted that NOTAMs include the geographic area of impact. For this to be useful to the broader community, it needs to include a visual representation of the area impacted.

Dr. Madani noted that in the energy sector we've heard DHS express desire for such notification. It's hard to assess potential impacts if we're not expecting it. So, yes, any form of notification beyond the aviation sector would be very helpful.

Dr. Filjar agreed that having inputs beyond just aviation would be valuable to the user community as a whole.

ADM Allen proposed that DOT take a look at this as a way to move forward as a prototype, along with exploring the opportunity to have a national level exercise and have that inform a national warning system with the current response structures.

Mr. Miller noted that we want to include on the record where the PNTAB stands on all three proposals.

Dr. Parkinson expressed concern about flooding the PNT EXCOM with too many recommendations. This approach risks diluting the impact of whatever is being recommended.

ADM Allen said that the recommendations being approved today will be included in a single Memorandum to the DoD and DOT deputy secretaries.

Mr. Shane noted he shares Dr. Parkinson's concerns. The board needs to package these recommendations in a way that the USG can take seriously.

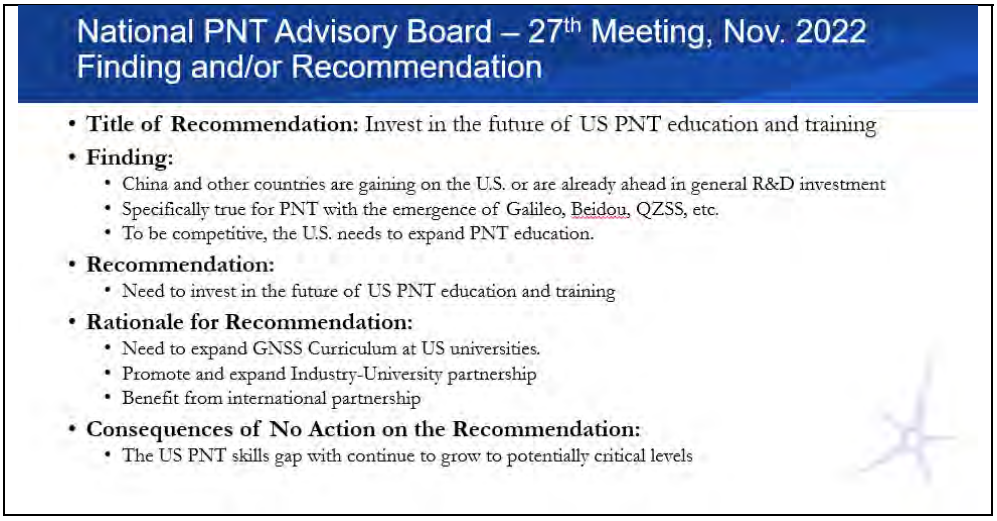
Mr. Shields suggested having just a few recommendations as the board's 'core submission', and then noting something along the lines that in additional to these critical things, here's a list of other things we believe are important for consideration by the PNT EXCOM agencies.

ADM Allen proposed accepting these recommendations and tabling the discussion on what to do with them

<All three CER Subcommittee recommendations were adopted without opposition>

2) *Education, Science, and Innovation (ESI) Subcommittee*

Prof. Moore (ESI Subcommittee, 1st Vice Chair) presented on behalf of Dr. Jade Morton (ESI, Chair). The ESI subcommittee only has one recommendation, which is to encourage increased funding that goes towards supporting R&D and training in the U.S. and its universities (Slide 6). This is supported by evidence presented by the subcommittee regarding the closing gap in R&D between the U.S. and other countries.



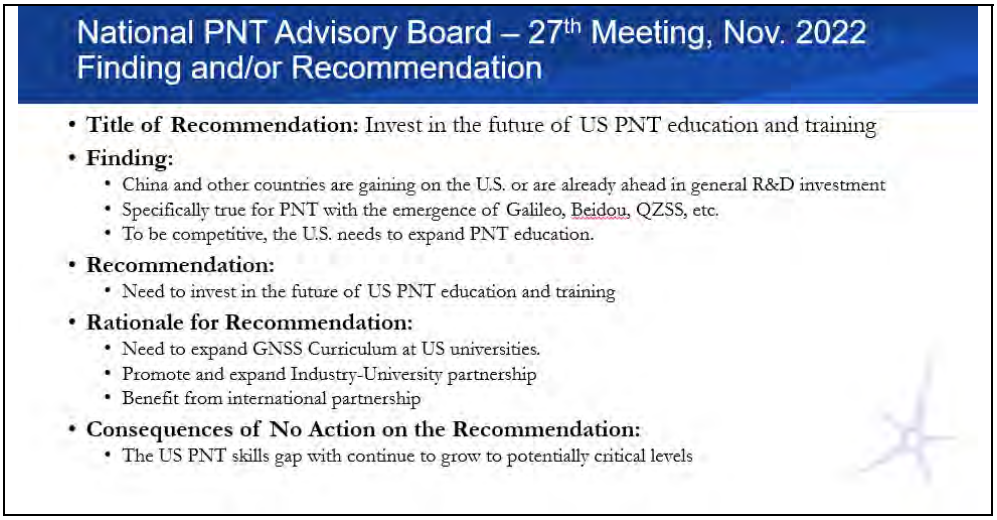
Slide 6

Discussion:

<The ESI Subcommittee recommendation was adopted without opposition>

3) Emerging Capabilities, Applications & Sectors (ECAS) Subcommittee

Dr. Axelrad (ECAS Subcommittee, 1st Vice Chair) presented on behalf of Dr. Frank van Diggelen (ECAS, Chair). The ECAS Subcommittee has one recommendation, which is for the USG to develop and implement a GPS HARS high accuracy and robustness service (HARS) delivered to users on the internet with performance initially comparable to that of other constellations (Slide 7). The service should provide both corrections to support PNT at the < 1 meter level and satellite navigation data bits.



Slide 7

Dr. Parkinson asked where there is an agency that would be accountable for this?

Dr. Axelrad noted on the previous day she talked with Rick Hamilton, and the USCG may be able to facilitate this. There is more background information in the White Paper being developed by the subcommittee. The data would be generated at JPL, and then an agency would be responsible for distributing the data to users. This process needs to be owned by the agency distributing the data.

ADM Allen said that this would probably require legislation, but it doesn't mean the PNTAB should be demurring on this. We need to make sure we get the subcommittee's White Paper.

Discussion:

<The ECAS Subcommittee recommendation was adopted without opposition>

4) International Engagement (IE) Subcommittee

Mr. Higgins (Chair, IE Subcommittee) explained that the subcommittee has been developing fact-sheets, with four down and five more to go. The objective of these fact-sheets is to show how GPS capabilities compare with other GNSS, and what GPS is doing about it. These fact sheets are not intended to be recommendations, but rather part of an overarching finding.

Discussion:

ADM Allen commented that a proposed recommendation could be something along the lines, "in the following areas, this is additional information we need to complete these fact-sheets." The point is to articulate a recommendation on producing fact-sheets that will assist the USG in future decision making. This would essentially put the fact-sheets on the formal record.

Mr. Higgins noted that the IE Subcommittee's plan is to continue developing these fact sheets and present them at the next PNTAB meeting.

Mr. Shields asked whether the PNTAB would have the courage to make a recommendation for the EXCOM to accept that is no longer the Gold Standard in all areas.

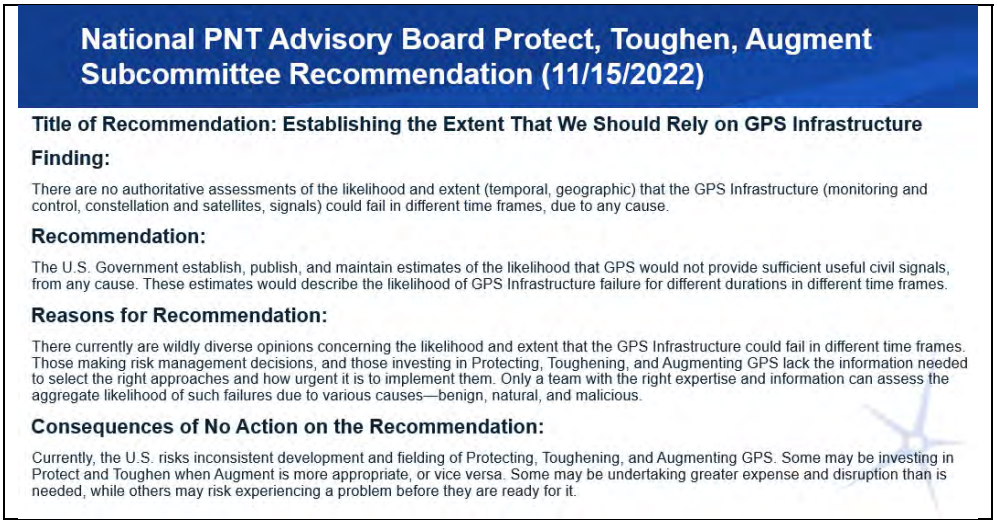
Mr. Higgins noted that the issue about the Gold Standard is one of the seventeen taskings proposed by the PNT EXCOM. Perhaps we could also post these fact-sheets on gps.gov to call attention on the issue.

