SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

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

Twenty-Eighth Meeting

May 3-4, 2023

Crowne Plaza

Annapolis, MD

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

Mr. James J. Miller, *Executive Director*

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Agenda

(https://www.gps.gov/governance/advisory/meetings/2023-05/)

Wednesday, May 3, 2023 Day 1 Livestream: https://www.youtube.com/watch?v=pag3HtApkms		
9:00-9:05	**BOARD CONVENES** *Call to Order, Logistics, & Announcements*	Mr. James J. Miller, *Executive Director, National Space-Based PNT Advisory Board, NASA HQ*
9:05-9:30	Welcome & Introductions – Meeting Goals & Objectives (10 min) VIEW PDF PNT Board NASA Sponsor Opening Remarks (15 min)	Dr. Brad Parkinson, *1st Vice Chair, PNTAB,* and Gov. Jim Geringer, *2nd Vice Chair, PNTAB* Mr. Badri Younes, *Deputy Associate Administrator for Space Communications and Navigation, NASA HQ*
9:30-10:00	Celebrating 50 Years of GPS Serving Humanity VIEW PDF	Dr. Brad Parkinson, *1st Vice Chair, PNTAB*
	Theme 1: PNT Policy	
10:00-10:15	PNT EXCOM Policy Update VIEW PDF	Mr. Harold (Stormy) Martin III, *Director, National Coordination Office for Space-Based PNT*
10:15-10:45	Greetings from PNT Executive Steering Group Chairs: Thoughts on PNT Governance – DoD Perspective (15 min) – DOT Perspective (15 min)	Mr. Fred Moorefield, *Deputy Chief Information Officer, DoD* Dr. Robert Hampshire, *Deputy Assistant Secretary for Research and Technology, DOT*
10:45-11:00	**BREAK**	
11:00-12:30	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 / Prof. Terry Moore – Dr. Frank van Diggelen – Mr. Matt Higgins – Dr. John Betz – Hon. Jeff Shane
12:30-1:30	**LUNCH *(Queen Anne Ballroom)***	
	Theme 2: Emerging GNSS Capabilities & Alternative PNT – Synergies with GPS?	
1:30-2:00	China's Strategic Approach to the Leveraging of its BeiDou System – *virtual briefer*	Dr. Sarah Sewall, *Executive Vice President, Strategic Issues, InQTel*
2:00-2:30	Galileo High Accuracy Service (HAS) & Open Service Navigation Authentication (OSNMA) – *virtual briefer* VIEW PDF	Ms. Fiammetta Diani, *Head, Market Development, European Agency for Space Programme (EUSPA), Prague, Czechia*
2:30-3:00	PNT as a Service (PNTaaS) Solution Benefits VIEW PDF	Dr. Alison Brown, *President & CEO, NAVSYS Corporation*
3:00-3:15	**BREAK**	
	Theme 3: Protect, Toughen, and Augment – Ensuring Access to GNSS Services	
3:15-3:45	2023 Space Threat Assessment: Trends in Development, Testing, and Use of Counterspace Weapons VIEW PDF	Ms. Makena Young, *Associate Fellow with the Aerospace Security Project, Center for Strategic and International Studies (CSIS)*
3:45-4:15	Toughening via Reducing Export Restrictions on GNSS Adaptive Antennas VIEW PDF	Mr. Tim Murphy, *Member, PNTAB*
4:15-4:45	DOT System-of-Systems Interference, Detection, and Mitigation VIEW PDF	Mr. James S. Aviles, *DOT OST-R Office of the Assistant Secretary for Research and Technology*
4:45-5:15	Nationwide Integration of Time Resiliency for Operations (NITRO) VIEW PDF	Dr. Laura Callahan, *Special Advisor to Vice Chief, National Guard Bureau*
5:15-5:45	DHS Update: Progress in Toughening & Augmenting PNT in Critical Infrastructure VIEW PDF	Mr. Michael Roskind, *Strategic Defense Initiatives Section Chief, Cybersecurity and Infrastructure Security Agency (CISA)*
5:45-6:00	Key Highlights & Closing Thoughts: – Deliberation Preparation for May 4	All members, led by Dr. Parkinson
6:00	**ADJOURNMENT**	

Thursday, May 4, 2023 Day 2 Livestream: https://www.youtube.com/watch?v=bGoCvOD3fQg		
9:00-9:05	**BOARD CONVENES** *Call to Order*	Mr. James J. Miller, *Executive Director, National Space-Based PNT Advisory Board, NASA HQ*
9:05-9:15	PNTAB Leadership Observations from Day 1 & Member Feedback	Dr. Bradford Parkinson, *1st Vice Chair, PNTAB,* and Gov. Jim Geringer, *2nd Vice Chair, PNTAB*
	Theme 4: Updates from International Members & Representatives	
9:15-10:45	Countries/Associations – Croatia VIEW PDF – Australia – United Kingdom VIEW PDF – Resilient Navigation and Timing (RNT) Foundation – Consumer Technology Association (CTA) – International Air Transport Association (IATA)	Representatives (15 min each) – Dr. Renato Filjar – Mr. Matt Higgins – Prof. Terry Moore – Mr. Dana Goward – Mr. David J. Grossman – Hon. Jeff Shane
10:45-10:55	**BREAK**	
10:55-11:55	Roundtable Discussion – CER Subcommittee VIEW PDF – ESI Subcommittee VIEW PDF – PTA Subcommittee VIEW PDF – SPG Subcommittee VIEW PDF – White Paper - GPS HARS VIEW PDF – White Paper - GPS 50th Anniversary VIEW PDF	Subcommittee Chairs to Present Findings and/or Proposed Recommendations
11:55-12:00	Wrap-Up – Determine date & venue for next meeting	Dr. Bradford Parkinson, *1st Vice Chair, PNTAB,* and Gov. Jim Geringer, *2nd Vice Chair, PNTAB*
12:00-1:00	**LUNCH – Working as needed *(Queen Anne Ballroom)***	
1:00	**ADJOURNMENT**	

Table of Contents

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Executive Summary

The National Space-Based PNT Advisory Board (PNTAB) held its 28th public meeting on May 3-4, 2023, in Annapolis, MD. 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 May 2. Table 1 below summarizes the actions approved during the deliberations held on May 4.

Table 1: Summary of Actions Agreed at PNTAB-28 Meeting

Subcommittee	Action	Status
CER	Reword recommendation to EXCOM PNT27-09-SPG (50th Anniversary of GPS WH Summit) to make it an explicit short-term action for the two EXCOM co-chairs. Reworded recommendation to be named **PNT27-09A-SPG**. The supporting White Paper was also approved.	Approved
CER	New recommendation to EXCOM (**PNT28-01-CER**) calling for EXCOM to provide within 90 days of submission written feedback to recommendations from the board, and for the National Coordination Office (NCO) for Space-based PNT to prepare a list of all the recommendations from the board since its inception in 2007.	Approved
ESI	ESI subcommittee to conduct a PNT Skills, Education, and Training Study to present at the next PNTAB meeting.	Approved
ESI	ESI subcommittee to conduct a Science Innovation Quantum and Artificial Intelligence Review to present at the next PNTAB meeting.	Approved
ECAS	Approval of White Paper supporting recommendation PNT27-04-ECAS (Develop and Implement HARS)	Approved
IE	IE subcommittee to pull all the GNSS factsheets into a White Paper for distribution and comment by the board.	Approved
PTA	New recommendation to EXCOM (**PNT28-02-PTA**) calling to promptly remove any source of interference to GPS.	Approved
SPG	Reword proposed new recommendation, "PNT and Great Power Competition – Resilient PNT Architectures," for discussion at next PNTAB meeting. Dr. Parkinson and Dr. Betz to review/update their comparison between GPS and other GNSS as supporting material.	Approved
SPG	New recommendation to EXCOM (**PNT28-03-SPG**), "Legislation to Reduce Conflict over Spectrum Use."	Approved

This report summarizes the discussions & deliberations during this meeting. Snapshots of the briefings presented have also been embedded. Links to the briefings & livestream recordings are embedded in the meeting agenda (pp 3-4). For a higher resolution version of the briefing slides, see the embedded link in each section (next to the title of the briefing).

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Session of Wednesday, May 3, 2023

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 28th PNTAB meeting.

The last time the Board met was on November 16, 2022, we had the privilege of watching the launch of Artemis 1 and the new Space Launch System, experiencing history together as America's new Moon rocket flew amongst the stars for 25 days and 1.4 million miles.

Today May 3, 2023, reflects another historic time, as we now mark the 50th Anniversary of the start of the Global Positioning System (GPS) program that we all enjoy today. I am very proud to have worked with our Chair Dr. Brad Parkinson for over 20 years, and in a short while he will remind us that the success of such a wonderful utility as GPS, was never a sure thing, even back in the 1970s.

GPS and similar systems have come to serve humanity around the world. However, maintaining such a thing, requires constant diligence and action, and the Board, comprised of our users, is intended to advise the Federal government to help ensure we continue enjoying the benefits it brings to us all.

So, for today's 28th meeting, let's recapture the national pride we get, when America leads with such beneficial programs as Artemis and GPS, and keep them advancing for decades to come, even as we hand the torch to a newer generation. We can do this with the collective effort of the members and government experts we have gathered here today.

Our 28th session will be Chaired by Dr. Parkinson, only because Admiral Thad Allen, has a duty to his family on this important occasion. We also have some members participating virtually, and so I note for our Chair that we do have a quorum to proceed.

On that note, let me also thank our sponsor from NASA, Mr. Badri Younes, our Dept. of Defense (DoD) partner, Mr. Fred Moorefield, and our Dept. of Transportation (DOT) partner, Dr. Robert Hampshire. This program requires the collaboration of many Federal agencies, although we are particularly grateful to the Space Force for considering the new ideas brought forward in forums such as this.

As a reminder, Board deliberations are governed by the Federal Advisory Committee Act, or 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 Dept. of Commerce (DOC) colleague, Mr. Jason Kim.

Board Recommendations are provided as independent advice and council, and the Federal government reserves the right to accept or not the input of this body. It is important to the overall process however, for the Board to receive feedback on what can be supported and what may have to be set aside at a time of fiscal constraint.

As members 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 raise your hand and clearly recuse yourself from that subject matter.

Finally, at if you access GPS.gov or even just Google "PNT Board", you should be able to access the presentations in real-time thanks to Jason Kim at Commerce, which is sometimes easier on the eye. And your Agenda / Bio Booklets will prove to be a helpful guide with our latest charter and key Presidential Policy guidance and responsibilities to the Federal Departments and Agencies highlighted.

* * *

28th PNTAB Welcome & Introduction
Goals & Objectives, Establishment of Six New Subcommittees
Dr. Brad Parkinson, 1st Vice Chair

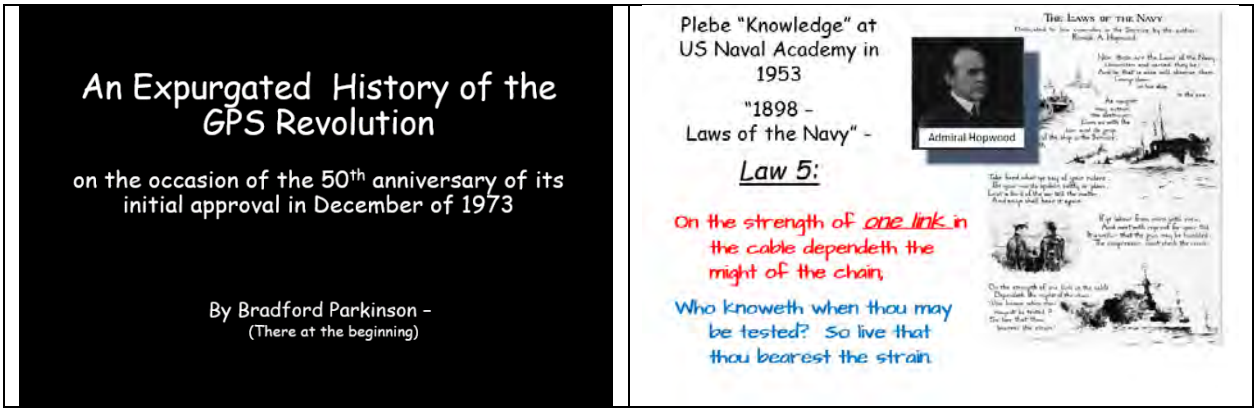
Dr. Parkinson thanked Mr. James. J. Miller for how well these meetings are prepared, and proposed a round of applause to James J. Miller and his whole staff. He then went over the Meeting Agenda, and said he was honored to have Mr. Fred Moorefield, Dr. Dr. Robert Hampshire, and Mr. Badri Younes here today. The objective for today is to come to some conclusions in terms of what recommendations the Board agrees to and what form they should take.

* * *

Celebrating 50 Years of GPS Serving Humanity (View PDF)
Dr. Brad Parkinson, *1st Vice Chair, PNTAB*

Dr. Parkinson thanked everyone for the opportunity to celebrate a successful revolution (Slide 1). Revolutions are very hard. Even when they are intended to be benevolent. As much as anything, the GPS revolution was successful, due to extremely competent people. Dr. Parkinson noted he was very lucky in the beginning to be given the authority to hire, in his opinion, the best officer engineers in the U.S. Air Force (USAF). They were also very fortunate to hire, competent, selfless contractors, and be supported by a marvelous but small cadre of engineers from The Aerospace Corporation. Dr. Parkinson said he would open the discussion with a metaphor.

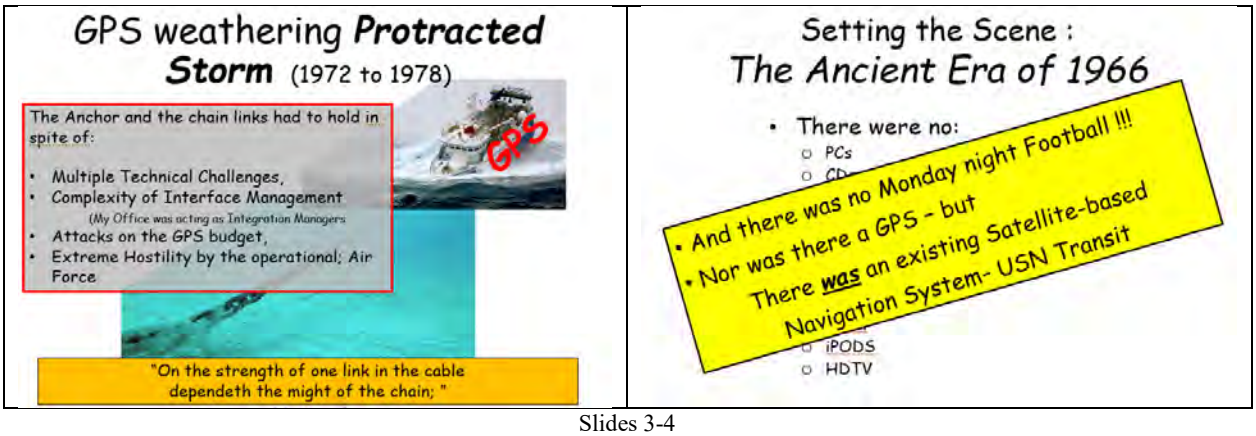
Sixty years ago, Dr. Parkinson was a plebe [freshman] at the U.S. Naval Academy (Slide 2). This was in 1953. Plebes had to learn something called "Plebe Knowledge". This included somewhat nonsensical stuff. If an upper classman wanted a plebe to pass the milk pitcher at a meal table, he would say: "Mr. Parkinson, how is the cow?" Dr. Parkinson said he'd spare the Board the memorized response. But there was also serious wisdom in their rote learning. This introduces the idea of critical links. There was a poem composed by Admiral Ronald Hopwood of the Royal Navy that imparted that wisdom. The verse that applies was law number five: *on the strength of one link in the cable dependeth the might of the chain*. Virtually every link in the GPS development Revolution was critical, and failure of that link would have meant failure of all.



Slides 1-2

So, the metaphor is this: the good ship GPS was beset by gale force winds and waves, attempting to hold our anchor, lest we were blown onto the rocks of a lee shore (Slide 3). He was honored to be the anchor, but without the links our ship would have crashed. They were beset with politics, technical issues, a very complex management problem, budget constraints and (at the time) a very hostile USAF. This cadre of engineering revolutionists were the links for our achievement. Those links were essential. Like many good engineers they are now fading away, but several of them are still around and Dr. Parkinson would call them in the next few charts.