ADM Allen said we can include a statement that the timesheets are in development.

<The board agreed., without opposition, to this approach >

5) Protect, Toughen, and Augment (PTA) Subcommittee

Mr. Tim Murphy (1st Vice Chair, PTA Subcommittee) presented on behalf of Dr. John Betz (Chair, PTA Subcommittee). The first recommendation (Slide 8) was drafted by Dr. Betz. It calls for the USG to establish, publish, and maintain estimates of the likelihood that GPS would not provide sufficient useful civil signals, from any cause. For example, currently there is no authoritative guidance from the USG on the probability of GPS outages. Such information very helpful for GPS users trying to develop a backup. Today there are many opinions, but no authoritative guidance, on things such as the probability of a Carrington Event[1] taking out all the satellites, an adversary intentionally causing an outage, etc.



Slide 8

Discussion:

ADM Allen noted that a decision-maker could infer there is a need for a National Risk Assessment. This recommendation could become the basis for a policy funding authorization.

Mr. Murphy asked if such assessment makes this recommendation redundant.

ADM Allen said that wouldn't necessarily be the case. The risk assessment would help establish how the USG would issue public warnings.

Ms. Van Dyke noted there is a distinction between issuing a specific warning vs. issuing a probability estimate. A National Risk Assessment would help inform the implementation of this recommendation.

ADM Allen asked the board if there would be any problem to refile this recommendation to include the need for a National Risk Assessment.

Mr. Goward noted that DHS did a National Risk Assessment in 2011, but agreed that it would be helpful to have more eyes on this problem.

Mr. Murphy agreed to reword this recommendation to update the risk assessment. Also, the results should be documented and available as an authoritative reference the public can use.

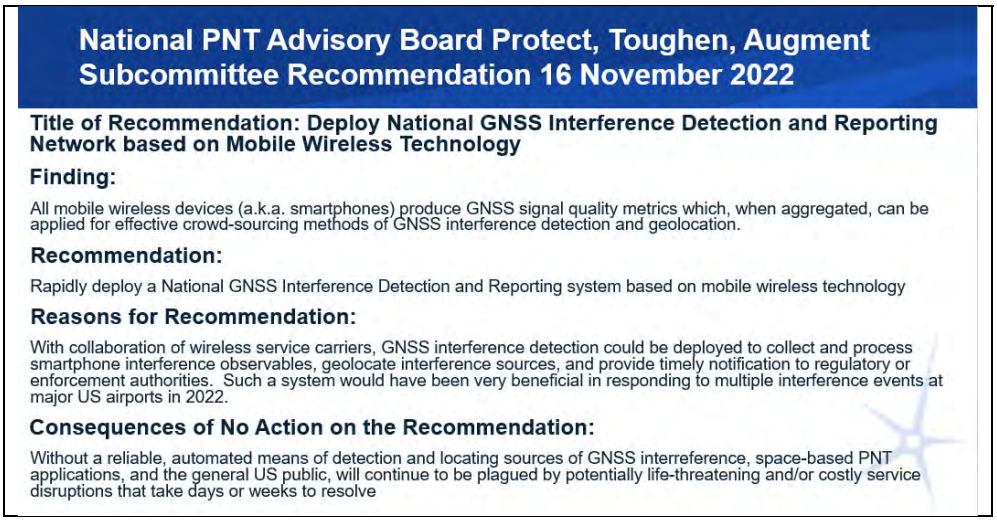
Mr. Goward noted that the 2011 assessment initially was not public, and a Freedom of Information Act (FOIA) request was required for its disclosure. A risk assessment could have classified annexes, etc., but the main document should be publicly available.

<The board agreed., without opposition, to the approach proposed by Adm Allen >

Mr. Murphy noted that the second recommendation (Slide 9) was drafted by Tom Powell, and invited him to present it.

Dr. Powell noted that this recommendation addresses a number of proposals the PTA subcommittee heard during its fact-finding meetings. It calls to rapidly deploy a National GNSS Interference Detection and Reporting system based on mobile wireless technology. We recognize there are a lot of technical details that need to be flushed out, so the board might perhaps want to propose something simpler like developing a prototype. This approach is also synergistic with the interference detection system that DOT is working on.

[1] The Carrington Event is the most intense geomagnetic storm in recorded history, peaking on Sep. 1- 2, 1859.



Slide 9

Discussion:

Dr. Filjar noted he supports this recommendation, and proposed extending the detection system to include not just mobile phones, but also deploying GNSS receivers at the base stations of the communication network. The system could also leverage the proliferation of Io) devices to expand the detection capabilities. Such system could also consider using machine learning format and structure to enable the integration of other intelligent systems relying on this information.

ADM Allen agreed, and noted that maybe there is a two-step process here. First is to have a wide network to detect interference, and second is to use intelligent systems to deal with the problem. We can word this as a first step to an "all source" prototype system. We should include this caveat in the recommendation.

Dr. Powell agreed to provide a revised recommendation.

Mr. Murphy noted that on the previous day, Ms. Karen Van Dyke's briefing mentioned machine learning as part of the ADS-B system.

Ms. Van Dyke said that, yes, there is a company called Data Robot working on this.

Mr. Murphy asked if we should recommend that Data Robot take this as an additional source to their model.

Mr. Van Dyke, it's possible. I support the "all source" approach.

That Allen suggested to incorporate a caveat about machine-learning in the recommendation.

<The board agreed., without opposition, to this approach >

Mr. Burgett said he liked this idea, but as a manufacturer he believes there would need to be some guardrails around this on what constitutes interference or how you would interpret this data, rather than just leaving it up to any particular manufacturer. We should do some extra work on how to categorize these events so that we can report them in a consistent way.

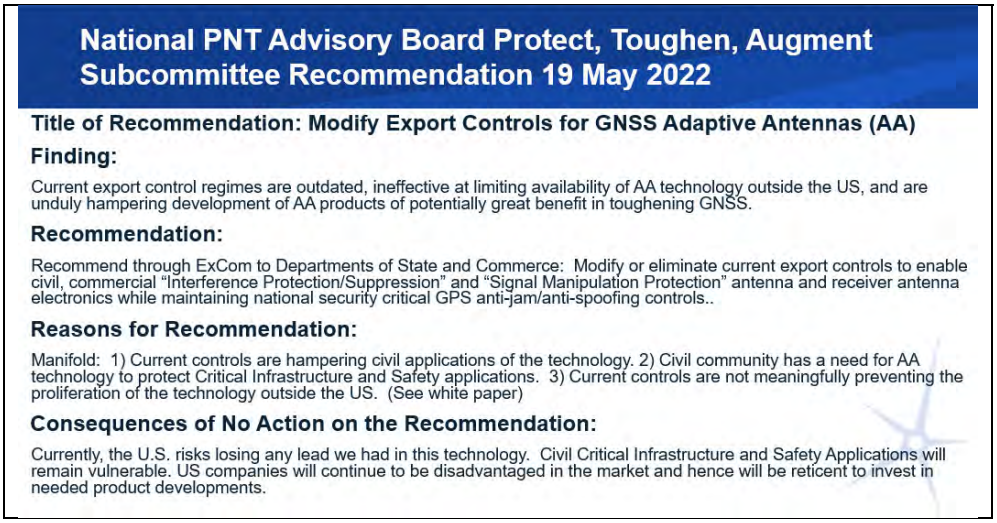
ADM Allen asked Scott to provide the PTA subcommittee with some wording to address this in the recommendation.

Mr. Burgett agreed. He will send an e-mail to Tom Powell.

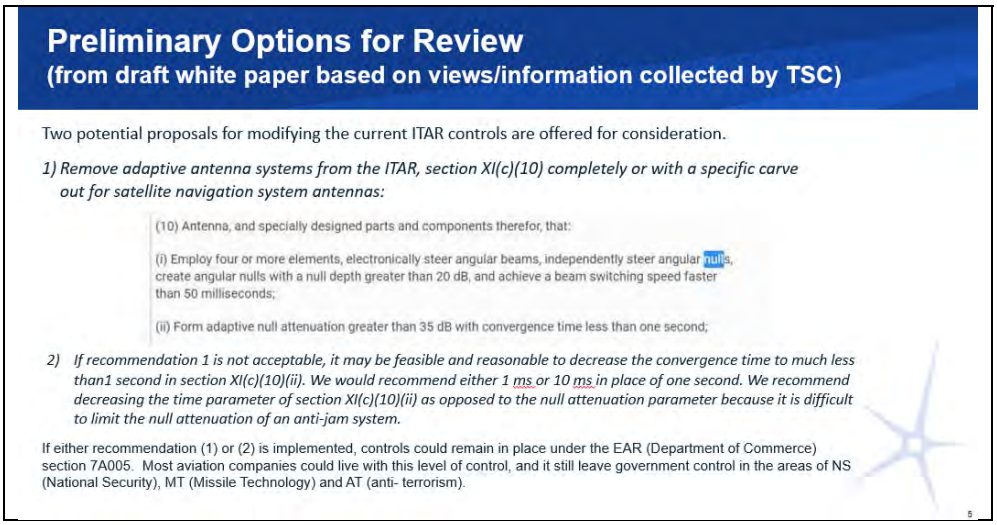
Dr. Parkinson agreed, and noted that we would use the prototype as a process to allow us to explore various alternatives and come up with what will reasonably work, and what will reasonably not work. We are not in a position to decide whether a parameter such as C/N_0 or other something else is the deciding factor, but a prototype would help us explore which approach is most effective.

ADM Allen agreed that the revised recommendation include the adjusted working.

Mr. Murphy then presented the third recommendation (Slide 10). It calls for the PNT EXCOM to recommend to DOS and DOC to modify or eliminate current export controls to enable civil, commercial "Interference Protection/Suppression" and "Signal Manipulation Protection" antenna and receiver antenna electronics while maintaining national security critical GPS anti-jam/anti-spoofing controls. The details for this recommendation will be captured in detail in a White Paper under development. Slide 11 provides some additional detail about the recommendation.



Slide 10



Slide 11

Discussion:

Mr. Shields noted that this is an important recommendation, but it should probably be stripped down to just say that current export control regulations have caused the U.S. industry to fall behind because they've made it uneconomical to do R&D for products geared towards the U.S. civil market.

Mr. Murphy said we also need to emphasize the part about these restrictions having failed to protect the U.S.

Dr. Parkinson noted there is a need to demonstrate U.S. industry has fallen behind while these regulations are no longer effective to protect U.S. military and defense. Perhaps the language can be tightened a bit.

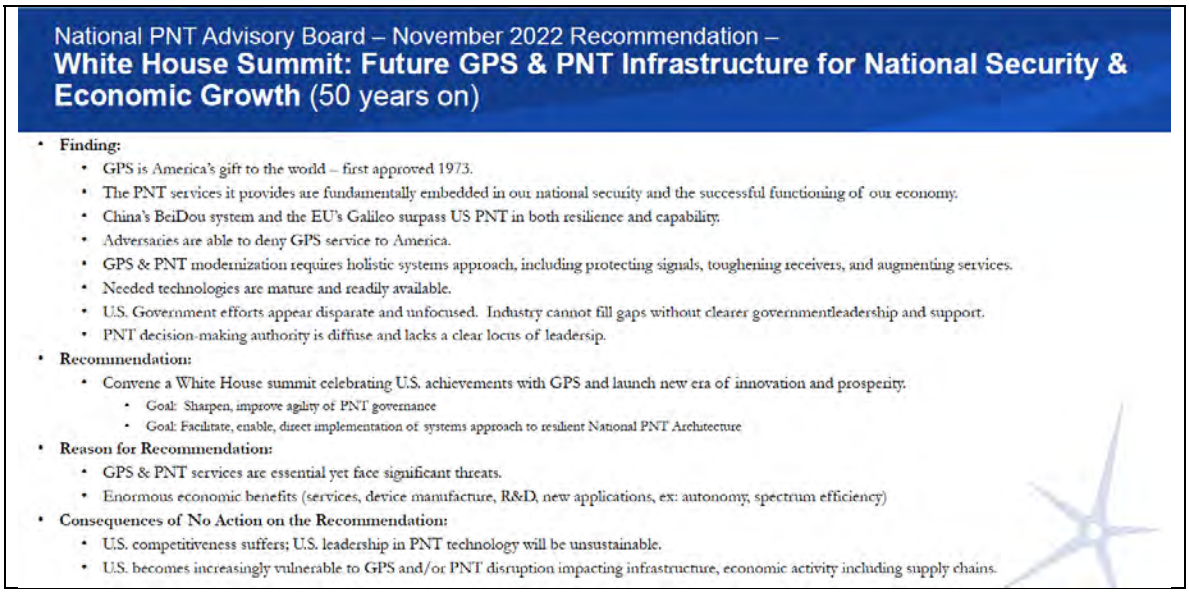
Mr. Murphy to revise the text.

ADM Allen asked Mr. Shields to provide some text back to the subcommittee.

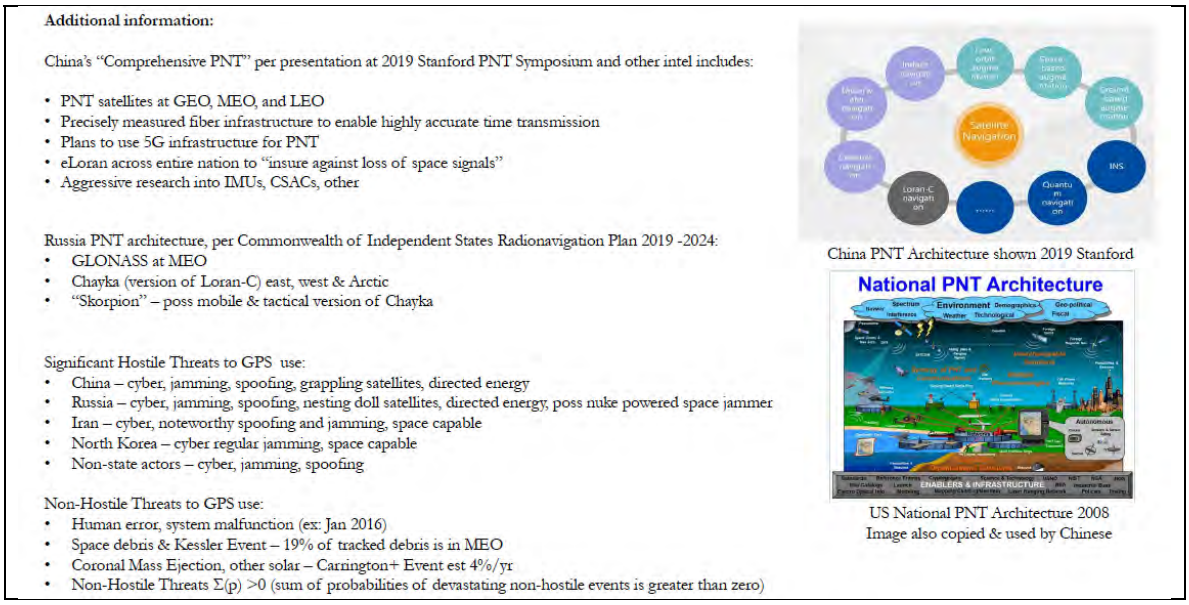
<The board agreed., without opposition, to this approach >

6) Strategy, Policy, and Governance (SPG) Subcommittee

Mr. Shane (Chair, SPG Subcommittee) said that the board needs to provide some context to its recommendations. To that effect, the SPG subcommittee developed a recommendation to convene a White House summit celebrating U.S. achievements with GPS and launch new era of innovation and prosperity (Slide 12). The Executive Office of the President should do a victory lap because it will soon be 50 years since the U.S. approved GPS, a technology that is now driving much of the global economy. The reason for this recommendation is to put the spotlight on GPS so that decision makers can better appreciate how essential GPS has become and its enormous economic benefits. This will help in providing context on what the threats are, and what the administration can do about it. Slide 13 provides supporting information.

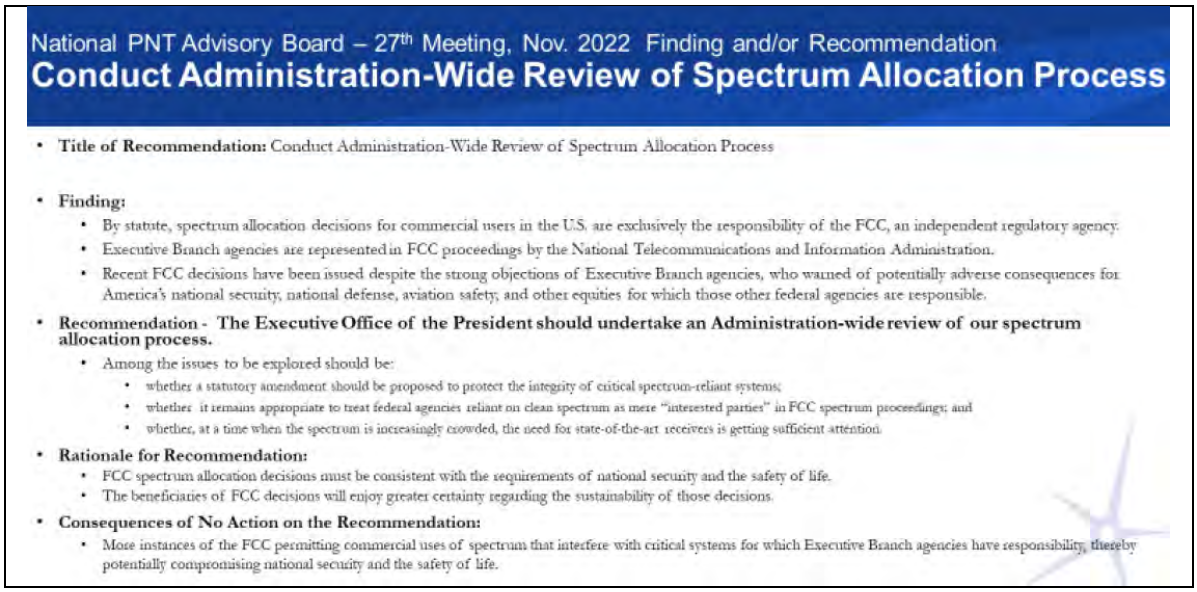


Slide 12



Slide 13

The second recommendation is for the Administration to conduct a wide review of the spectrum allocation process (Slide 14). This is not easy, because it would require amending the legislation there is legislation, and it could very well be a bridge too far. The communications industry is very plugged into to its authorizing and appropriating committees, and it will not be easy to make a dent into this process. However, there ought to be a conversation between the Administration and the FCC about how we avoid disruptions like we've had as a result of the auctions of spectrum and their impact on GPS and aviation. A whole variety of sub-optimal spectrum decisions, that were entirely avoidable, were nevertheless made because of the administrative process through which they do get made.