In the "Ancient" era of 1966, there were no PCs, CDs and DVDs, Cell Phones /Text Messaging, Satellite TV, Internet, etc., nor was there GPS, but there was an existing satellite-based navigation system called Transit (Slide 4).

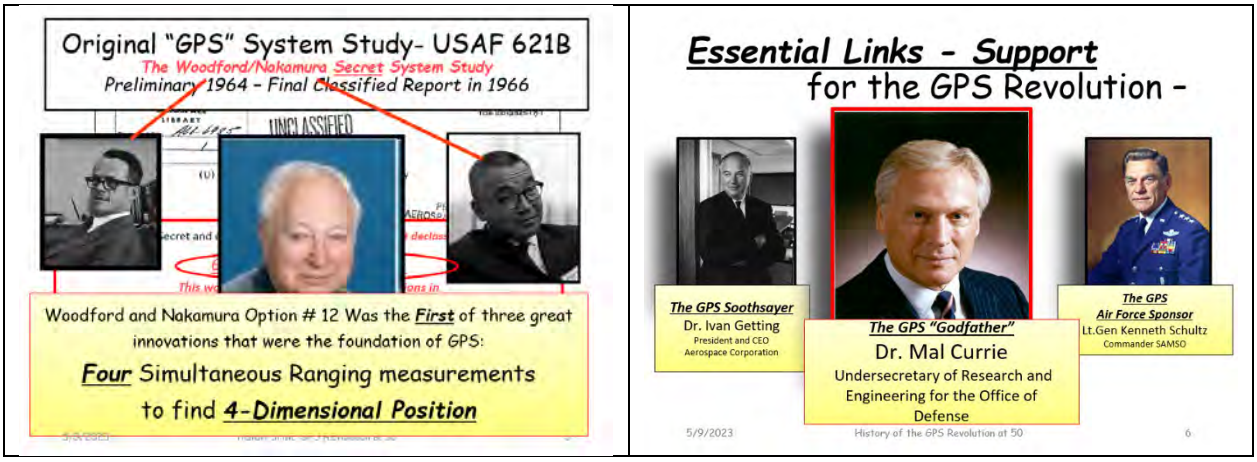


Slides 3-4

The origins of the GPS revolution began in the early 60s, thanks to the energy and efforts of Dr. Ivan Getting, head of The Aerospace Corporation (Slide 5). He felt there had to be a better way to navigate, using space satellites, but did not choose a specific design. At his urging, the U.S. Air Force 621B program commissioned this comprehensive System Engineering Study in 1964. The two wonderful revolutionists and essential links were Systems Engineers Jim Woodford and Hiroshi Nakamura of Aerospace. They

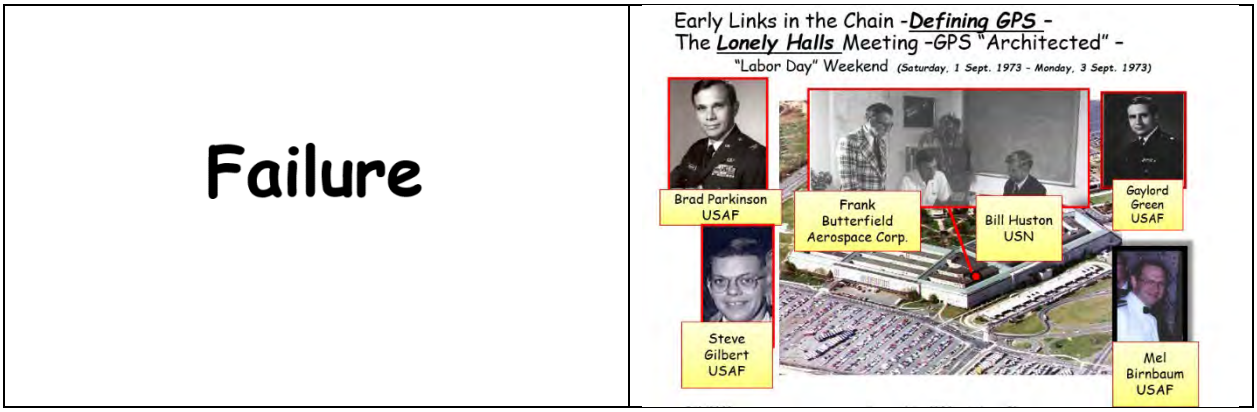
discovered 12 alternative designs, about 58 years ago. This predated some claims by the Navy of invention by at least 4 years, but the study was classified Secret and not declassified until 1979. We ended up selecting as the fundamental GPS design the most complex and difficult technique they discovered. It used four satellite measurements that gave 3D position plus time, and did not require an atomic clock. We tend to call this 4D. This concept was first identified by Woodford and Nakamura. It was the first of the three essential innovations of the GPS revolution.

We have already introduced the first Supporter and essential link (Slide 6). Now he introduced Dr. Ivan Getting (Aerospace Corporation President), which he called the GPS Soothsayer because of his foresight into what was possible. The second key supporter of the GPS revolution is what Dr. Parkinson calls the Air Force sponsor. He was Lieutenant General Kenneth Schultz. In 1972, he selected Dr. Parkinson to head a struggling Advanced Space Program called 621B. He had been a Program Director and understood the extreme pressure and stresses of the position. Dr. Parkinson had a background that seemed hand-tailored to this job -sort of a unique alignment of stars. His main discipline was Guidance and Control. He had been Chief Analyst for Inertial Navigation Systems at Holloman AFB and had taught Space Mechanics to Astronauts at the Air Force Test Pilot School. Because of his combat experience, he had a keen appreciation of the Military value of Precision. General Schultz helped him in every way he could. In particular, he pulled strings to allow him to recruit the best and brightest young Officers he could find – six had PhD's and most of the rest had master's degrees from some good schools like MIT, Michigan, and Purdue, as well as another western school that is near Palo Alto [Stanford]. But above all, GPS needed a godfather within the department of defense, for protection from the budget wars. That Godfather was Dr. Mal Currie, the Undersecretary of Defense for Research and Engineering. He was the third ranking decision maker in the DoD. Dr. Currie believed in what he was doing and protected his infant program from harmful decisions at the Pentagon. His strong support was essential to the success of GPS.



Slides 5-6

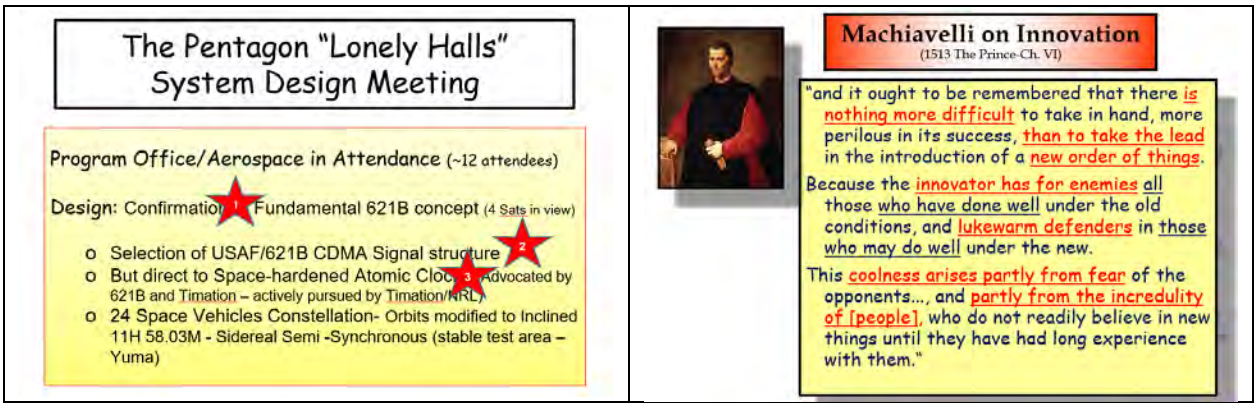
So, back in 1972, he became a revolutionary leader (Slide 7). At that point it was not much of a Revolution. He had inherited a design that he thought could be improved, but they were only asking for a demonstration. By August 1973 he felt ready to formally ask for the budget to build the demonstration. But, at a critical high-level meeting in the Pentagon he failed to gain approval for the design he had inherited. With encouragement from his godfather, Dr. Mal Curry, who chaired the decision, Dr. Parkinson went back to rethink their proposed system. The program was in Los Angeles, but he convened a remote meeting over a long Labor Day Weekend, and they developed an amended proposal. The meeting was held in the "Lonely Halls" of the Pentagon. His purpose was to select a navigation system architecture that combined the best knowledge they had at that time. The only attendees at that meeting were about 12 young officers/engineers from his program office, and two Aerospace Corporation engineers (Slide 8).



Slides 7-8

After three days they came up with a document that redesigned the system. They selected a new signal structure called CDMA (code-division multiple access), decided to go have an on-board atomic clock, and a 24 nominal spacecraft constellation design (Slide 9). It turned out this had a very important advantage as it enabled having 12-hour orbits where, for an initial constellation of four spacecraft, one satellite would fly over Yuma, Arizona, every day allowing us to set a fixed text range. In slide 9, the starts indicate the three main innovations in the revised design.

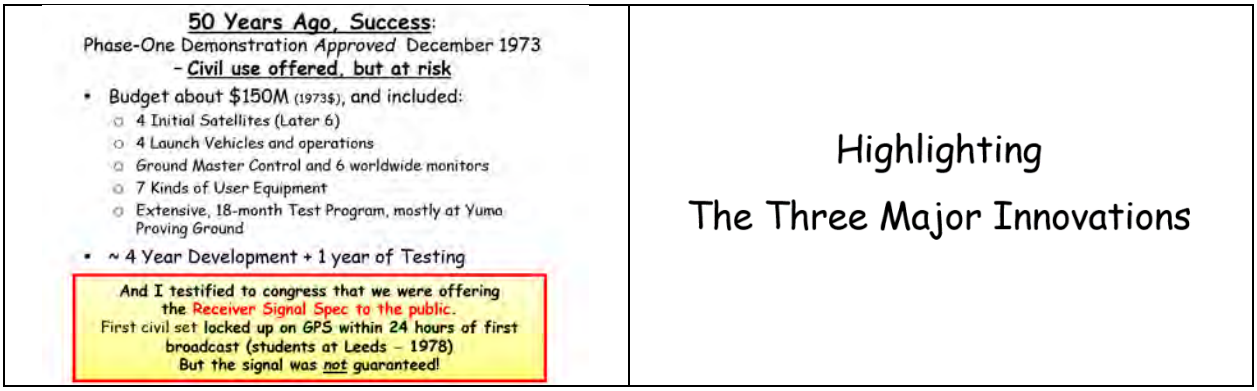
Dr. Parkinson took this and ran it through a difficult process in the Pentagon. Such difficulties aren't new. Introducing anything new, any real innovation, meets the situation described over 500 years ago by Machiavelli (Slide 10). It was indeed both difficult and perilous, but not that unique. Many new things qualify as revolutions. Many encounter the same sort of resistance. Large, complex systems require many contributors for success. Dr. Parkinson regards this anniversary as an occasion to mention a few of those engineers.



Slides 9-10

After many difficult conversations, on Dec. 13, 1973, Dr. Parkinson returned to Defense Systems Acquisition and Research Council and this time was successful (Slide 11). Civil use of this system was offered right from the beginning, but at risk. For budget of about $150M (in 1973 $, which when adjusting inflation comes to $1.025B today), this would include: four initial satellites (later six), four launch vehicles and support, a Ground Master Control station with six monitor stations scattered throughout the world, seven kinds of user equipment, and an extensive 18-month test program (mostly at the Yuma Proving Ground). Dr. Parkinson also said they could do this in four years, including one year of testing. When testifying before congress, he said he would take the receiver signal specification and make it available to the public. Because of this, it turns out the first civil set, by students under Dr. Peter Daly at the University of Leeds, UK, locked on GPS within hours of the first broadcast in 1978.

Next, Dr. Parkinson highlighted the three major innovations in GPS (Slide 12).

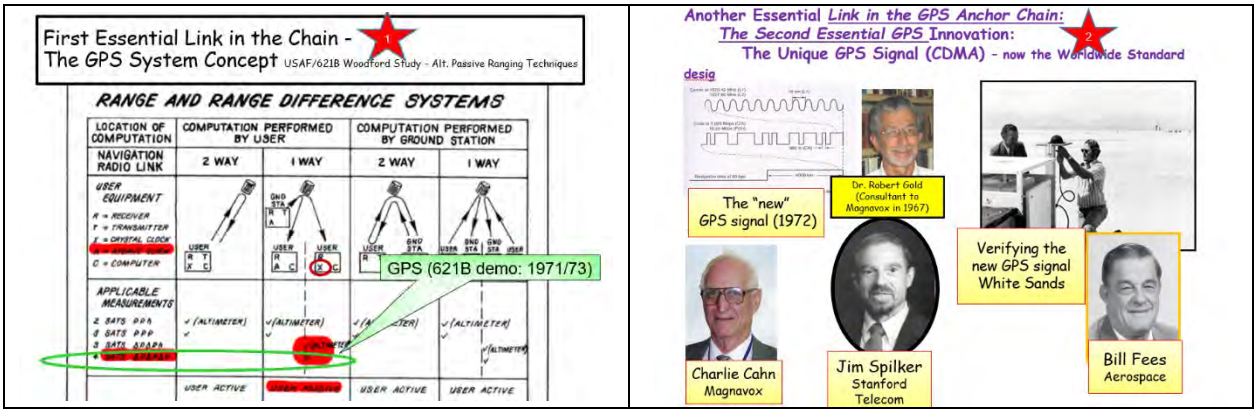


Slides 11-12

The first innovation was getting measurements from four satellites in view (Slide 13). This was essential to enable calculation by the users from one-way signals.

The second innovation was adapting a relatively new signal, called CDMA for ranging (Slide 14). It would allow all satellites to broadcast on the same frequency. Because each satellite was assigned a distinct code, the user could search in the noise background and find that faint signal. It would also enable unprecedented accuracy because the user could reconstruct the underlying carrier wave which had a wavelength of about 10 inches and measure that to a fraction of the wavelength. An applied mathematician, Robert Gold had discovered a way to select the codes, so they all were orthogonal [This is where the term "Gold Code" comes from]. The specific signal structure studies were led Dr. Charlie Cahn of Magnavox and Dr. Jim Spilker, founder of Stanford Telecommunications. But theory wasn't enough. There was substantial skepticism about this signal. Well before the Pentagon

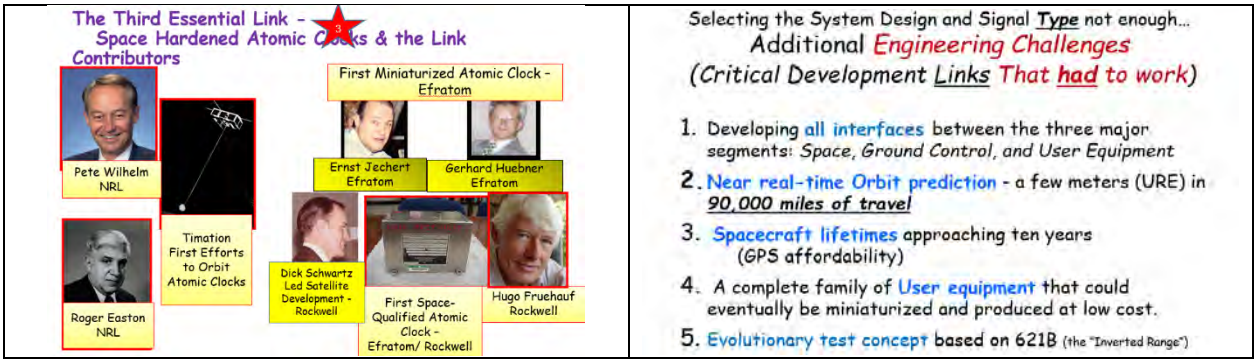
lonely halls meeting, we had set up a hardware test in the New Mexico desert. We put four inverted transmitters, that looked like GPS, out in the desert. We called this the "inverted range." For some technical reasons, this was extremely challenging. This essential link was an aerospace corporation engineer named Bill Fees who led the painstaking 18-month analysis. His results proved that the architecture would give accuracies of 5 meters in three dimensions at the 50th percentile. We had this essential confirmation in time for that Labor Day Weekend meeting. As affirmation of that decision, the GPS signal structure is now the worldwide standard for all the look-alike systems under development in Europe, Russia, and China.