Slide 14

Finally, Mr. Shane noted that rather than having a pile of recommendations submitted to the PNT EXCOM, it might be better to develop a White Paper with a comprehensive assessment of where we are and that embraces all the recommendations discussed today. This approach would provide an in-depth state-of-play on where we are on PNT, which may be more effective than submitting separate recommendations.

Discussion:

Adm Allen said he thought it would indeed be appropriate to submit a paper, with the recommendations, one year in advance of the 50-year anniversary since the GPS program started (Dec. 17, 1973). This paper would coalesce all these issues into an overarching strategy document that also calls attention to the upcoming anniversary. This is something I could bring up across cabinet secretaries.

Mr. Shane agreed, noting that this approach would intrigue the administration. This is a good opportunity for a GPS victory lap. The administration needs to understand how GPS has become a central utility supporting the nation.

ADM Allen commented that, having worked with both Democrat and Republican administrations, this is something that both sides are likely to endorse.

Mr. Miller noted that Dr. A.J. Oria will put together a summary [Ed. Note: See Appendix D]. There is some duplication amongst the recommendation, so we'll need to condense them a bit. Also, as noted by Mr. Goward, work is already being done covering parts of these recommendations. That's what, for example, DHS would say. He recommended that the PNTAB Leadership Committee develop a memorandum that captures these recommendations, and then send it out to the rest of the board for review and approval. We should turn this out by January 2023, at the latest. Mr. Harold martin could then set up ADM Allen and Dr. Parkinson to present the findings and recommendations at the next PNT EXCOM meeting. Once submitted, then it's up to the government to respond on that.

ADM Allen noted that this discussion is already on the record, and we are ready to synthesize these ideas and proposed a coherent solution.

Mr. Miller added that while the DOS representatives that participated in the PTA subcommittee fact-finding meeting were not present today, Mr. Auerbach (DOS) noted he'll work to have them present at the next PNT EXCOM meeting.

* * *

Wrap-Up

<The board agreed that the next meeting will be held on the week May 1, 2023. The Smithsonian Air and Space at Dulles, Virginia, was proposed as the venue..>

<The meeting was adjourned at 12:00 PM>

* * *

Appendix A: National Space-Based PNT Advisory Board Membership as of the 27th Meeting

Special Government Employees

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

- Thad Allen (Chairman), 38th Commandant, U.S. Coast Guard
- Bradford Parkinson (1st Vice Chair), Stanford University
- James E. Geringer (2nd Vice Chair), Environmental Systems Research Institute (ESRI)
- Penina Axelrad, University of Colorado Boulder
- John Betz, MITRE
- Scott Burgett, Garmin International
- Joseph D. Burns, The Airo Group
- Patrick Diamond, Diamond Consulting
- Dorota A. Grejner-Brzezinska, The Ohio State University
- Michael Hamel, Former Commander, Space and Missile Systems Center
- Larry James, Jet Propulsion Laboratory
- Vahid Madani, GridTology
- Jade Morton, University of Colorado Boulder
- Timothy A. Murphy, The Boeing Company
- Tom Powell, Aerospace Corporation
- Eileen Reilly, Global Train Services
- T. Russell Shields, Former President and CEO, RoadDB
- Gary Thompson, North Carolina Geodetic Survey
- Frank van Diggelen, Google
- Todd Walter, Stanford University
- Gregory D. Winfree, Texas A&M Technology Institute

Representatives:

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

- Renato Filjar, University of Rijeka (Croatia)
- Dana Goward, Resilient Navigation and Timing Foundation
- J. David Grossman, Consumer Technology Association
- Matt Higgins, International GNSS Society (Australia)
- Terry Moore, University of Nottingham (UK)
- Jeffrey N. Shane, International Air Transportation Association (IATA)

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

Appendix B: Sign-In Sheets

27TH PNT ADVISORY BOARD MEETING

SONESTA, REDONDO BEACH, CA

General Session Wednesday – November 16, 2022

	NAME	ORGANIZATION	E-MAIL
1	Andrew Hansen	US DOT	andrew.hansen@dot.gov
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4	VAHID MADANI	Grid Tology	VXMadani@gmail.com
5	Brad Hutton	Hutton Systems	brad.hutton@huttonsystems.com
6	TERRY MOORE	UNIVERSITY OF NOTTINGHAM	terry.moore@nottingham.ac.uk
7	RICK HAMILTON	USCG NAVCEN	STEPHEN.R.HAMILTON@USCG.MIL
8	Jim Burton	NCO	jim.burton@mac.com
9	Michael Stanitz	Aerospace/SSC	Michael.i.stanitz@aero.org
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15	Krzysztof Czaplewski	IAIN / RNTFnd	krzysztof@czaplewski.pl
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27TH PNT ADVISORY BOARD MEETING

SONESTA, REDONDO BEACH, CA

General Session Wednesday – November 16, 2022

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27TH PNT ADVISORY BOARD MEETING

SONESTA, REDONDO BEACH, CA

General Session Wednesday – November 16, 2022

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27TH PNT ADVISORY BOARD MEETING

SONESTA, REDONDO BEACH, CA

General Session Wednesday – November 16, 2022

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27TH PNT ADVISORY BOARD MEETING

SONESTA, REDONDO BEACH, CA

General Session Thursday – November 17, 2022

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General Session Thursday – November 17, 2022

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Appendix C: Acronyms & Definitions

$	U.S. Dollar Currency
2D	Two Dimensional
3D	Three Dimensional
5G	5th Generation Mobile Communications Standard
ABC	Adjacent Band Compatibility
ADM	Admiral
ADS-B	Automatic Dependent Surveillance-Broadcast
AEP	GPS Architecture Evolution Plan
AFB	Air Force Base
AFRL	Air Force Research Lab
AI	Artificial Intelligence
AIS	Automatic Identification System
ALPA	Air Line Pilots Association
ATSC	Advanced Television Systems Committee
B	Billion
BeiDou	China's GNSS
BEIS	UK Department of Business, Energy, and Industrial Strategy
BLUF	Bottom Line Up Front
BOM	Build of Materials
BPS	Broadcast Positioning System
C/A	GPS Coarse Acquisition
C/N_0	Carrier to noise floor ratio
C-SWAP	Size, Weight, Power, and Cost (sometimes referred to as SWAP-C)
CARMEN	Center for Automated Vehicles Research with Multimodal AssurEd Navigation
CER	Communications & External Relations (PNTAB Subcommittee)
CGSIC	Civil GPS Service Interface Committee
cm	Centimeter
COVID-19	Coronavirus Disease 2019
CORS	Continuously Operating Reference Stations
CRPA	Controlled Reception Pattern Antennas
CTA	Consumer Technology Association
dB	decibel
DFO	Designated Federal Officer
DFW	Dallas Fort Worth Airport
DGPS/RTK	Differential GPS / Real-Time Kinematic
DHS	Department of Homeland Security
DIU	Defense Innovation Unit
DOC	Department of Commerce
DoD	Department of Defense
DOE	Department of Energy
DOP	Dilution of Precision
DOS	Department of State
DOT	Department of Transportation
DSAC	Deep Space Atomic Clock
E5	Galileo Aviation Signal
EAR	Export Administration Regulations