Slides 13-14

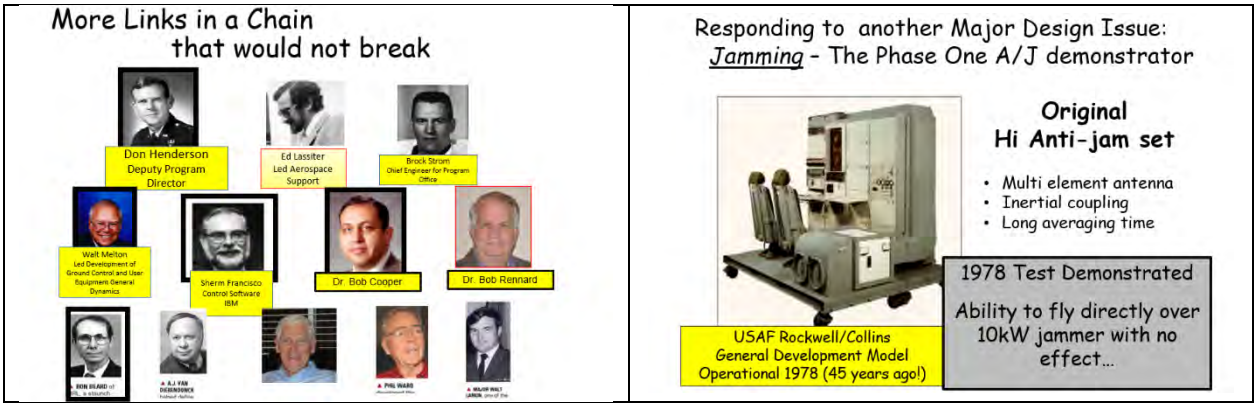
The third innovation technology was space hardening of an atomic clock (Slide 15). The heartbeat of GPS satellites is an atomic clock with a stability of better than one second in 300,000 years. Atomic clocks had been invented several decades before GPS but making them small enough and hardened to the severe space radiation environment was challenging. The first program attempting to do this was the Navy's Timation, led by Roger Easton at the Naval Research Laboratory (NRL). The lead satellite designer was Pete Wilhelm at NRL. While they made the first attempts, their clocks all had early orbital failures and could not be used for our early GPS demonstration. Fortunately, they had contracted Rockwell for a backup. This was derived from another technology development chain and used a miniaturized laboratory atomic clock developed by a company called Efratom. With only 10 lbs weight and 15 W power, this astonishing package was created by Ernst Jechert and Gerhard Huebner. While it was a ground-based device, it led to the development of the first, truly space-qualified, atomic clock. The key space engineer for hardening this clock was Hugo Fruehauf, at Rockwell International. The spacecraft program was led by one of the greatest satellite development leaders Dr. Parkinson has known: Mr. Dick Schwartz. So, these were the three essential innovations, and Dr. Parkinson would next touch on a few of the other challenges.

So, those were big challenges. There were a few other engineering challenges (Slide 16). At the Joint Program Office, we elected to be the integration contractor and developing all the interfaces between the three major segments: Space, Ground Control, and User Equipment. We also had to know in near real-time where the GPS satellites were within a few meters (User Range Error, or URE) after having travelled a distance of 90,000 miles so that we could provide updates. We also had to have a demonstration that the spacecraft would not fail prematurely, because if they did then we couldn't afford the constellation. In the beginning we had satellites that would last 8-9 years. Incidentally, a few years later the Russians tried to replicate this and ran head on into this problem, and ended up with satellites that only lasted a year or two, which resulted in many years until they reached a nominal satellite constellation. GPS satellites are not lasting 20-25 years which, paradoxically, is more than we want them to last because the USAF does not want to launch a new satellite with a new capability while there's still a perfectly good satellite in orbit. We also had to develop a complete family of User equipment that could eventually be miniaturized and produced at low cost. Finally, we took that Yuma test range concept we had on the ground and replicated it so that as each satellite flew overhead we'd turn off one of the transmitters and use the other three, so we'd have four GPS signals available for testing.



Slides 15-16

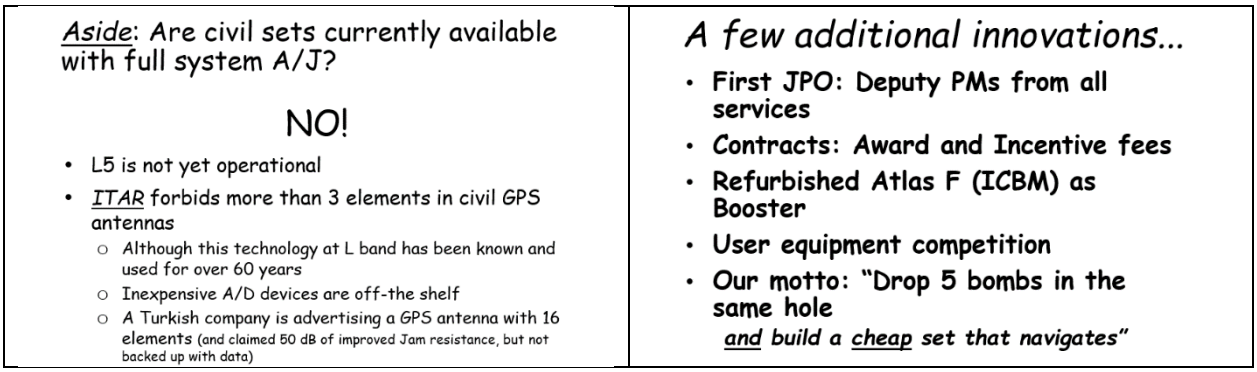
Slide 17 depicts additional key individuals in the development of GPS. Dr. Parkinson noted there is another major design issue he needed to bring up to the Board, which is how to respond to GPS jamming (Slide 18). As GPS was being developed, he knew that sooner or later the weak (a tenth of a millionth of a billionth Watt) GPS signals would be jammed. So, Dr. Parkinson got the avionics lab to put together a high anti-jam demonstrator. To achieve this, it included a multi-element antenna, inertial coupling, and a long averaging time. It was not little, and required two operators, but it demonstrated back in 1978 that we could fly directly over a 10 kW jammer with no effect. Back then it was clear to me that GPS civil users would eventually need to be equipped with this technology.



Slides 17-18

So, are civil sets currently available with full system A/J capabilities (Slide 19)? The answer is no. Also, unfortunately the GPS L5 signal is not yet fully operational. In addition, there are International Traffic in Arms Regulations (ITAR) restrictions in place which limit U.S. commercial user access to more than three elements in civil GPS antennas, even though the application of this technology in L-band frequency has been known and used for over 60 years, its components are inexpensive, off-the-shelf, and already available internationally. In fact, there is a Turkish company already advertising a GPS antenna with 16 elements Mr. Tim Murphy, PNTAB member, will discuss this in more detail later in the day.

There were a few additional innovations in the GPS contract award (Slide 20). It was the first Joint Program Office (JPO) with development across the DoD, and Dr. Parkinson had program managers from all DoD services. The contract used an award and incentive fee structure, which was new at the time. They also initiated a user equipment competition, which back then was almost unheard of. This enabled us to have two contractors to build the user equipment. Dr. Parkinson invented a motto, "*Drop five bombs in the same hole … and build a cheap set that navigates,*" which was on a plaque above the entry to their workspaces.

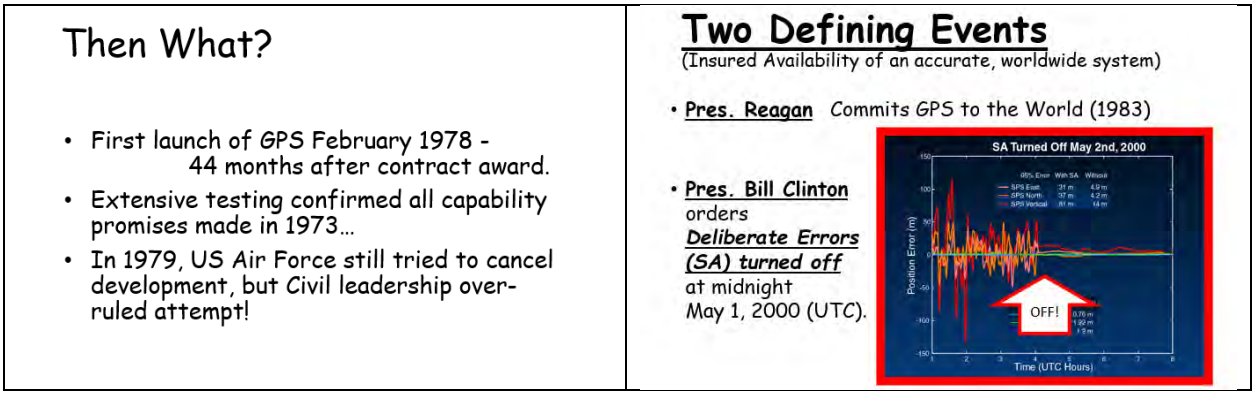


Slides 19-20

So, then what happened (Slide 21)? I had said we could launch in 36 months but was wrong. It took us 44 months, but I'm still very proud of that. The first launch was in February 1978, and the extensive testing we did in Yuma confirmed all the capabilities we had promised in 1973. However, in 1979 the USAF still tried to cancel the whole program, but civilian leadership overruled that attempt.

There were two very important events that enabled the widespread use of GPS (Slide 22). The first was triggered by the Soviet destruction of a Korean airliner on September 1, 1983, over the Sea of Japan. Because this was attributed to a navigation error, President Reagan announced, in September of 1983, that GPS would be made available for worldwide use, free of charge, in order to avoid such problems in the future. When testifying before congress in 1976, Dr. Parkinson made it clear that there would be a widely available civil signal. So, the civil signal had already been known and used by civilians since the first launch, but use at your risk. Reagan's decree was a guarantee of worldwide civil availability. The second real enabler was this: In the early days of GPS, military operators used a technique, called Selective Availability (S/A), for deliberately creating up to 100 m of ranging errors

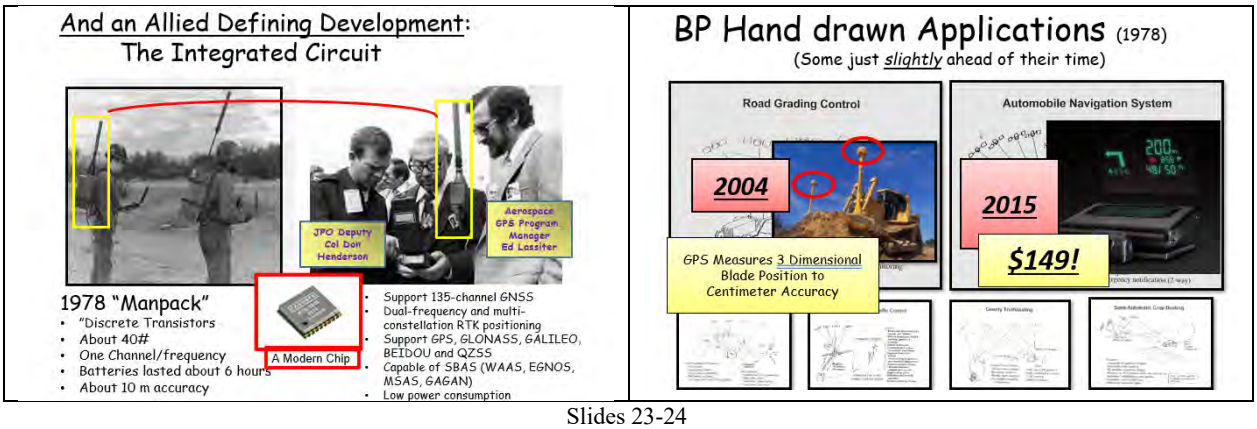
in the signals. Dr. Parkinson developed a presentation that showed the futility of these deliberate, induced errors, but the commander-in-chief of U.S. Space Command, General Myers said he did not have the authority to remove the deliberate errors. President Clinton finally ordered these errors turned off on May 1, 2000. In fact, the current GPS satellite, Block III, has no provision in its design for such perturbations. The figure in the chart shows an actual plot of the errors before and after the key event. Notice that the magnitude of the error was abruptly reduced and that the remaining natural errors changed very slowly, which means that a differential correction would remain valid over many minutes. So, by the year 2000, GPS was guaranteed to the world, with full accuracy.



Slides 21-22

Another important coincidence was the allied development of the integrated circuit (Slide 23). This was just coming along as we were emerging from testing. Slide 23 depicts two versions of the "manpack", which weighed about 40 lbs and gave about 10 m accuracy. Because it only used one channel, it meant it had to sequence around the four GPS satellite signals. In contrast, the modern chip shown here supports 135 channels, dual frequency, and signals from multiple Global Navigation Satellite System (GNSS) constellations and space-based augmentations.

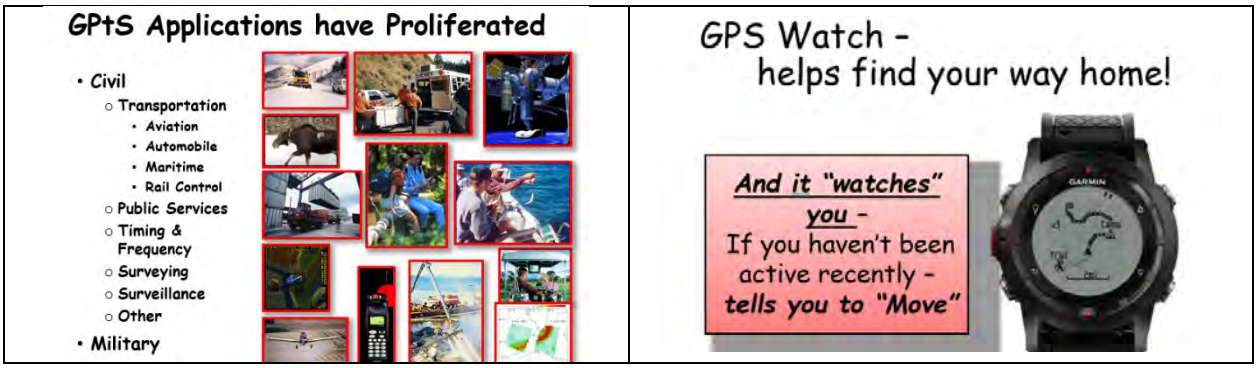
Dr. Parkinson noted he is frequently asked whether he fore sought the myriad of GPS applications that have been developed (Slide 24). The crisp answer is that he saw some, saw others with optimism of further improvements, but missed many. Two things have happened: First, good engineers have discovered how to consistently achieve dynamic differential accuracies of about one inch – 2 ½ centimeters. This is called Real Time Kinematic (RTK), which is used to guide farm tractors. Second, companies like Irwin Jacob's Qualcomm sell the GPS capability in cell phones for about $1, whereas our first sets were about $300K! Thus, both low cost and superb accuracy have driven the wealth of applications. Dr. Parkinson noted he dredged up some of his old drawings of applications from about 1978. He had about a dozen of these that he used to illustrate what GPS capability would eventually do. Two examples where my forecast took a long time coming, include Trimble started selling robotic earth moving equipment in about 2004 (25 years after his prediction), and just last year he found out that Garmin is selling an add on Head Up Display (HUD) product for cars that mimics his chart from 36 years ago. He had hopefully predicted it would cost $1500, but was overly pessimistic.



Slides 23-24

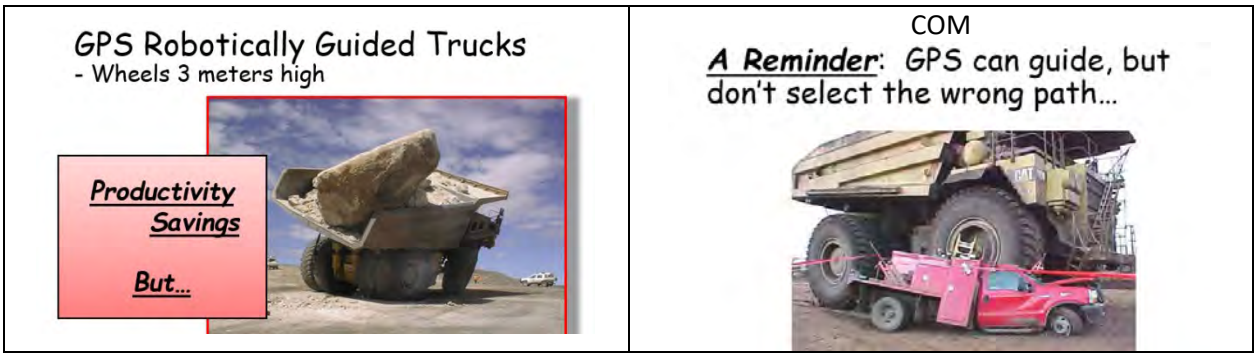
Of course, applications have indeed proliferated (Slide 25), particularly in transportation. But, also hidden away is the dependency of Time and Frequency on GPS. Indeed, GPS is a "Stealth Utility" that is everywhere, in ways that even amaze Dr. Parkinson.