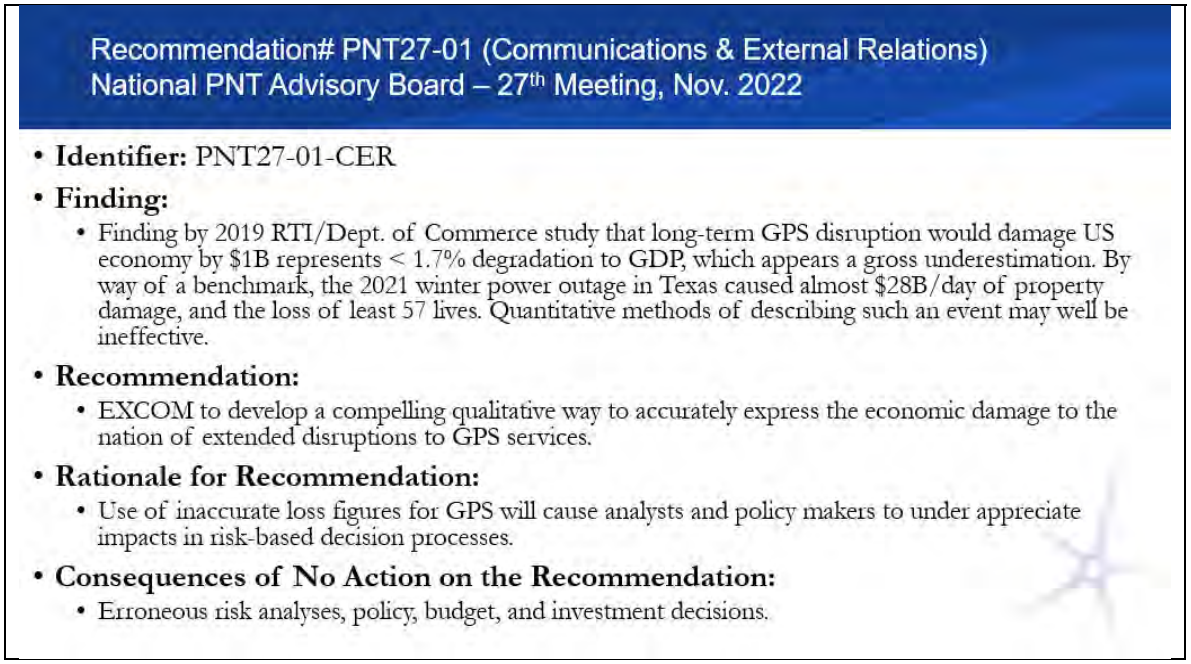
EAS	Emergency Alert System
ECAS	Emerging Capabilities, Applications, & Sectors (PNTAB Subcommittee)
EOP	Executive Office of the President
ESI	Education and Science Innovation Subcommittee
ESI	Education & Science Innovation (PNTAB Subcommittee)
EU	European Union
EUNP	European Union Navigation Plan
EXCOM	National Space-Based PNT Executive Committee
FAA	Federal Aviation Administration
FACA	Federal Advisory Committee Act
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
FRP	Federal Radionavigation Plan
Galileo	European GNSS
GBP	UK Pounds Sterling
GDP	Gross Domestic Product
GDGPS	Global Differential GPS System
GEO	Geosynchronous Orbit
GHz	Gigahertz
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HARS	High Accuracy & Robustness Service
HAS	High Accuracy Service
Hz	Hertz
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICG	International Committee on GNSS
IDM	Interference, Detection and Mitigation
IE	International Engagement (PNTAB Subcommittee)
IEEE	Institute of Electrical and Electronics Engineers
IGNSS	International GNSS (Australia's premier conference on GNSS and related PNT technologies)
IGS	International GNSS Service
IGSO	Inclined Geosynchronous Orbit
IMU	Inertial Measurement Unit
ION	U.S. Institute of Navigation
IoT	Internet of Things
IPR	Intellectual Property
ISM	Industrial, Scientific, and Medical frequency band
IT	Information Technology
ITU	International Telecommunication Union
ITAR	International Traffic in Arms Regulations
JPL	Jet Propulsion Laboratory
K	Thousand
km	kilometer
kW	kilowatt
L1 C/A	1st GPS Civil Signal (C/A = coarse acquisition)
L5	3rd GPS Civil Signal (safety-of-life / aviation)
L-band	Operating frequency range of 1–2 GHz in the radio spectrum

LEO	Low Earth Orbit
LIDAR	Light Detection and Ranging
LORAN	Long-Range Aid to Navigation
LOS	Line-of-Sight
m	meter
MATLAB	Matrix Laboratory
MEO	Medium Earth Orbit
MHz	Megahertz
MIPS	Million Instructions per Second
MGUE	Military GPS User Equipment
MOA	Memorandum of Agreement
NASA	National Aeronautics and Space Administration
NASEM	National Academy of Sciences, Engineering, and Medicine
NAVCEN	USCG Navigation Center
NCO	National Coordination Office for Space-Based PNT (hosted at Dept. of Commerce, Washington, D.C.)
NDAA	National Defense Authorization Act
NOI	Notice of Inquiry
NSB	National Science Board
NSC	National Security Council
NGA	National Geospatial-Intelligence Agency
NGS	National Geodetic Survey
NIST	National Institute of Standards and Technology
NLOS	Non-Line-Of-Sight
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Air Mission
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration
OEM	Original Equipment Manufacturer
OCX	GPS Next Generation Operational Control System
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
PhD	Doctor of Philosophy
PNT	Positioning, Navigation, and Timing
PNTAB	National Space-Based PNT Advisory Board
PPP	Precise Point Positioning
PRN	Pseudorandom Noise [Code Assignment]
PRS	Galileo Publicly Regulated Service
PTA	Protect, Toughen, and Augment, or referring to the PTA Subcommittee
PVT	Position, Velocity, and Time
QZSS	Japan's Quasi Zenith Satellite System
R&D	Research and Development
RF	Radio Frequency
RIN	Royal Institute of Navigation (United Kingdom)
RMP	Regional Military Protection
RNSS	The Radionavigation Satellite Service
RNT	Resilient Navigation and Timing Foundation
RTI	An independent, nonprofit institute that provides research, development, and technical services to government and commercial clients worldwide.

RTK	Real-Time Kinematic
SAR	Search and Rescue
SBAS	Space-Based Augmentation System
SDR	Software Defined Radio
SGE	Special Government Employee
SI	International System of Units
SiS	Signal-in-space
SLS	NASA Space Launch System
SOP	Signals of Opportunity
SouthPAN	Australian Southern Positioning Augmentation Network
SPD-7	Space Policy Directive 7 for U.S. Space-Based PNT
SPG	Strategy, Policy, & Governance (PNTAB Subcommittee)
SouthPAN	Southern Positioning Augmentation Network
SPPI	Strategic Plan for Potential Interference from Ligado
SPPI WG	SPPI Working Group
SSV	Space Service Volume
STEM	Science, Technology, Engineering, and Math
SV	Space Vehicle (formerly referred to as Satellite Vehicles)
SWaP	Size, Weight, and Power
T-CORS	Test CORS
TAI	International Atomic Time
TSO	Technical Standard Order
TV	Television
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
U.S.	United States of America
UAE	United Arab Emirates
UHF	Ultra High Frequency is the ITU designation for radio frequencies in the range between 300 MHz and 3 GHz
USCG	U.S. Coast Guard
USG	U.S. Government
USSF	U.S. Space Force
VHF	Very High Frequency (VHF) is the ITU designation for the range of radio frequency electromagnetic waves from 30 to 300 MHz
VPN	Virtual Private Network
W	Watt
WAAS	Wide Area Augmentation System
WRC	World Radiocommunication Conferences

Appendix D: Summary of Draft Recommendations

1) CER Subcommittee (Slides 1-3)



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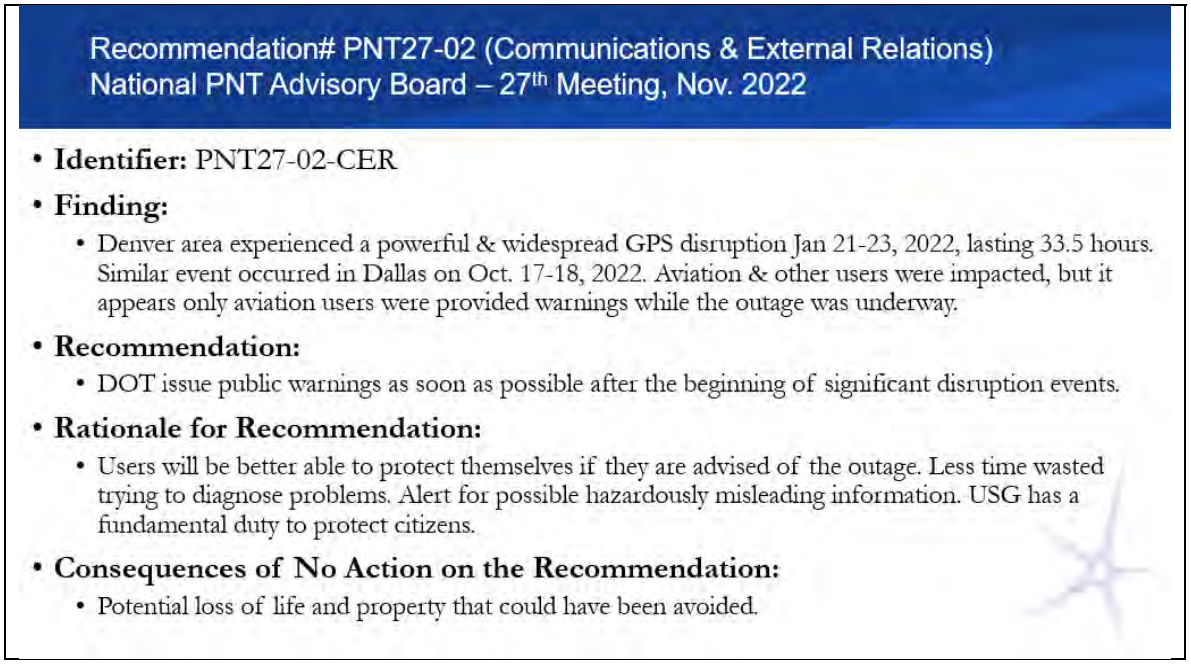

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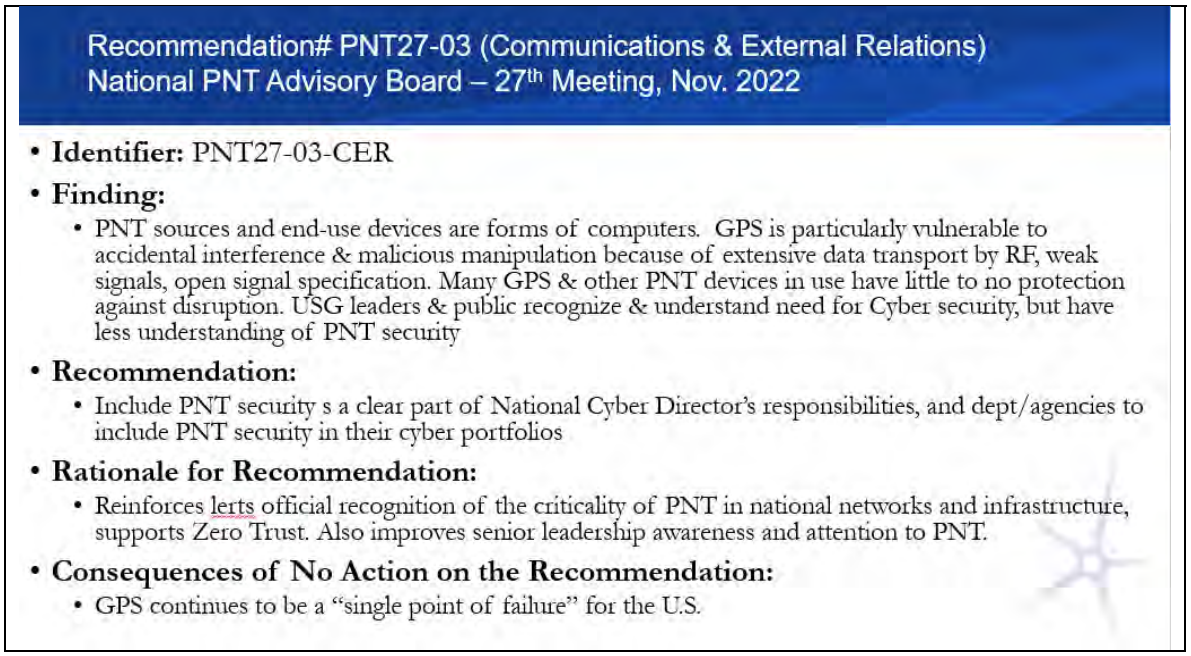
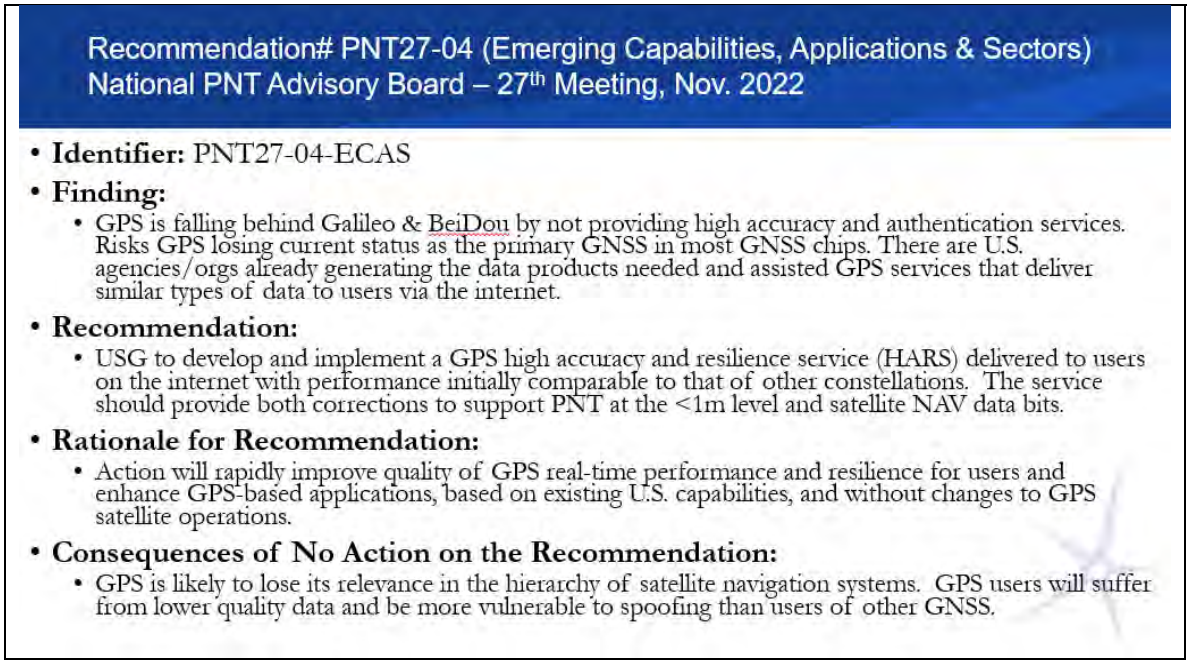


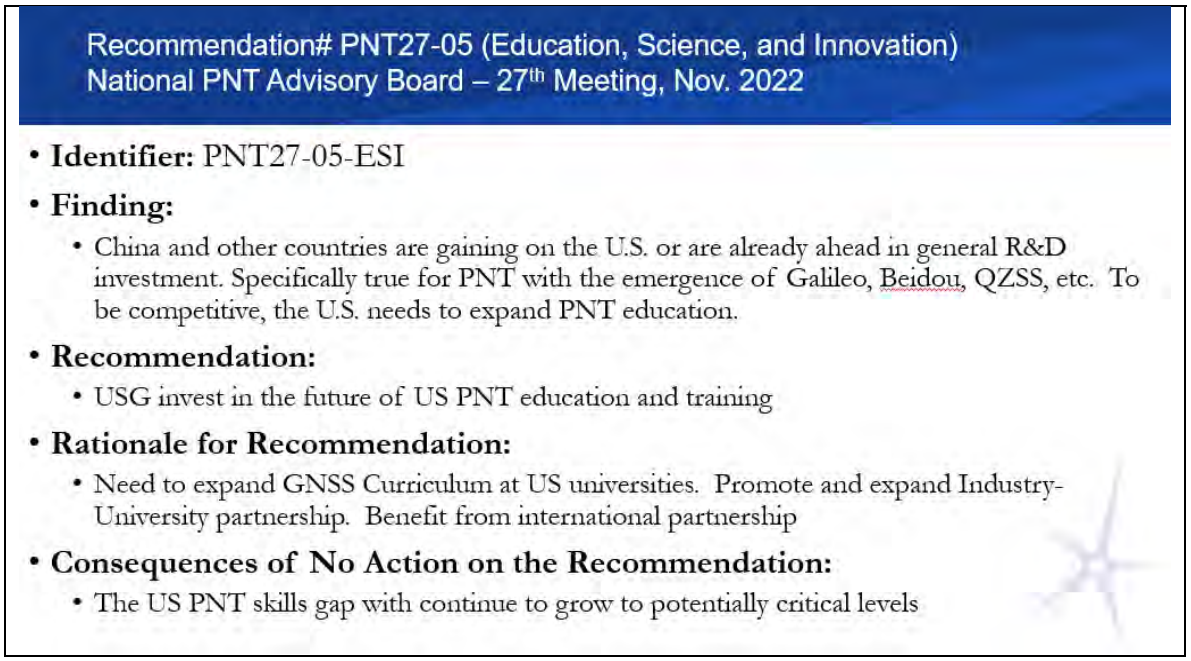
Slide 3

2) ECAS Subcommittee (Slide 4)