Dr. Parkinson noted he finds his GPS Watch particularly satisfying (Slide 26). This watch measures GPS position, heartbeat, altitude, time, distance and can guide you back to where you started from. In fact, it watches you. If you stand in one place too long, it vibrates and flashes the command "Move" on the face.



Slides 25-26

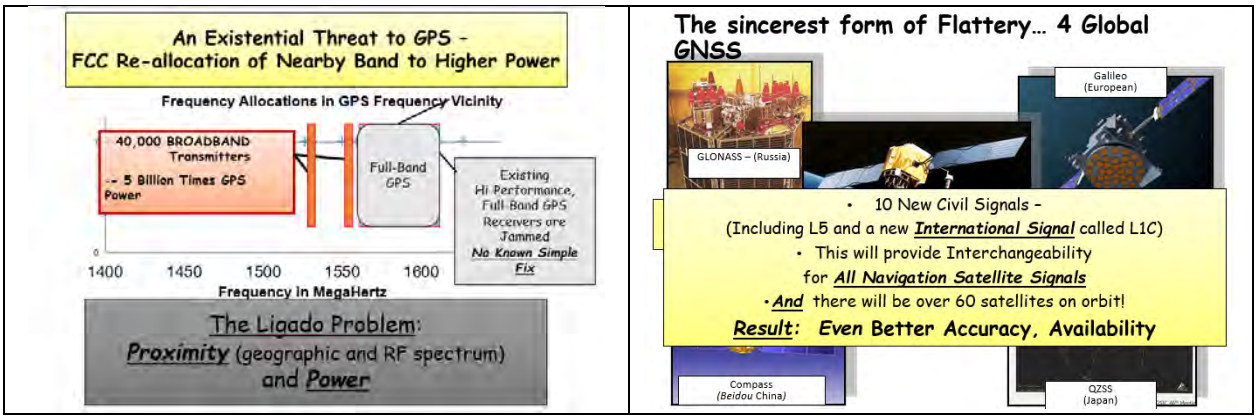
But we also need to be cautious. GPS has been used in deep open pit mines to robotically control huge dump trucks for over 10 years (Slide 27). Note that the wheels are over 10 feet high and there is no human in the cab. The productivity savings in GPS robotically guided trucks are enormous. However, GPS can guide but it is up to the user not to select the wrong path (Slide 28).



Slides 27-28

There are threats to GPS (Slide 29). One is the Federal Communications Commission (FCC) reallocation of frequencies adjacent to GPS from space broadcasts to terrestrial broadcasts. Up to 40,000 terrestrial transmitters at 1500 W each could blanket the U.S. Most affected are highly accurate machine control, aviation, and surveying applications. These applications drive the greatest Productivity gains. The problem is the frequency & geographic proximity coupled with the high power of these transmissions. The DoD has been very helpful in trying to stop this, and it appears that at the moment we are in "neutral" regarding this threat.

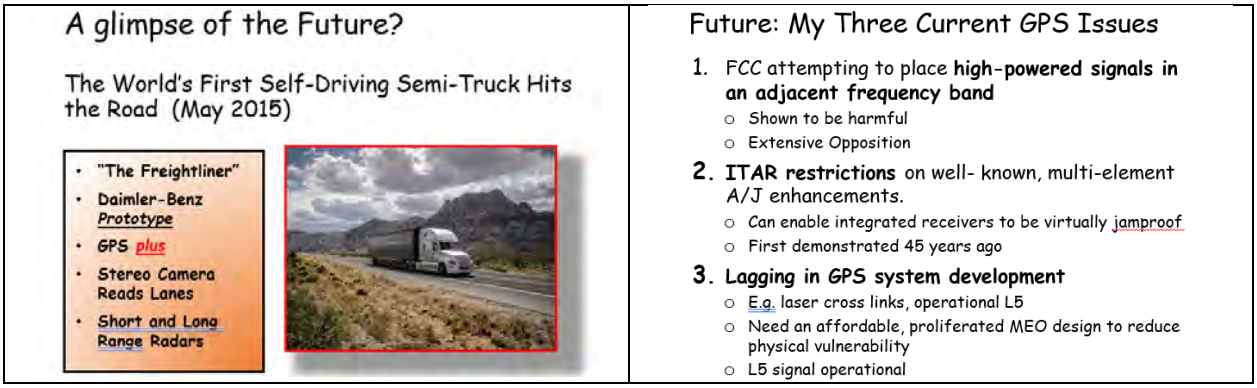
Now, let's switch to the positive future (Slide 30). The number of worldwide PNT systems is going to greatly expand over the next decade. GPS provided the first signal and has been responsible for the applications described earlier, but the Russian GLONASS is rapidly improving. GPS has already begun the trial broadcast of four new civil signals at two new frequencies. GLONASS has now adopted the GPS signal type and will begin broadcasting four new civil signals at two new frequencies. Also, the European system, Galileo, will also broadcast four new civil signals at two new frequencies. The new Qualcomm chips can reportedly receive the signals from all three of these providers. In addition, China is developing BeiDou, and at this time has more operational satellites than GPS. Japan is deploying a regional system called Quasi-Zenith Satellite System (QZSS), and India is also putting one up (NavIC). So, at least 10 new civil signals, including a common international format, will be available soon.



Slides 29-30

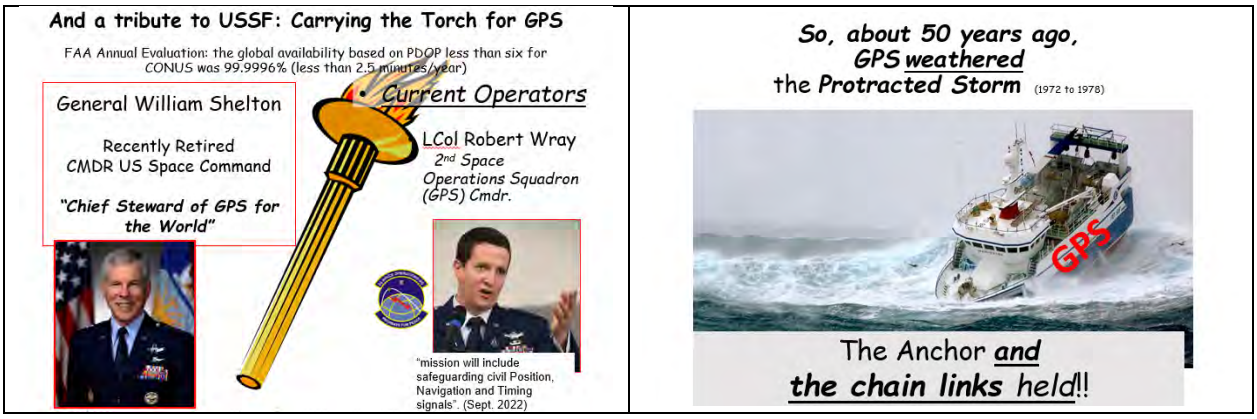
Where is this going? GPS is a strong contributor to self-driving (Slide 31), one of Dr. Parkinson's favorite applications. Daimler-Benz has created a prototype of the world's first self-driving 18-wheel truck. It uses GPS and other sensors to robotically Control the vehicle. The Wall Street Journal had a recent article on a Coors Beer Delivery truck that drove from Fort Collins to Colorado Springs without a driver in either front seat. Potential productivity and safety improvements are quite persuasive, but much work must be done to ensure an airtight design.

Next, let's talk about future GPS issues. These include: (1) FCC note yet rescinding its authorization to place high-powered signals in an adjacent frequency band, which has been shown to be harmful and has extensive opposition among the Executive Branch's departments and agencies; (2) ITAR restrictions on well- known, multi-element A/J enhancements. Without these restrictions, we could enable commercial receivers to be virtually jam-proof; and (3) Remaining the Gold Standard. We seem to be lagging in GPS system development, such as implementing laser cross links, making the L5 frequency fully operational, and implementing a proliferated Medium Earth Orbit (MEO) constellation design to reduce physical vulnerability.



Slides 31-32

Dr. Parkinson noted that, before stepping off, we must also recognize that the USSF has developed and fielded this system both for military use and also for humanity (Slide 33). For 365 days a year and 24 hours a day there is a tiny cadre of seven young Captains, Lieutenants, and airmen who man the GPS consoles at Schriever AFB. They bear the heavy burden of monitoring, uploading, and nurturing the precious GPS resource. Their average age may astound you – it is just 23 years. They are essential links and have compiled a near-perfect record. At the highest level, GPS is under the U.S. Space Command, commanded by a four star General. Dr. Parkinson has personally known every one of those commanders over the last 20 years. They take the Stewardship of GPS very seriously – for both Military and civilian applications. In fact, perhaps the finest example of Chief Steward is General Willie Shelton (in the audience today) recently retired as Commander of U.S. Space Command. Dr. Parkinson wouldn't go into details, but at one point he threw his whole weight and prestige behind stopping a government decision that would have greatly harmed the GPS utility. In conclusion, GPS weathered its storm about 50 years ago thanks to all these links in the chain (Slide 33).



Slides 31-32

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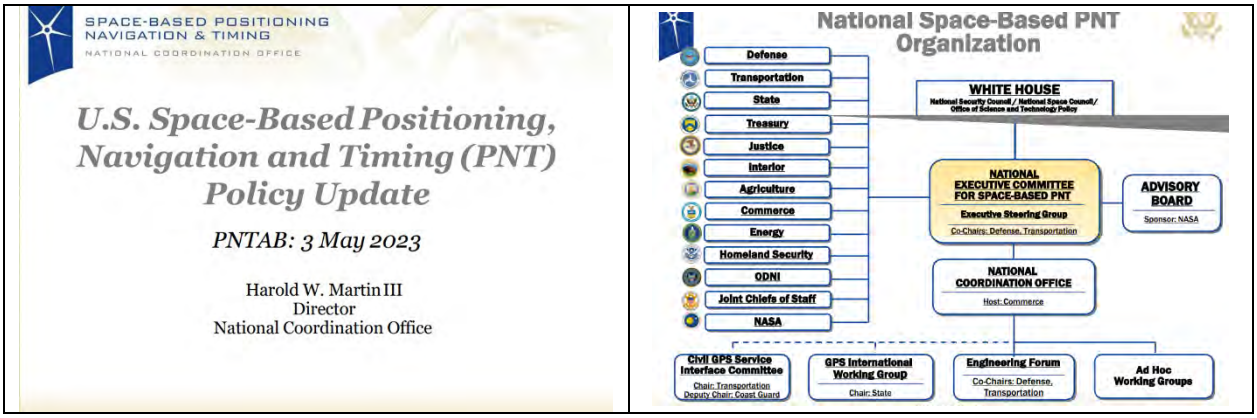
Theme 1: PNT Policy

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

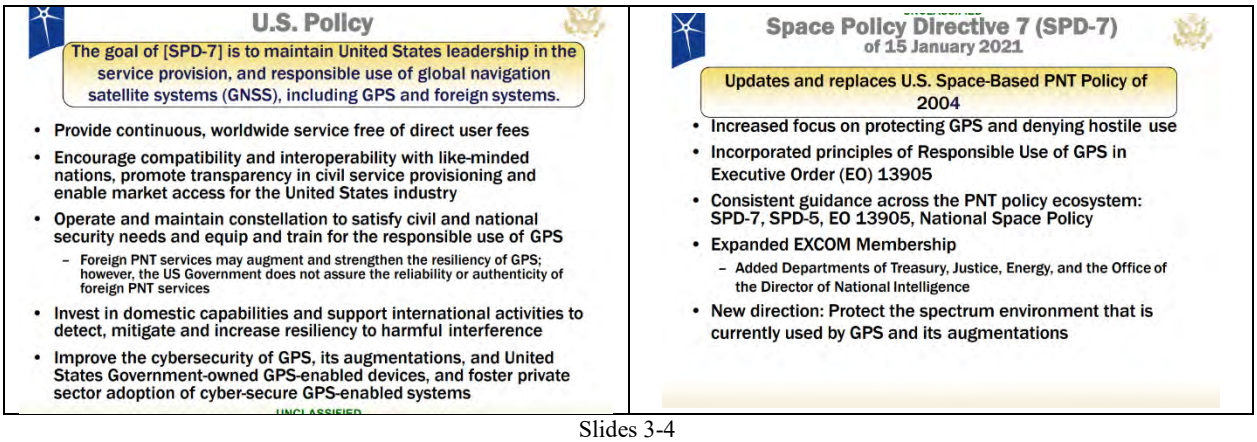
Mr. Martin opened by thanking Dr. Parkinson and the Members of the Board for having him here. It is always an honor to speak to this esteemed group. It is amazing that we are coming up on the 50th anniversary of GPS, and I want to say "thank you" from the federal government to the Members of this Board. All the Members have long and distinguished careers helping make this a reality.



Slides 1-2

The Executive Committee (EXCOM_ is the organization that helps manage PNT related services across the U.S. government. This organization was expanded upon in the Space Policy Directive 7 (SPD-7) and has been around since the 2004 policy. On the left in Slide 2 are department and agencies that are a part of EXCOM. The EXCOM is co-chaired by the Deputy Secretary of Defense and the Deputy Secretary of Transportation, and it has an Executive Steering Group (ESG). Mr. Martin noted that the co-chairs of the ESG will be presenting to the Board shortly. All the representatives from the various agencies on the EXCOM, who are also Mr. Martin's bosses, are all users of GPS and PNT along with their constituents.

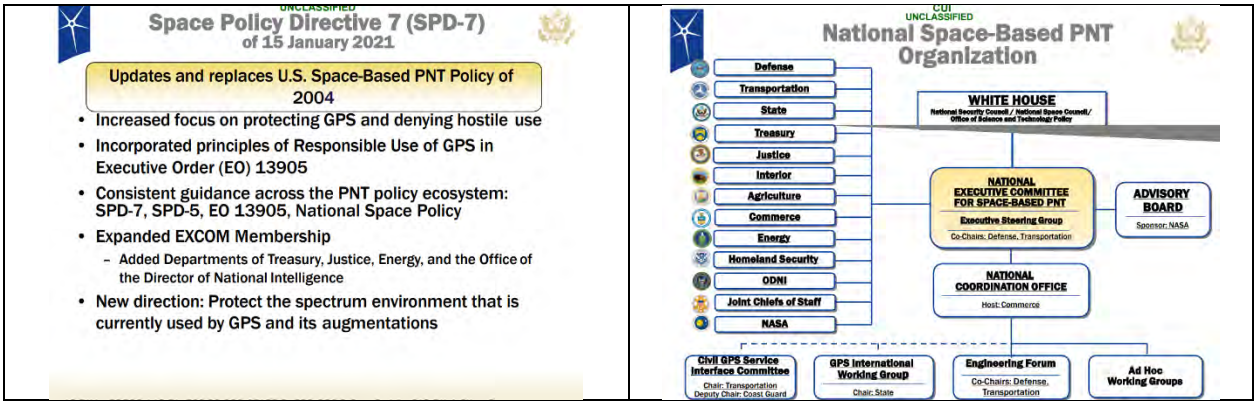
Precision agriculture across the U.S., and critical infrastructure that uses GPS for planes, trains, automobiles, and power is all very important. An integral part of this Space-Based PNT Organization is the Board. We thank you for your work. We thank you for your recent batch of recommendations. The EXCOM is in the process of developing responses to those recommendations. Mr. Martin, once again, thanked the Board for being an integrated part of the overall process.



Slides 3-4

One of the main goals of SPD-7 is to maintain U.S. leadership in GNSS. One of the tasks in SPD-7 is to compare GPS to global navigation systems around the world every four years. The Board has already been doing that comparison and therefore, helping to inform that process. GPS still provides continuous, world-wide service free of direct user fees. There are an estimated 900 million active and operational GPS devices in the U.S., and about 7 billion world-wide. With the increasing number of drones and automated vehicles on land, in the air, on the sea, and in space, intelligent transportation systems, and the Internet of things, I think those estimations will continue to grow. The number of receivers will soon eclipse the number of people on the planet. The Board's help to continue this process will be greatly appreciated.