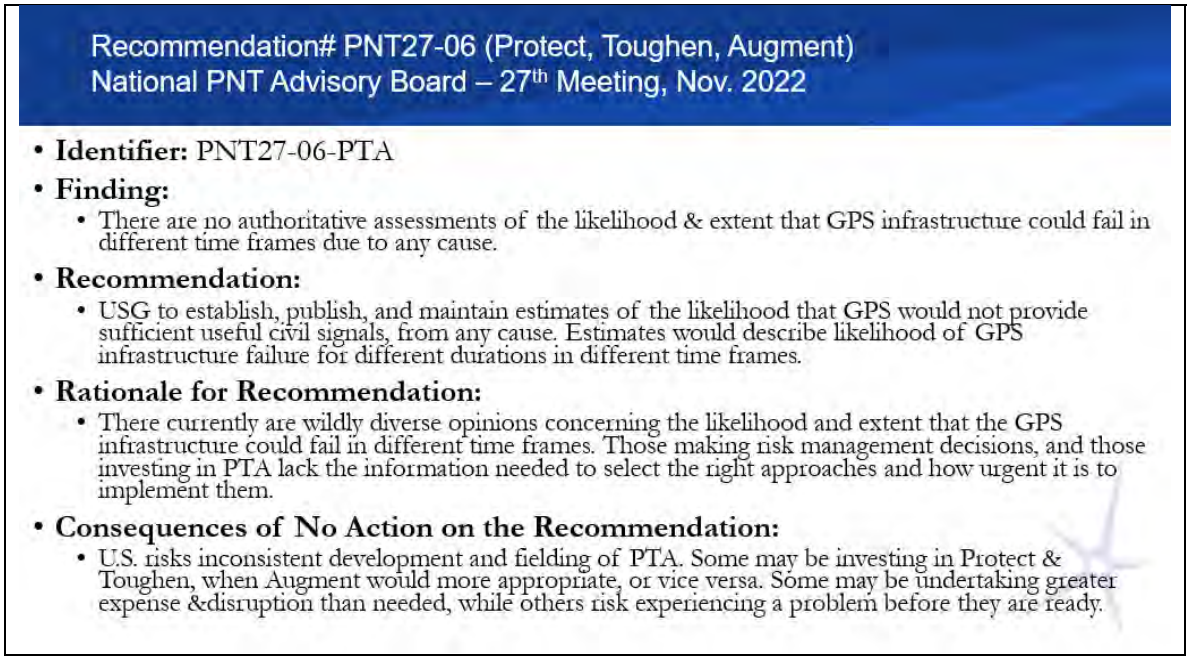
Slide 4

3) ESI Subcommittee (Slide 5)



Slide 5

4) PTA Subcommittee (Slides 6-8)



Slide 6

Recommendation# PNT27-07 (Protect, Toughen, Augment)
National PNT Advisory Board – 27th Meeting, Nov. 2022

- **Identifier:** PNT27-07-PTA
- **Finding:**
  - Mobile wireless devices (a.k.a. smartphones) produce GNSS signal quality metrics which, when aggregated, can be applied for effective crowd-sourcing methods of GNSS interference detection & geolocation.
- **Recommendation:**
  - USG to rapidly deploy a National GNSS Interference Detection and Reporting system based on mobile wireless technology.
- **Rationale for Recommendation:**
  - With collaboration of wireless service carriers, GNSS interference detection could be deployed to collect and process smartphone interference observables, geolocate interference sources, and provide timely notification to regulatory or enforcement authorities. Such a system would have been very beneficial in responding to multiple interference events at major US airports in 2022.
- **Consequences of No Action on the Recommendation:**
  - Without a reliable, automated means of detection and locating sources of GNSS interreference, space-based PNT applications, and the general US public, will continue to be plagued by potentially life-threatening and/or costly service disruptions that take days or weeks to resolve.

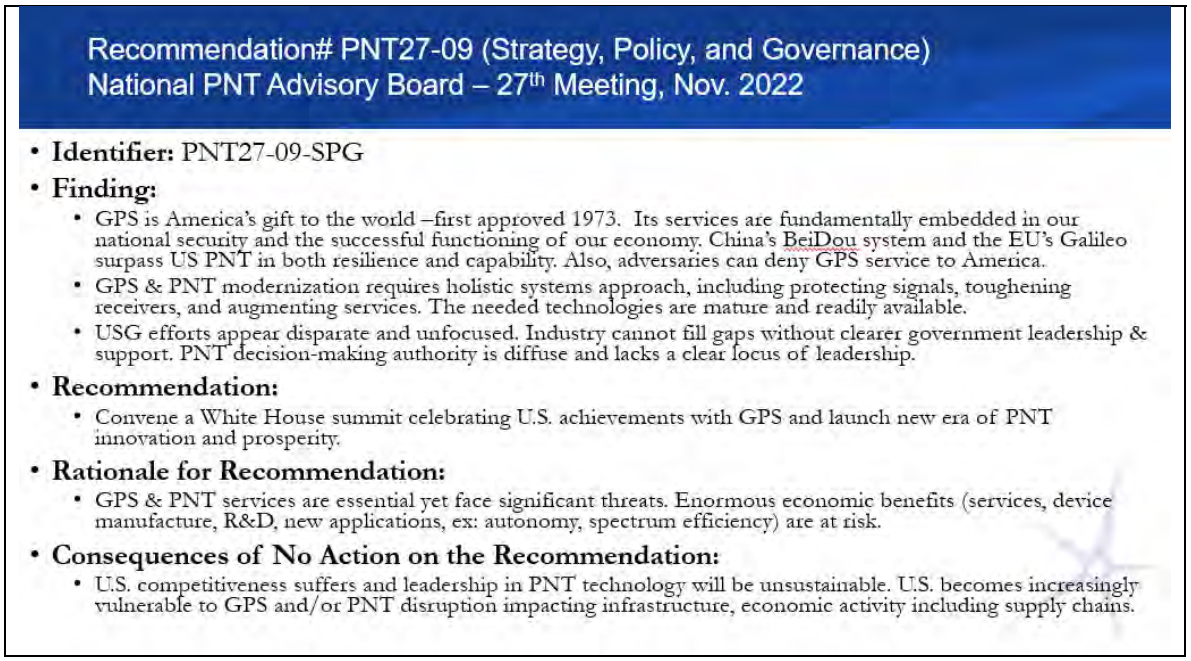
Slide 7

Recommendation# PNT27-08 (Protect, Toughen, Augment)
National PNT Advisory Board – 27th Meeting, Nov. 2022

- **Identifier:** PNT27-08-PTA
- **Finding:**
  - Current export control regimes are outdated, ineffective at limiting availability of Adaptive Antennas (AA) technology outside the US and are unduly hampering development of AA products of potentially great benefit in toughening GNSS.
- **Recommendation:**
  - USG to rapidly deploy a National GNSS Interference Detection and Reporting system based on mobile wireless technology.
- **Rationale for Recommendation:**
  - Current controls are hampering civil applications of the technology. Civil community has a need for AA technology to protect Critical Infrastructure and Safety applications. Current controls are not meaningfully preventing the proliferation of the technology outside the US.
- **Consequences of No Action on the Recommendation:**
  - U.S. risks losing any lead we had in this technology. Civil Critical Infrastructure and Safety Applications will remain vulnerable. US companies will continue to be disadvantaged in the market and hence will be reticent to invest in needed product developments.

Slide 8

5) SPG Subcommittee (Slides 9-10)



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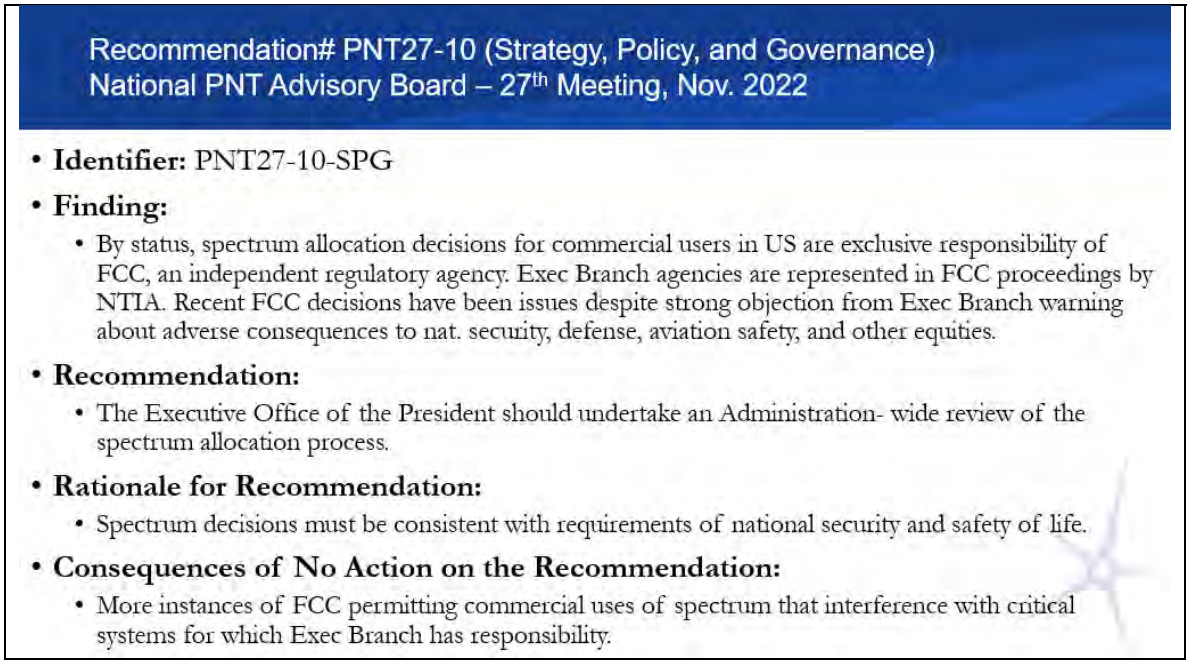