GPS is the cornerstone of the U.S. PNT system. The full faith and trust of the U.S. government is in GPS. Although the U.S. does not guarantee them, foreign systems can be used with the focus on allied and likeminded systems. The last two bullets of slide 3 review the Board's support via its "protect, toughen, and augment" strategies and recommendations. Mr. Martin noted that later presentations will focus on detecting interference and ITAR regulations relative to anti-jam (A/J) antennas.



Slides 5-6

We have an ecosystem of policies: Executive Order (EO) 13905 covers responsible use of GPS and resilience, and SPD-5 discusses cybersecurity in space. There are commercially owned satellites in orbit that are providing navigation and blossoming ground systems that are providing PNT. SPD-7 expanded the EXCOM to include the Departments of Treasury, Justice, Energy, and the Office of National Intelligence. There is also an emphasis on protecting the spectrum environment that is used by GPS. Mr. Martin stated that at the last Board meeting in November of 2022, he discussed the National Academies of Science, Engineering, and Mathematics' study regarding Ligado's terrestrial system. The EXCOM, Department of Defense, National Telecommunications and Information Administration (NTIA) all released statements supporting this study. Ligado later issued a statement of intent that they were not going to begin their operations in Northern Virginia. As of today (May 3, 2023) that has not changed; there are still no operations going on. At November's meeting, Mr. Martin also mentioned the strategic plan for potential interference and the capabilities that are ready to detect interference, should it occur. The Department of Transportation's modified vehicle and Continuously Operating Reference Station (CORS) stations operated by the DOC are all still ready. The Department of Transportation has also developed new capabilities to better detect interference.

The EXCOM is the interagency body to preserve whole-of-government interests in PNT. Mr. Martin noted that representatives from the Department of Defense, Homeland Security, and Transportation will present later in the day. T hese agencies are working to ensure that national security, homeland security, and civil requirements all receive full and appropriate consideration in the decision-making process. The Vice President of the U.S. chairs the National Space Council (NSpC), and one of their objectives is to revive Science, Technology, Engineering, and Mathematics (STEM) in the U.S. The EXCOM is aiming to do this as well.

Mr. Martin thanked the Board and noted that he always learns something when he attends these meetings.

* * *

Thoughts on PNT Governance
Mr. Fred Moorefield, *Deputy Chief Information Office, Department of Defense*
Dr. Robert Hampshire, *Deputy Assistant Secretary for Research and Technology, Department of Transportation*

Part 1: DoD Perspective
Mr. Fred Moorefield, *Deputy Chief Information Office, Department of Defense*

Mr. Moorefield thanked the Board for inviting him to speak and welcomed General Shelton to the team. Mr. Moorefield noted that Gen. Shelton use to be his boss when the Air Force moved the AF Spectrum Management Office under Space Command. Mr. Moorfield also thanked Dr. Parkinson for sharing his perspective on a half-century of GPS service and its contribution to advances in science and technology around the globe. On behalf of the DoD, Mr. Moorefield acknowledged the exceptional work of this Board in support of the U.S.'s vital national PNT enterprise.

This important work supports the relationship and cooperative spirit between the DoD and our government partners, who work to sustain our national critical infrastructure through the PNT enterprise. Additionally, the participation of our international partners highlights the global nature of PNT services, and their importance to the global community.

When speaking to the Board in December of 2021, Mr. Moorefield highlighted several areas which he felt would be valuable for the Board to consider, and he is pleased to see that the Board is addressing those areas of concern and more. The Board's subcommittees have produced valuable recommendations for actions by the U.S. government for vital areas. These recommendations include:

1. Detecting and responding to the disruption of GPS signals.
2. Incorporating PNT security and national cyber protection portfolios.
3. Addressing shortfalls in education and training of a new generation of geodesy professionals who must manage and improve the underlying physical and spatial reference frames on which PNT technology rests.
4. Responding with functional backup technologies to natural and hostile threats posed to GPS services.

DoD is implementing a department-wide strategy to integrate diverse sources of PNT information along modernized GPS services to provide robust and resilient PNT applications tailored toward individual platforms and military mission needs. These products are specific to military, yet the threats they overcome are similar to those facing many civil and commercial applications, which currently depend primarily on civil GPS services. DoD has articulated their strategy to Congress and is working to obtain the resources necessary to advance both modernized GPS and integration of moldable, multisource, resilient PNT applications. Mr. Moorefield strongly encourages his civil counterparts to follow this example and act on the recommendations by this Board and work with the executive branch offices and oversight committees to ensure adequate resources are made available to strengthen all aspects of our national PNT enterprise.

It is in areas, such as these, where the work of this Board is essential. The tasks that are undertaken by the Board on behalf of the EXCOM and the recommendations the Board provides build awareness of both the value of the PNT enterprise to the Nation, as well as the efforts necessary to sustain its services for the benefit of all citizens.

Mr. Moorefield pivoted towards the Board's recommendation to acknowledge the 50th anniversary of GPS. He noted that most Americans are not aware that this national PNT enterprise, which enables most of the technical wonders we use daily and is largely taken for granted, has evolved overtime from a seed planted 50 years ago with the birth of GPS. We are proud that on April 7, 1973, the Deputy Secretary of Defense, William P. Clemens, signed a memorandum approving the Defense Navigation Satellite Development Program. This became known as NavStar, the beginning to what has become one of the most ubiquitous utilities serving all of mankind today. Most of the members of this Board have contributed to the evolution of GPS and the global PNT enterprise over the decades. Mr. Moorfield acknowledged Dr. Parkinson's role as the first NavStar Program Director, who has continued to contribute his knowledge and experience over time. It is most fitting that this Board recommends that this Administration formally acknowledges the 50th anniversary of GPS so the Nation will be better aware of the enormous contributions that this program has made to our national security, economic and scientific communities, and the daily lives to all of our citizens.

Mr. Moorfield, once again, thanked the Board for the opportunity to provide comments.

Part 2: DOT Perspective
Dr. Robert Hampshire, *Deputy Assistant Secretary for Research and Technology, Department of Transportation*

Dr. Hampshire thanked Dr. Parkinson and the Board for inviting him to speak. He stated that Dr. Parkinson's presentation was fantastic, as we celebrate the 50th anniversary of GPS. DOT is civilian led, but partners with agencies such as DoD to ensure that sources of PNT are accurate and reliable. GPS also plays an enormous role in aviation, which Dr. Parkinson mentioned in his speech earlier in the day. Dr. Hampshire also stated that, although he is not present at this meeting, he appreciates Adm. Allen's leadership of this Board, and he thanked the subcommittees for their recommendations.

Deputy Secretary of Transportation Polly Trottenberg greatly appreciates the efforts of the Board and the recommendation. DOT is currently working with the EXCOM to provide formal responses to the recommendations. These recommendations are important

to DOT both internally and externally. DOT and DoD's Deputy Secretaries are co-chairs of the EXCOM, and through this EXCOM, DOT is working with other agencies to put together responses to the recommendations. Dr. Hampshire stated that the Board will receive those responses soon.

Dr. Hampshire agreed with the recommendation stating the need for automated GPS interference detection capabilities. DOT has been working to set up this capability through a partnership with the Defense Innovation Unit. Mr. James Aviles will discuss this in further detail later.

DOT also embraces toughening GPS receivers particularly through the removal of the ITAR restrictions. Dr. Hampshire stated that he sees a way forward with this through interagency conversation. DOT also supports complementary PNT technologies, particularly regarding resilience, toughening, and augmentation. DOT is currently implementing the Bipartisan Infrastructure Law, which invests in the Nation's infrastructure. PNT is key infrastructure.

DOT's mission primarily focuses on safety, which PNT is also critically linked to. Last year, 43,000 people died in car accident. If you look to your left and right, it is likely that one of those people has lost someone in a fatal car crash. PNT is a critical enabler of safety, and the new technologies that come online via connected and automated vehicles will have PNT at their heart. This fits into what the Board has been working on regarding assured PNT.

DOT has recently funded two university transportation centers around assured PNT: (1) The Center for Automated Vehicle Research with Multimodal Assured Navigation, which is led by The Ohio State University, and (2) A new center for Assured and Resilient Navigation, and Advanced Transportation Systems that is led by Illinois Institute of Technology. These two new PNT university partnerships underscores the need for cybersecurity and the level of trust that we put into our PNT solutions, particularly in critical transportation missions.

As GPS advanced over the course of 50 years, threats to the system have also increased. Critical infrastructure sectors, such as communications, banking, agriculture, and transportation rely on accurate, reliable PNT. Last summer, DOT held an industry roundtable to bring together technology vendors and critical infrastructure operators to build towards adoption of complementary services. Since then, DOT has made good progress toward their action plan for complementary PNT, which includes the implementation of field test ranges at federal, vendor, and critical infrastructure facilities. Other significant activities include vulnerability testing and assessment, standards development, and performance monitoring.

Dr. Hampshire thanked Dr. Parkinson, again, for his presentation. GPS has come a long way in 50 years, and DOT will fully support a celebration later this year.

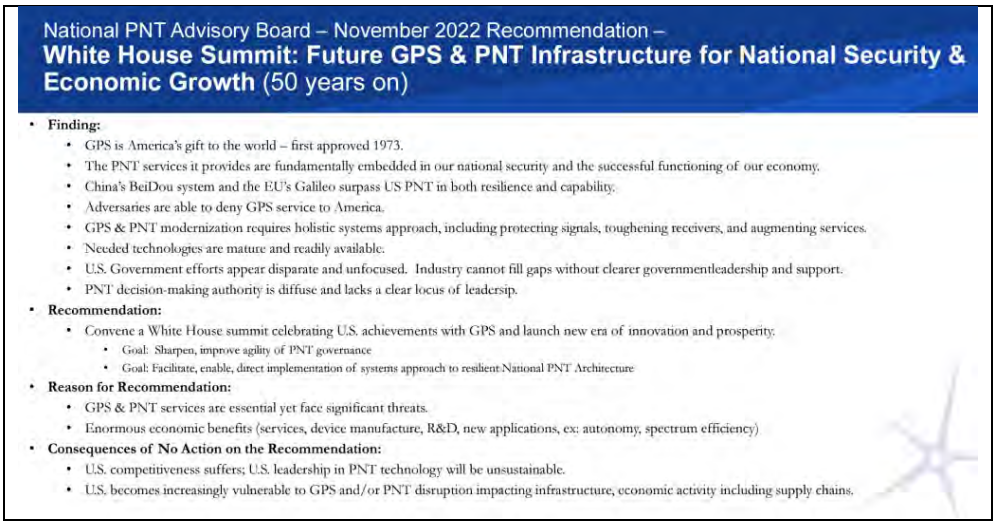
* * *

Subcommittee Updates: Topics & Priorities

1) Communications and External Relations Subcommittee (VIEW PDF): Mr. Dana Goward

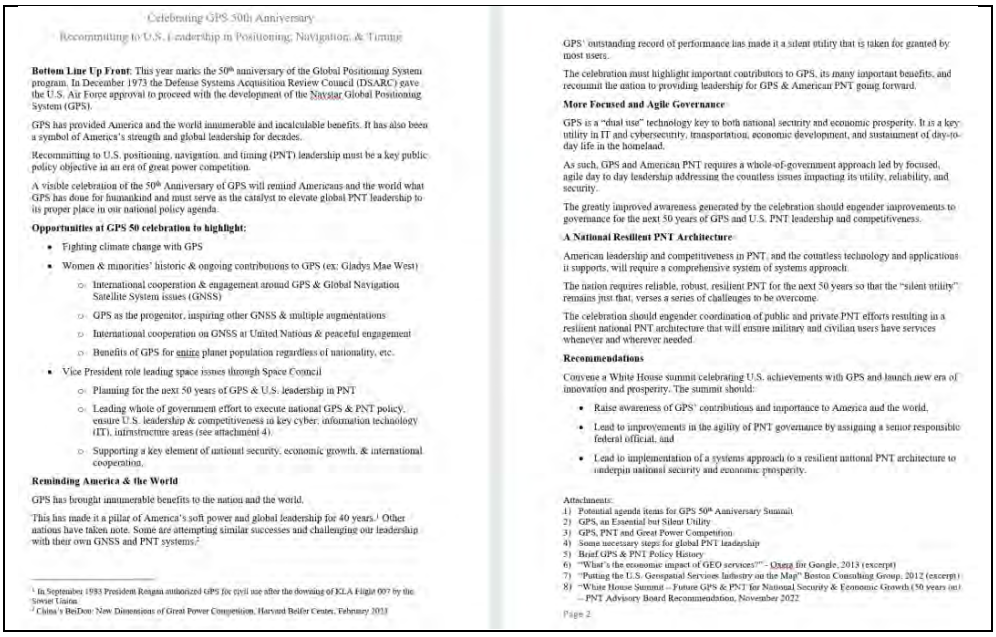
Mr. Goward introduced himself and the CER subcommittee members (Slide 1). He noted that at the last Board meeting, this subcommittee but forth a significant recommendation regarding a White House Summit celebrating the 50th anniversary of GPS (Slide 2). This led to a mandate for a White Paper to expand upon the recommendation. The purpose of this celebration is to not only raise awareness about the greatness of GPS and PNT, but to also assist the government lead towards more focused and agile governance and, eventually, a national resilient PNT architecture. The process of drafting of the White Paper included an abundance of information, which reminded Mr. Goward of President Lincoln's closing remarks in a letter to General Grant during the Civil War. In his closing remarks, Lincoln stated, "I apologize for writing you such a long letter, but I didn't have time to write a short one." Over the course of six months, the subcommittee was able to condense the information to two pages.

Slide 1



Slide 2

The two-page White Paper was previously circulated to board members for comment and discussion. Included in the White Paper are eight attachments that reference the information in the document. These attachments are meant to target readers that would like more information beyond what is included within the White Paper (Slide 3).



Celebrating GPS 50th Anniversary

Recommitting to U.S. Leadership in Positioning, Navigation, & Timing

Bottom Line Up Front: This year marks the 50th anniversary of the Global Positioning System program. In December 1973 the Defense Systems Acquisition Review Council (DSARC) gave the U.S. Air Force approval to proceed with the development of the Navstar Global Positioning System (GPS).

GPS has provided America and the world innumerable and incalculable benefits. It has also been a symbol of America's strength and global leadership for decades.

Recommitting to U.S. positioning, navigation, and timing (PNT) leadership must be a key public policy objective in an era of great power competition.

A visible celebration of the 50th Anniversary of GPS will remind Americans and the world what GPS has done for humankind and must serve as the catalyst to elevate global PNT leadership to its proper place in our national policy agenda.

Opportunities at GPS 50 celebration to highlight:

- Fighting climate change with GPS
- Women & minorities' historic & ongoing contributions to GPS (ex: Gladys Mae West)
  - International cooperation & engagement around GPS & Global Navigation Satellite System issues (GNSS)
  - GPS as the progenitor, inspiring other GNSS & multiple augmentations
  - International cooperation on GNSS at United Nations & peaceful engagement
  - Benefits of GPS for entire planet population regardless of nationality, etc.
- Vice President role leading space issues through Space Council
  - Planning for the next 50 years of GPS & U.S. leadership in PNT
  - Leading whole of government effort to execute national GPS & PNT policy, ensure U.S. leadership & competitiveness in key cyber, information technology (IT), infrastructure areas (see attachment 4)
  - Supporting a key element of national security, economic growth, & international cooperation.

Reminding America & the World

GPS has brought innumerable benefits to the nation and the world.

This has made it a pillar of America's soft power and global leadership for 40 years.[1] Other nations have taken note. Some are attempting similar successes and challenging our leadership with their own GNSS and PNT systems.[2]

[1] In September 1983 President Reagan authorized GPS for civil use after the downing of KLA Flight 007 by the Soviet Union.
[2] China's BeiDou: New Dimensions of Great Power Competition, Harvard Belfer Center, February 2013

GPS' outstanding record of performance has made it a silent utility that is taken for granted by most users.

The celebration must highlight important contributors to GPS, its many important benefits, and recommit the nation to providing leadership for GPS & American PNT going forward.

More Focused and Agile Governance

GPS is a "dual use" technology key to both national security and economic prosperity. It is a key utility in IT and cybersecurity, transportation, economic development, and sustainment of day-to-day life in the homeland.

As such, GPS and American PNT requires a whole-of-government approach led by focused, agile day to day leadership addressing the countless issues impacting its utility, reliability, and security.

The greatly improved awareness generated by the celebration should engender improvements to governance for the next 50 years of GPS and U.S. PNT leadership and competitiveness.

A National Resilient PNT Architecture

American leadership and competitiveness in PNT, and the countless technology and applications it supports, will require a comprehensive system of systems approach.

The nation requires reliable, robust, resilient PNT for the next 50 years so that the "silent utility" remains just that, verses a series of challenges to be overcome.

The celebration should engender coordination of public and private PNT efforts resulting in a resilient national PNT architecture that will ensure military and civilian users have services whenever and wherever needed.

Recommendations

Convene a White House summit celebrating U.S. achievements with GPS and launch new era of innovation and prosperity. The summit should:

- Raise awareness of GPS' contributions and importance to America and the world,
- Lead to improvements in the agility of PNT governance by assigning a senior responsible federal official, and
- Lead to implementation of a systems approach to a resilient national PNT architecture to underpin national security and economic prosperity.

Attachments:
1) Potential agenda items for GPS 50th Anniversary Summit
2) GPS, an Essential but Silent Utility
3) GPS, PNT and Great Power Competition
4) Some necessary steps for global PNT leadership
5) Brief GPS & PNT Policy History
6) "What's the economic impact of GEO services?" – Oxera for Google, 2013 (excerpt)
7) "Putting the U.S. Geospatial Services Industry on the Map" Boston Consulting Group, 2012 (excerpt)
8) "White House Summit – Future GPS & PNT for National Security & Economic Growth (50 years on) – PNT Advisory Board Recommendation, November 2022

Page 2

Slide 3

The subcommittee has also drafted another recommendation that is asking the EXCOM to provide feedback to the Board regarding their recommendations within 90 days (Slide 4). This recommendation is important because the Board must have feedback on their recommendations before they build upon those recommendations. This way, future deliberations can be properly built upon from previous deliberations.

National PNT Advisory Board – May 2023 Recommendation –

EXCOMM provide feedback on recommendations w/in 90 days

- **Finding:**
  - The PNT Advisory Board has made many recommendations to the EXCOMM since its establishment in 2004
  - Some recommendations have been implemented, some not. The board has occasionally received informal verbal feedback on its written recommendations
  - Board deliberations could be improved if it better understood the administration's response & rationale to recommendations
- **Recommendations:**
  - EXCOMM provide a written response to board recommendations within 90 days of them being submitted.
  - NCO to examine records & compile a list of all board recommendations since its founding & provide to the board.
- **Reason for Recommendations:**
  - PNT Advisory Board deliberations & subsequent recommendations will be improved w/ better feedback fm EXCOMM
  - Understanding previous recommendations will inform future deliberations, discussions, recommendations
- **Consequences of No Action on the Recommendation:**
  - Much less effective PNT Advisory Board deliberations & service to EXCOMM

Slide-4

The subcommittee has also been discussing bringing the Board meetings as close to the federal government as possible, in Washington, DC. Mr. Goward noted that several years ago, the Board met within close proximity to the Pentagon and, therefore, was able to have members from the National Security Council brief the Board. This is merely a discussion and not a recommendation.

Mr. Goward thanked Mr. Moorefield and Dr. Hampshire for joining the Board.

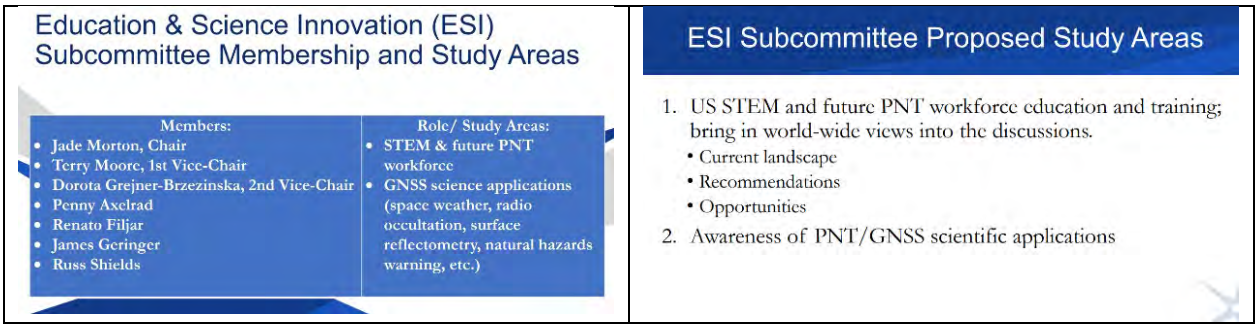
Discussion:

Dr. Parkinson stated that the Board will discuss meeting location and dates upon Admiral Allen's return.

* * *

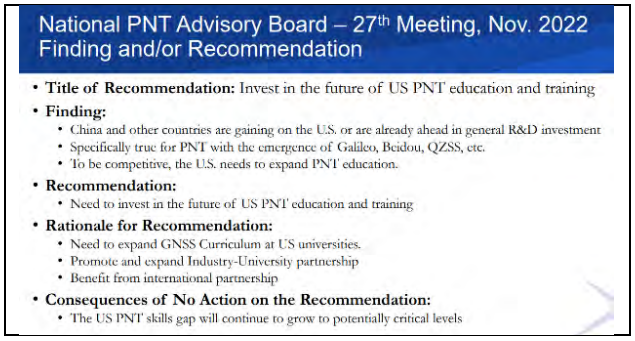
2) Education, Science, and Innovation Subcommittee (VIEW PDF): Professor Terry Moore

Prof. Moore noted that Dr. Jade Morton is participating online. The subcommittee has evaluated issues relating to STEM education and the needs of the U.S. workforce (Slides 1-2). The subcommittee has made recommendations regarding the educational landscape of the U.S. Additionally, they have looked at the scientific applications of GNSS.



Slides 1-2

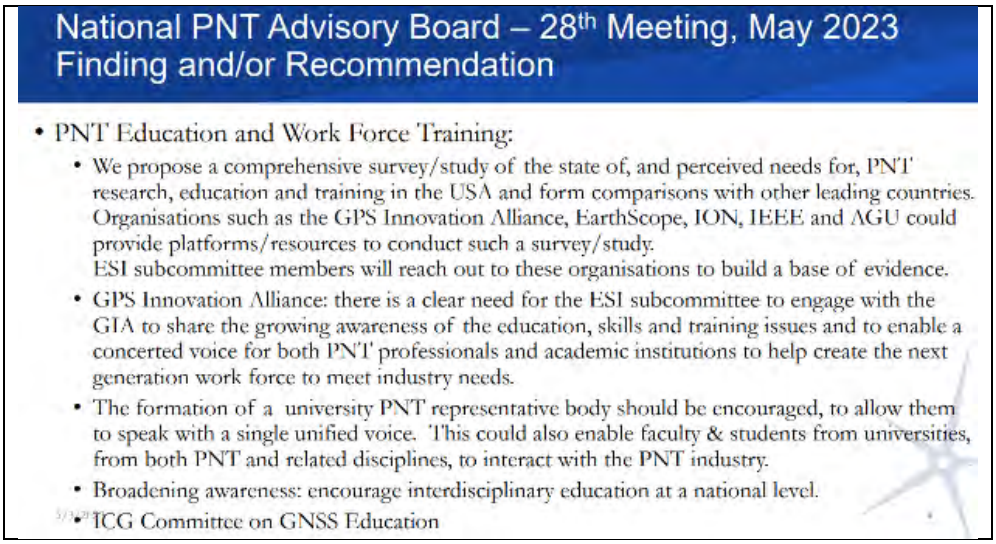
At the last Board meeting, the subcommittee made a recommendation regarding an increase in funding to support the future of U.S. PNT education and training (Slide 3). Since this recommendation, there has been developments regarding targeted funding, perhaps coincidentally. The subcommittee is evaluating if this recommendation is still relevant.



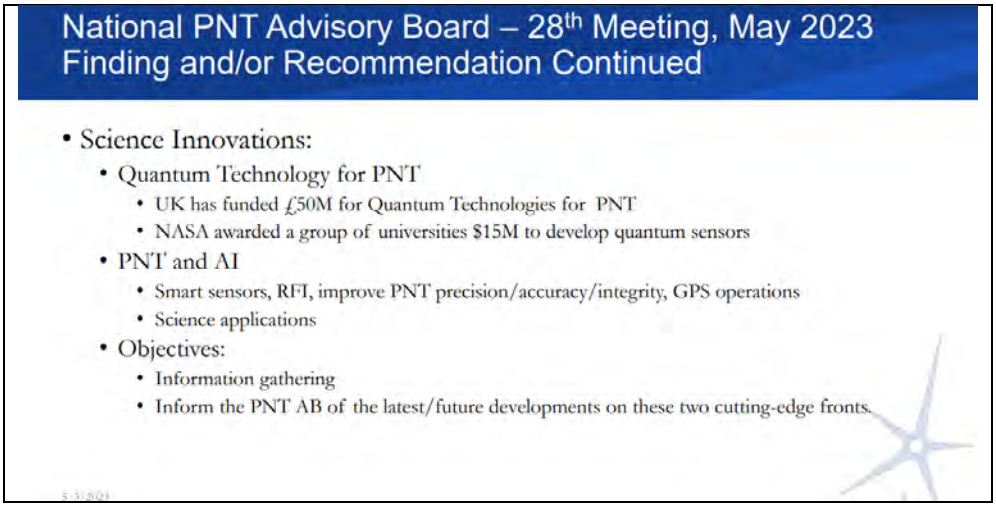
Slide 3

The subcommittee also discussed having a more positive and coordinated voice regarding PNT education and work force training (Slide 4). Specifically, it is evaluating how to create a single voice for both the academic and industrial communities. They are proposing a survey or study with organizations, such as the GPS Innovation Alliance, for concerted effort towards recognizing the needs and demands of industry and academia wholistically. There is no single voice for the university sector, and if this initiative is left up to individual academics, it will be very targeted and scattered. There is a need to bring universities together for collaboration so they can also speak on PNT with a single voice. The role of the Board is to facilitate this and to work alongside the recommendations that the subcommittee previously made. The subcommittee is also trying to broaden the scope of PNT, which can coincide with computer science, artificial intelligence, etc. The International Committee on GNSS (ICG) also has educational aspects that may be able to relate to the educational work conducted within the Board.

Lastly, the subcommittee proposes that the Board start conducting initial key technologies which will have a significant influence on PNT: quantum technology and artificial intelligence (AI) (Slide 5). The goal is draw information together to begin to collate activities taking place in the U.S. and around the world. Various countries, such as the UK and Australia are publishing their quantum technology strategies, and the subcommittee is asking what PNT aspects are in those publication and how will it affect the PNT landscape moving forward. The UK government has recently invested 50 million pounds to the development of quantum technology specifically for PNT. Regarding AI, how will this technology impact how we develop algorithms within PNT in the future? The subcommittee's recommendation is to conduct background research to present to the Board later.



Slide 4

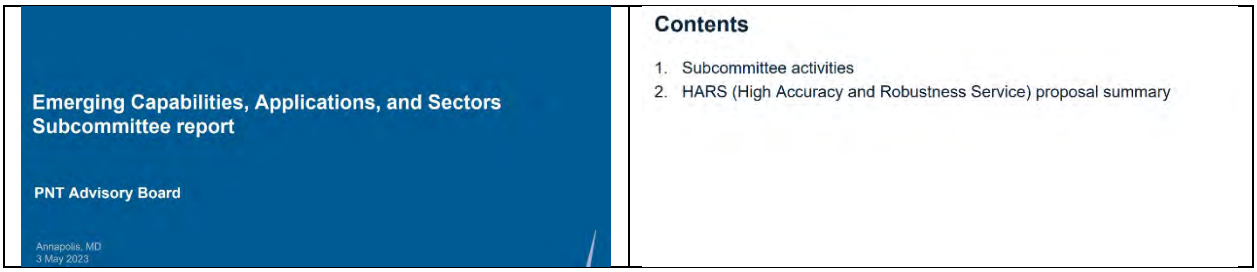


Slide 5

* * *

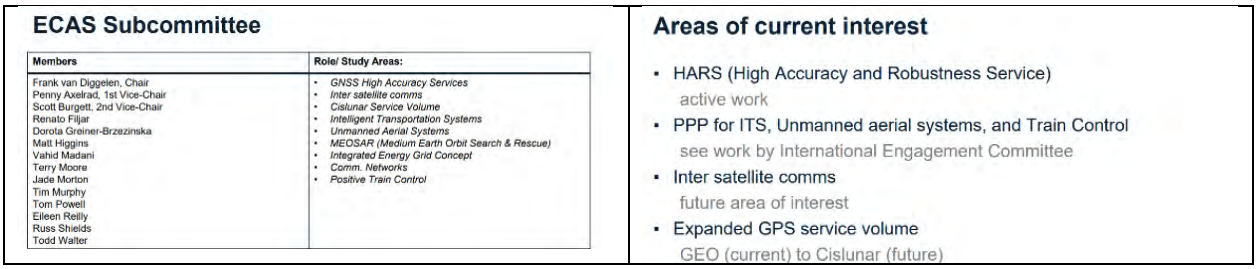
3) Emerging Capabilities, Applications, and Sectors Subcommittee (VIEW PDF): Dr. Frank van Diggelen

Dr. van Diggelen noted he would discuss the subcommittee's recommendation regarding a High Accuracy and Robustness Service (HARS) (Slides 1-2).



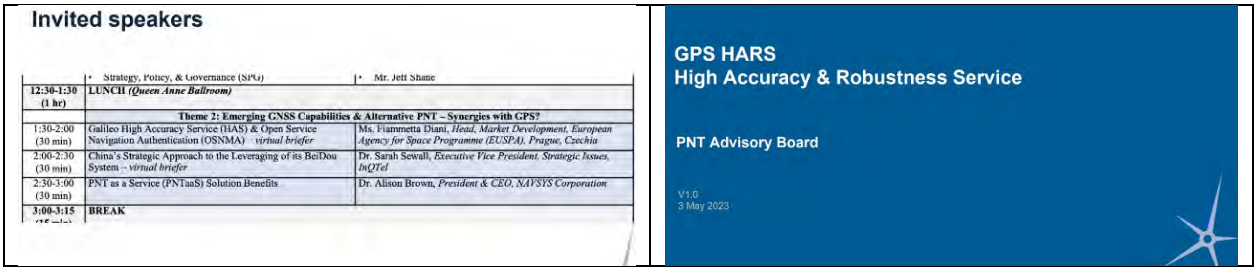
Slides 1-2

Slide 3 depicts the members of the subcommittee and their areas of interest. As shown on Slide 5, subcommittee work has revolved around HARS. Another focus of the subcommittee includes Precise Point Positioning (PPP) for Intelligent Transportation Systems (ITS), Unmanned Aerial Systems (UAS), and Positive Train Control (PTC) (Slide 4). Dr. van Diggelen noted he would also refer to work done by the International Engagement Subcommittee. Future interest areas include inter satellite communications and the expanded GPS service volume from Geosynchronous Orbit (GEO) through Cislunar Space.



Slides 3-4

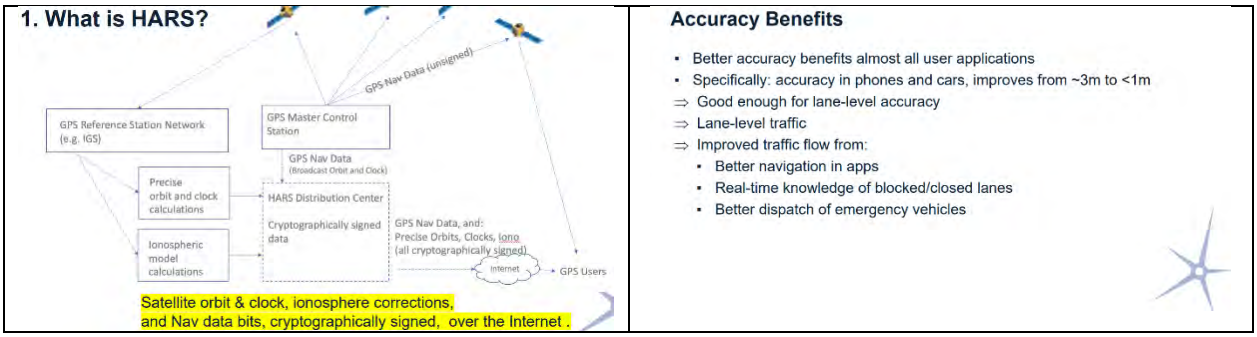
As noted on Slide 5, the subcommittee has invited three speakers to brief the Board today: (1) Ms. Fiammetta Diani will discuss Galileo, (2) Dr. Sarah Sewall who will discuss BeiDou, and (3) Dr. Alison Brown who will discuss PNT as a Service (PNTaaS). Dr. van Diggelen also noted he would discuss the subcommittee's formal recommendation for GPS HARS (Slide 6). Since the last Board meeting, the subcommittee has produced a White Paper on GPS HARS.