Slide 10

Appendix E: ADM Allen Report to PNT EXCOM Co-Chairs

SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

27 January 2023

MEMORANDUM

FROM: Thad Allen, Admiral (USCG, Ret), Chair, National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board

TO: Honorable Kathleen H. Hicks
Deputy Secretary, Department of Defense
Co-Chair, National Space-Based PNT Executive Committee

Honorable Polly E. Trottenberg
Deputy Secretary, Department of Transportation
Co-Chair, National Space-Based PNT Executive Committee

SUBJECT: Summary Report of the 27th National Space-Based PNT Advisory Board Meeting held 16-17 November 2022

Madam Co-Chairs,

The National Space-Based PNT Advisory Board (PNTAB) held its 27th public meeting November 16-17, 2022, in Redondo Beach, CA. The meeting was held under the provisions of the Federal Advisory Committee Act (FACA) with appropriate public notification and documentation for the public record. This report summarizes the PNTAB's findings and recommendations, provides current lines of effort moving forward, and proposes a national level event later this year to mark the ***50th Anniversary of the 1973 commencement of the Global Positioning System (GPS)*** program.

PNTAB Chair's Bottom Line Up Front (BLUF)

The Board has made significant progress in organizing its efforts around a subcommittee structure that allows a more focused consideration of the many issues affecting civil users of GPS and other evolving Global Navigation Satellite Systems (GNSS) and other PNT "ecosystems." This meeting reflected a shift to a more pragmatic body of work following the challenging COVID-19 pandemic, and the ongoing drama associated with the ill-advised permitting of Ligado Networks by the Federal Communications Commission (FCC). As an advisory body whose membership includes numerous critical infrastructure users, we have made clear our position on this egregious regulatory mistake and its likely adverse consequences for GPS reliability. We are moving on.

Three major themes emerged in our deliberations:

- First, while we will continue to monitor the Ligado issue, it will be in the larger context of national GPS monitoring, disruption, public warning, and risk assessment as discussed below.
- Second, as GNSS/PNT end user devices are now more appropriately viewed as digital computers, not radio receivers, it is time to fully integrate threats to and protection of PNT technology within existing cyber security measures.

- Third, the current state of PNT, and evolving risks to civil use, urgently require a clarification of the role of the federal government, revision of existing response plans and policies, and increased planning to prevent, detect, and mitigate disruptions. This includes a reconsideration of existing export controls for technologies that can mitigate jamming and are already widely available from other countries.

As noted in the Board's discussion, we believe GPS/PNT disruption would be an excellent candidate for a National Level or Senior Leader Exercise.

Summary of Recommendations

The following subcommittees were established at the PNTAB-26 session held 4-5 May 2022 in Annapolis:

- Communications and External Relations (CER)
- Education and Science Innovation (ESI)
- Emerging Capabilities, Applications, and Sectors (ECAS)
- International Engagement (IE)
- Protect, Toughen, and Augment (PTA)
- Strategy, Policy, and Governance (SPG)

At the PNTAB-27 meeting in November, the subcommittees presented results from fact-finding meetings in support of proposed Board recommendations. Those proposals are included in the public record. In addition, proposals to prepare White Papers on specific topics were accepted for development to support the Board's goals and objectives. The recommendations and proposals, tracked by number and subcommittee designation, are as follows:

1. GPS monitoring, disruption, public warning, and risk assessment:

   PNT27-01-CER: EXCOM is urged to develop a compelling, quantitative way to accurately express the economic damages to the nation attributable to extended disruptions to GPS services.

   PNT27-02-CER: The Department of Transportation is urged to issue public warnings to GPS users as soon as possible after the beginning of significant disruption events.

   PNT27-08-PTA: The U.S. Government (USG) should rapidly prototype a National GNSS Interference Detection and Reporting system based on mobile wireless technology. Such a system would have been very beneficial in responding to multiple interference events at major U.S. airports in 2022.

2. Fully integrate threats to and protection of PNT technology within existing cyber security measures:

   PNT27-03-CER: PNT security should be made a prominent part of the National Cyber Director's responsibilities. Departments and agencies should include PNT security in their cyber portfolios.

3. Risks to civil use dictate greater role clarity in the federal government, revision of existing response doctrine, plans, and policies, together with increased planning to prevent, detect, and mitigate disruptions:

   PNT27-04-ECAS: USG to develop and implement a GPS High Accuracy and Robustness Service (HARS) delivered to users via the Internet, with performance initially comparable to that provided by other GNSS such as the European Union's Galileo High Accuracy Service

(Galileo HAS). The service would provide corrections to support better than one-meter position accuracy, while providing cryptographically-protected satellite navigation data bits for integrity monitoring and spoofing resistance.

PNT27-05-ESI: USG to invest in the future of U.S. PNT education and training. There is a definitive shortage of geodesy experts being trained in relation to competitor nations such as China.

PNT27-06-PTA: There currently are wildly diverse opinions concerning the likelihood and extent that the GPS infrastructure could fail to provide useful signals in different time frames. Those making risk management decisions, and those investing in Protect, Toughen, and Augment, lack the information needed to select the appropriate approaches, and how urgent it is to implement them. Therefore, the USG should establish, publish, and maintain estimates of the likelihood that GPS would not provide sufficient useful civil signals, due to failures of the GPS infrastructure (GPS Ground Segment, GPS Space Segment, and GPS user equipment) from any cause.

PNT27-09-SPG: Convene a White House summit to recognize and celebrate U.S. achievements with GPS and to launch an initiative to regain U.S. PNT leadership and ensure resilient, reliable PNT for critical infrastructure and the larger economy. GPS's capabilities are now substantially inferior to those of China's BeiDou.

PNT27-10-SPG: The Executive Office of the President should undertake an Administration-wide review of domestic radio spectrum regulation processes.

White Paper Topics Assigned for Development

These papers are intended to reinforce what should be on-going USG efforts. Board members working on each may be available to assist the government on a fact-finding basis between meetings. As the papers are being developed by volunteers, subject to their availability, I strongly urge you to not delay action on these issues pending receipt of these efforts.

Celebrating GPS 50th Anniversary & Regaining U.S. PNT Leadership: To highlight how essential GPS services have become to the U.S. and the world and to plan for regaining U.S. PNT leadership over the next decade. A White House summit should be convened on or around December 17, 2023, to commemorate the 50th anniversary of the start of the GPS program and to celebrate its achievements and the immense economic benefits to the nation. The outcome of the summit should be a statement of national resolve to regain U.S. global leadership of PNT technology, and a plan to achieve it.

Addressing Shortfalls in PNT Education & Science: To ensure the U.S. maintains its leadership, funding should be increased to enhance PNT Research & Development, including Geodesy, and to strengthen education and training across U.S. academia and research institutions.

Implementing a GPS High Accuracy and Robustness Service: To augment GPS and overcome some inherent limitations of space-based PNT, the USG should provide a service comparable to the European Union's Galileo HAS that provides signal corrections than enable better than one-meter level accuracy, as well as cryptographically-protected satellite navigation message data bits for integrity processing. The U.S. should develop and implement GPS HARS, based on the capabilities developed by the Jet Propulsion Laboratory (JPL) for the Global Differential GPS System (GDGPS), to be made available to users over the Internet.

Modifying U.S. International Traffic in Arms Regulations (ITAR) on GPS Commercial Users: To toughen GPS and enhance user access and reliability, the USG must modify export control regulations that are restricting commercial use of adaptive antijam antenna systems

protecting GNSS receivers. The original intent to mitigate proliferation of this technology has been superseded by development and fielding of this technology by U.S. competitors.

Sincerely,

Adm (USCG, ret.) Thad Allen, Chair, PNTAB

CC:

- Bill Nelson, Administrator, NASA
- Pamela Melroy (USAF, ret.), Deputy Administrator, NASA
- Badri Younes, Deputy Associate Administrator for Space Communications and Navigation, NASA
- James J. Miller, Executive Director, PNTAB, NASA
- John Sherman, Chief Information Officer, DoD
- Fred Moorefield, Deputy Chief Information Officer, DoD
- Robert Hampshire, Deputy Assistant Secretary for Research and Technology, DOT
- Karen Van Dyke, Director, PNT & Spectrum Management, Office of the Assistant Secretary for Research and Technology, DOT
- Chirag Parikh, Executive Secretary, National Space Council
- Harold "Stormy" Martin, Director, PNT National Coordination Office – for distribution to all PNT EXCOM departments and agencies