Slides 5-6

HARS provides satellite orbit and clock data, ionospheric corrections, and NAV data bits cryptographically signed and delivered over the internet (Slide 7). This is a fairly simple proposal. The boxes that are solid already exist, and the proposal regards the boxes that are hash-lined. Specifically, the proposal is to take NAV data that already exists but is being broadcast from the satellites unsigned, and therefore vulnerable to spoofing; cryptographically sign the data; and then deliver it over the internet using similar security that is used with credit card transactions. This will add tremendous security to the system and provide higher accuracy through precise orbit and clock calculations and ionospheric corrections.

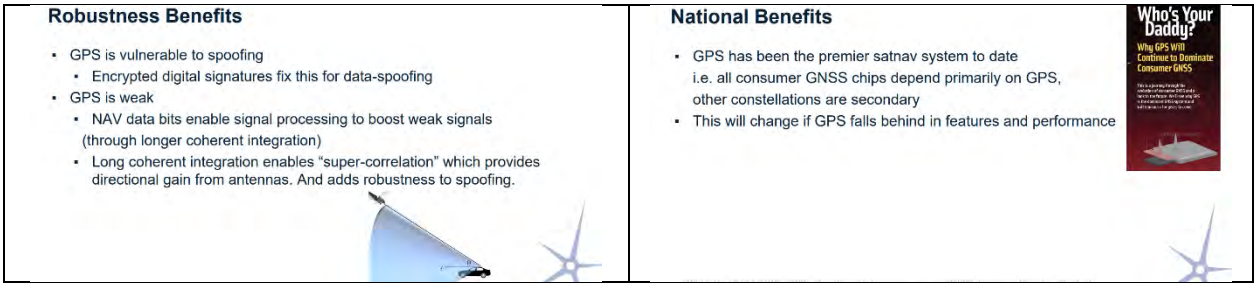
This technology provides benefits to accuracy, robustness, and the U.S. Any application of GPS benefits from increased accuracy (Slide 8). A majority of people use their phones in their cars for navigation purposes. With HARS, applications such as Google Maps can get the speed of a particular lane. Currently, the speed information that is derived from phones in cars is aggregated from express lanes that may be moving faster, exit lanes that may be stationary, etc., and these applications may not know which lane the phone is in. This can provide a societal benefit because lane-specific traffic information would give the driver better information such as traffic slow, real-time knowledge of blocked or closed lanes, and a better dispatch of emergency vehicles.



Slides 7-8

As shown on Slide 9, GPS is very vulnerable to spoofing. A solution to this is encrypting digital signatures on the data that is provided. Additionally, GPS is very weak, as Dr. Parkinson previously stated. Providing NAV data bits over another channel, such as the internet, allows signal processing that significantly boosts weak signals. This is known as longer coherent integration, which also enables "super-correlation" which accounts for the speed of the vehicle and therefore gives directional gain from the antennas. These bits enable high data processing which adds robustness to spoofing.

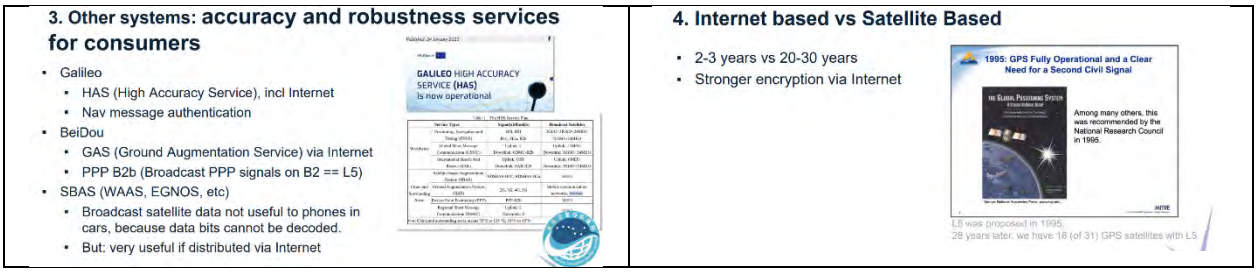
HARS can also help maintain GPS as the premier satnav system (Slide 10). GPS has been the premier satnav system to date quantitatively. Every consumer trip acquires GPS and then uses that position and timing information to then acquire other systems, such as Galileo and BeiDou. Other systems are literally dependent on GPS with consumer products. Ten years ago, Dr. van Diggelen gave a talk at Stanford University, titled, "Who's Your Daddy: Why GPS will Continue to Dominate Consumer GNSS." In that discussion, Dr. van Diggelen went into detail on why GPS was the optimal signal structure for chip designers to use and why it was not worth their while to acquire more complex signals that exist on other systems. During his talk, Dr. van Diggelen also stated that GPS will continue to be the dominant system for a while. Ten years later, chips are being designed that can directly acquire signals such as L5, which are more complex than the L1 C/A signals. So, it is possible that chip designers will begin to develop a chip that can acquire Galileo, for example. This may cause GPS to lose its primacy due to other advantages that other GNSS systems may have.



Slides 9-10

Galileo has deployed a High Accuracy Service (HAS) which will be made available over the internet (Slide 11). They also have NAV message authentication, which Ms. Diani will discuss later today. BeiDou has a Ground-Based Augmentation Service (GBAS) that is available via the internet. They also broadcast PPP signals on their B2 frequency band, which is equivalent to L5. Space-Based Augmentation System (SBAS) broadcasts satellite data from geostationary satellites with ionospheric corrections, however, the data are not useful to phones in cars because the data bits cannot be decoded. If this data was provided via the internet, it will become useful because phones have access to the internet. The Wide Area Augmentation System (WAAS) is an example of data that could be useful to consumers but is missing this link. The USG created the internet and GPS. Dr. van Diggelen stated that it is about time that they get introduced to each other

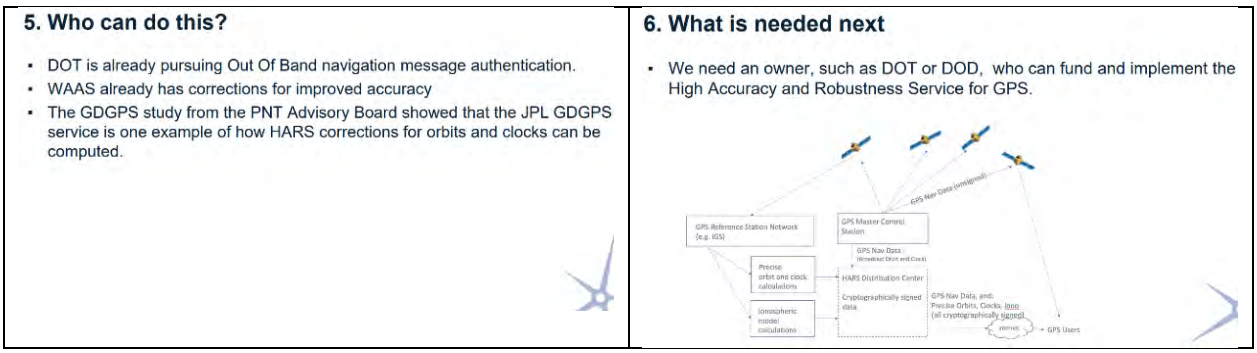
Providing information over the internet is also beneficial because it can happen sooner (Slide 12). If this is done over satellites, it will take 20 to 30 years. For example, L5 was first proposed in 1995, 28 years ago, and we have just passed the half-way point – 18 of the 31 satellites now have L5. Additionally, stronger encryption is available via the internet because the encryption depends on the length of the keys, and longer keys are available via the internet where broadband is not an issue versus broadcast data where broadband data length is a significant issue.



Slides 11-12

DOT is already pursuing Out-of-Band navigation message authentication, and HARS is exactly that (Slide 13). DOT also owns WAAS, which already has corrections for improved accuracy. This could be made available to everybody in the U.S. if it were made available through means such as the internet. Additionally, the Jet Propulsion Laboratory's (JPL) Global Differential GPS System (GDGPS) study from the Board showed that GDGPS service is one example of how HARS corrections for orbits and clocks can be computed.

Dr. van Diggelen finished by stating that we need an owner to fund and implement the HARS for GPS (Slide 14).



Slides 13-14

Discussion:

Lt. Gen. James asked, "with respect to the GDGPS, we did a study last year saying how you could provide a High Accuracy Service using GDGPS and the internet. So, is this somewhat different [or] is this relying on the same construct that we came up with?"

Dr. van Diggelen stated that the GDGPS program from JPL could be a part of this HARS proposal. The key point we're proposing is to have science data to provide robustness. GDGPS could be a subset of what we are proposing.

Dr. Parkinson suggested that DOT could be the right seat for this proposal.

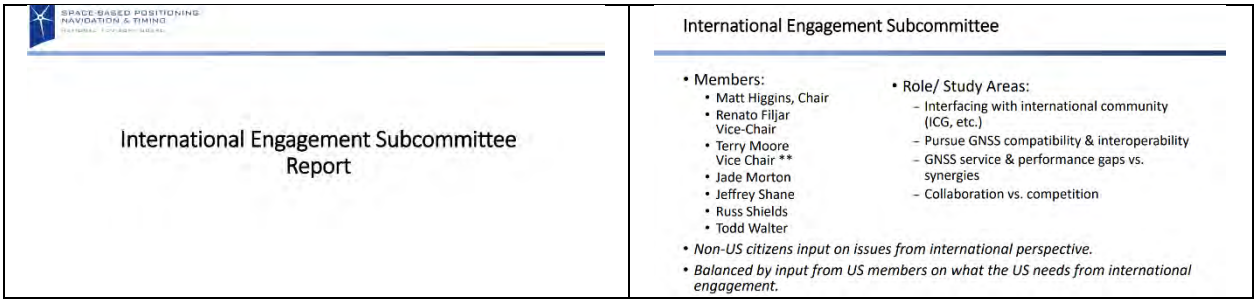
* * *

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

Mr. Higgins stated that the two asterisks next to Prof. Moore's name need to be addressed (Slide 2). He said that Sonia, who use to chair this subcommittee, has left the Board and the subcommittee proposes that Prof. Moore become the 2nd Vice Chair.

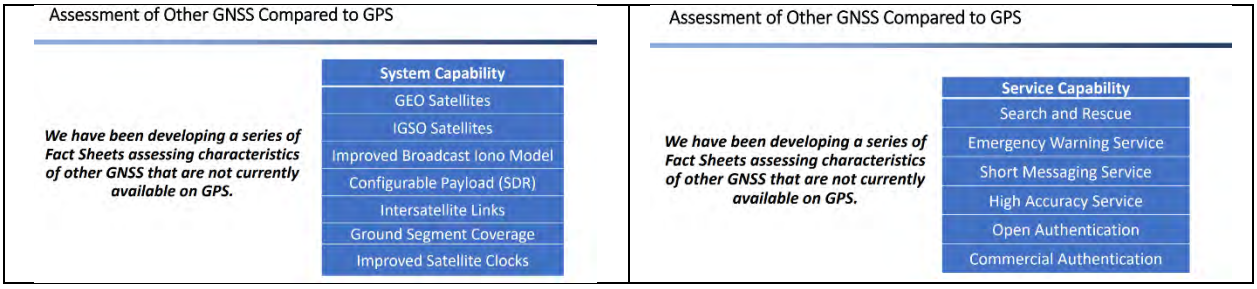
Dr. Parkinson asked Mr. Higgins is this is a nomination, and Mr. Higgins confirmed that it is.

Prof. Moore stated that he is happy to accept the nomination of 2nd Vice Chair.



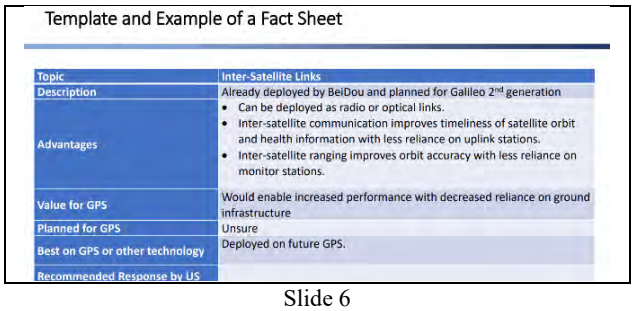
Slides 1-2

The subcommittee has primarily focused on GNSS service and performance gaps, as well as attempting to put a systematic approach to the question whether GPS is still the Gold Standard. Specifically, the subcommittee has been identifying capabilities in other GNSS that are not available on GPS. These capabilities have been separated into two groups: (1). System Capabilities, and (2) Service Capabilities (Slides 3-4).

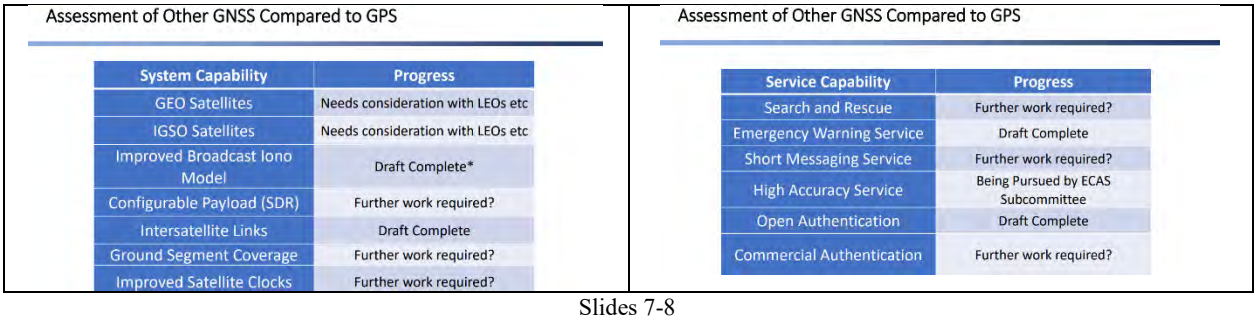


Slides 3-4

Using this information, the subcommittee has put together fact sheets (Slides 6-8). These fact sheets are intended to be used as one-pagers for high-level decision makers to gain a better understanding of the subject. Additionally, these fact sheets, combined, make a portfolio of information on other GNSS.



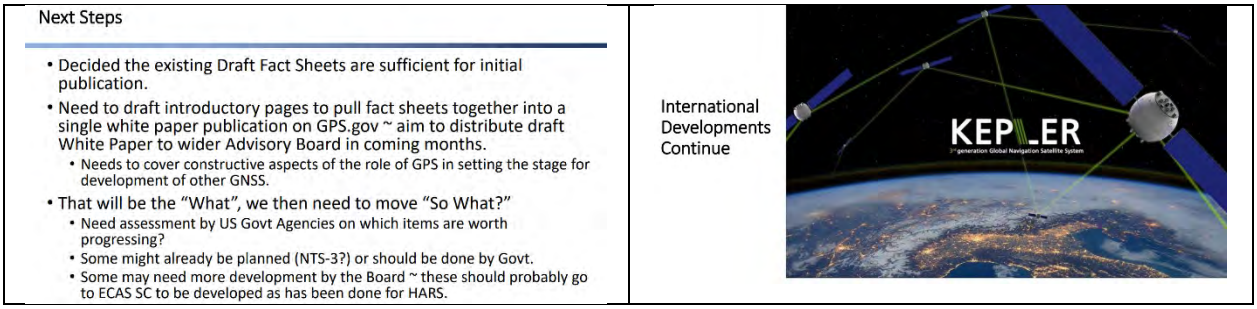
Slide 6



Slides 7-8

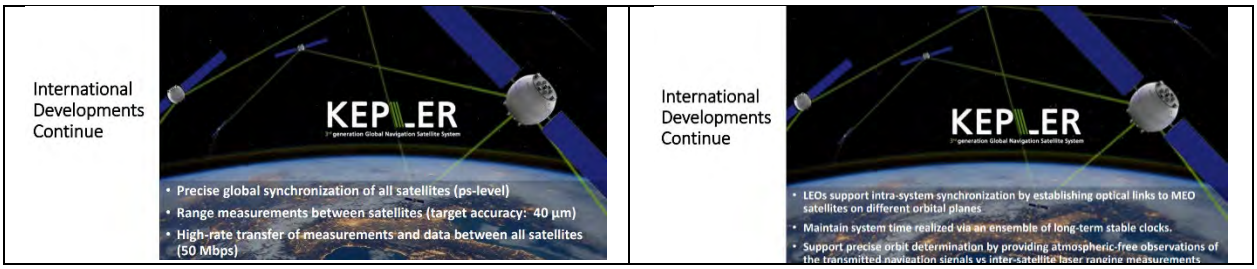
The subcommittee has decided that the existing fact sheets are ready enough for initial publication (Slide 9). Mr. Higgins will be drafting introductory pages for a White Paper, and aims to make a recommendation at the next meeting. The White Paper will also cover the constructive aspect of the role of GPS in setting the state for development of other GNSS. This is known at the "what," and the subcommittee is moving to the "so what?" This means we need input from USG agencies on which items are worth progressing. Of those that are worth progressing, some may already be planned, such as the Air Force Research Laboratory (AFRL) Navigation Technology Satellite 3 (NTS-3). Additionally, some items may need to be done within the USG and not by the Board, some may need further development by the Board and should therefore be placed under ECAS Subcommittee.

We are also responsible for bringing international developments to the attention of the Board. At the latest International Global Navigation Satellite Systems (IGNSS) conference held in Sydney, Australia in December of 2022, the German Space Agency (DLR) gave a presentation regarding what future generations of what European GNSS may look like. The DLR presented on a system called Kepler, which has optical communication links between the MEO satellites as well as the Low Earth Orbit (LEO) satellites (Slides 10-12). The high-rate (50Mbps) transfer of measurements and data between the satellites causes the synchronization of all of the clocks in the constellation. Range measurements can also be done between the satellites, which means the system can generate real-time, precise orbits.



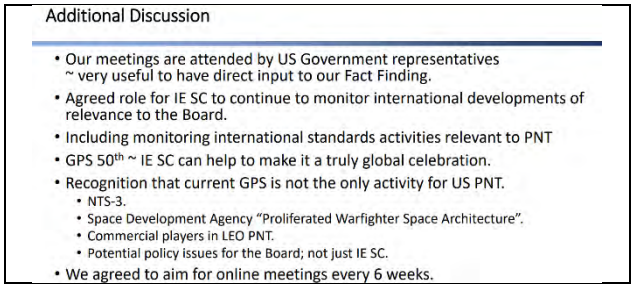
Slides 9-10

The LEO satellites have a GNSS receiver, so the RF range can be calibrated using laser ranging. This is a good example of where technology capabilities may be ten years from now.



Slides 11-12

Subcommittee fact-finding meetings have been attended by representatives from USSF, DOS, DOT, and others.. Additionally, the subcommittee will continue to monitor international developments to bring back to the Board, including international standards activities. The subcommittee can also help make the 50th Anniversary of GPS a global celebration by organizing global webinars, etc. It is also important to note that GPS is not the only U.S. PNT activity. Other examples include NTS-3, the Space Development Agency (SDA) "Proliferated Warfighter Space Architecture," commercial players in LEO PNT. Lastly, the subcommittee has agreed to meet every six weeks.



Slide 13

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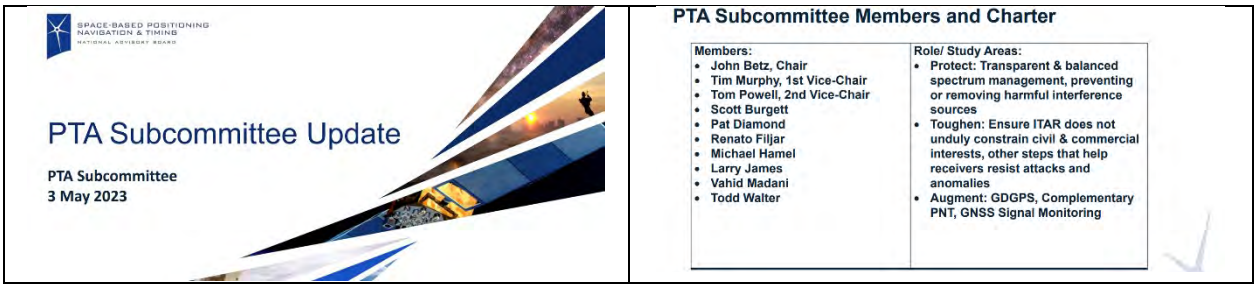
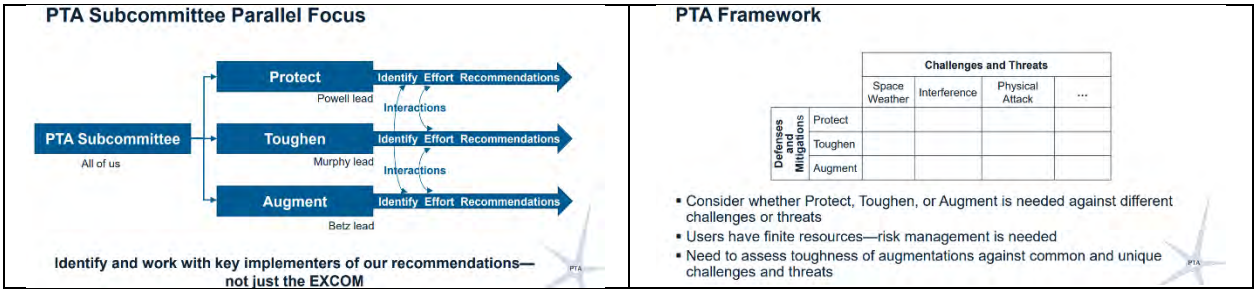
5) Protect, Toughen, and Augment Subcommittee (View PDF): Dr. John Betz

The subcommittee has been primarily focusing on GNSS service and performance gaps, and attempting to put a systematic approach to the question on whether GPS is still the gold standard (Slides 1-2).



Slides 1-2

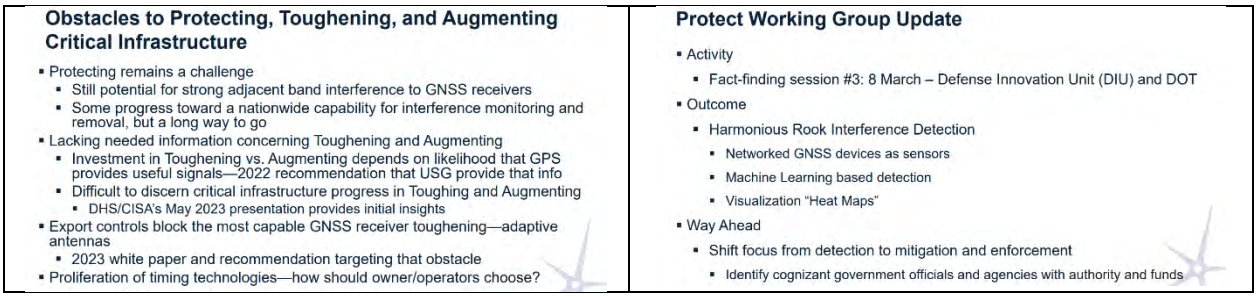
Due to the depth of the subcommittee's scope, it has identified activities that fall under the three areas: Protect, Toughen, and Augment. Chair Betz, 1st Vice Chair Murphy, and 2nd Vice Chair Powell each chose one topic to lead (Slide 3). Information is share among each of these subgroups, as well as with the government. The subcommittee is focusing on the challenges and threats to the use of GPS, GNSS, and other sources of PNT (Slide 4). We need to understand how to better protect owner operators and critical infrastructure from those threats, and what they need to do to toughen or augment against threats. Eventually, risk mitigation will be needed, and resources will have to be allocated across toughening and augmenting.



Slides 3-4

Protecting remains a challenge (Slide 5). The potential for string adjacent band interference has not disappeared. There has been progress toward a capability of nation-wide interference monitoring and removal, which will be briefed to the Board later today. But there is still a long way to go. Owner operators are lacking needed information when making their decisions between toughening and augmenting. How they invest their resources in toughening their use of GPS, as opposed to augmenting because GPS is no longer there, depends on the likelihood that GPS will continue to provide useful signals. The subcommittee recommends that the USG provide information on the likelihood that GPS may long longer provide useful signals for days, weeks, months, etc. The subcommittee also found it difficult to understand the progress that is being made across critical infrastructure with respect to toughening and augmenting. Additionally, export controls block the most capable GNSS receiver toughening, as Dr. Parkinson stated earlier today. Mr. Murphy will brief the Board later today regarding the subcommittee's efforts to document why export controls should be relaxed or removed. Finally, the subcommittee has observed that timing and critical infrastructure is the easiest part of the problem to address. There are multiple technologies emerging to address this issue, and owner operators may not have the technical expertise to decide which of those issues to pursue.

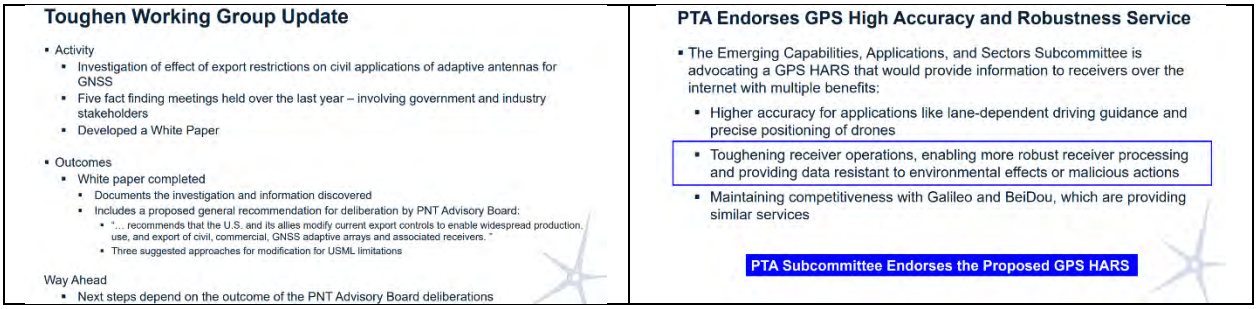
The Protect Working Group had been working with the Defense Innovation Unit (DIU) and DOT that are focused on developing a capability called Harmonious Rook (Slide 6), which the Board will be briefed about later this afternoon. The subcommittee recognizes that is it important to move from the current focus, those sources of interference.



Slides 5-6

The Toughen Working Group is focused on export controls for adaptive antennas (Slide 8). The next step will be to engage with the relevant entities of the USG to pass on the information that the subcommittee has gathered.

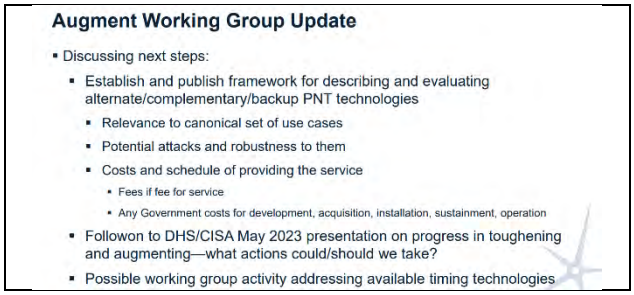
Earlier, Dr. van Diggelen briefed the Board on the GPS HARS with the recognition that this technology will toughen receiver operations, enabling more robust receiver processing, and providing data that is resistant to different types of challenges. This subcommittee strongly endorses the proposed HARS (Slide 8).



Slides 7-8

The subcommittee will aim to put emphasis on "Augment" over the next few months (Slide 9). Three potential activities in this area are:

1. There is an inconsistency in the way alternative augmentations are described and assessed, so the subcommittee will develop a framework that asks advocates to describe and evaluate these technologies with canonical use cases so the advocates can describe which use cases can be addressed and which cannot. These advocates will also describe what kinds of attacks may be made against their system and how robust they assess their system against attacks. Additionally, what would be the cost to the government and the user if such a system were developed and deployed?
2. Relating to the briefing earlier today on the process of toughening and augmenting, the subcommittee will discuss what they can to in that area.
3. With the emergence of multiple timing technologies, the subcommittee believes that this is an opportunity for some timing experts to assemble a White Paper that lays out a technical description and attributes of these technologies to serve as an information source for owner operators and critical infrastructure consideration.



Slide 9

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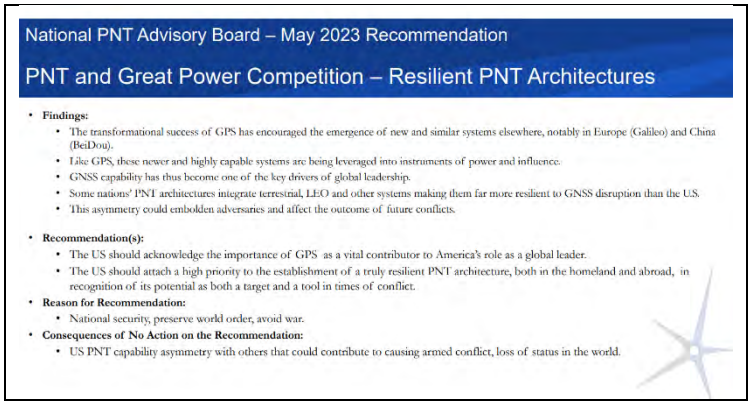
6) Strategy, Policy, and Governance Subcommittee (View PDF): The Hon. Jeffrey Shane

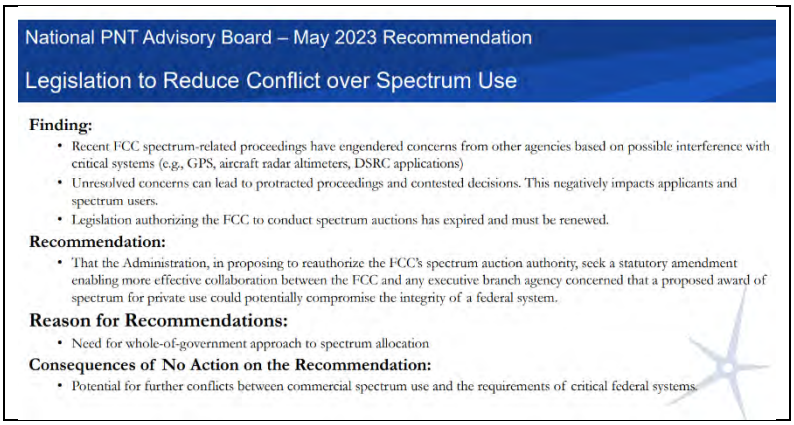
The Hon. Jeff Shane stated that the subcommittee is still discussing its recommendations, and that they have not been shared widely and have not been adopted as Board resolutions. The first of two recommendations regards the larger significance that is being attached to GPS and GNSS (Slide 1). Later in the afternoon, Dr. Sewall will give a presentation on the importance of BeiDou to China. The transformational success of GPS has, not surprisingly, engendered several other GNSS systems around the world. Those systems have become more than just PNT systems. They have become instruments of national influence and global power. We know that China views BeiDou in this way, and they are using that system to broaden their influence around the world. The U.S. also began doing this with GPS long before BeiDou was developed, so this position by China is not surprising.

The U.S. has numerous dedicated public servants that go to work every week thinking about nothing but the strategic importance of PNT. Therefore, the question is not whether people are thinking about this issue, but whether this issue is in its rightful place on the national policy and national security agendas. We know that the folks who are working on this clearly have the right idea; the issue for us is that we do not have clear visibility of what is going on within the government. There is still some scope for classified information within our government. It is critical that our leadership understand the importance of PNT and the importance of continuing to invest in a world-class, state of the art system. This is not an easy ask because it takes a high level of dedication, investment, and a continuing push at all levels of government, especially from leadership. Hon. Shane stated that this Board is on record urging our government to place PNT, GPS, and all of its iterations at the appropriate level in our national policy and security agendas.



Slide 1

The second recommendation regards a very serious anomaly in the way we allocate spectrum in the U.S. (Slide 2). It is common knowledge that spectrum is allocated by the FCC for private use while NTIA and DOC are responsible for federal use. There has been an issue of conflicts between federal use and private use, which can be attributed to the system that we have structured. Our system, enshrined in law, gives the FCC final say over who within the private sector gets to use spectrum, what spectrum they use, and for what purpose they use it. The law states that anybody who is opposed to an innovation based on spectrum has the burden of proof before the FCC to explain why that proposed innovation should not be licensed. Examples of this include: (1) The Ligado episode, in which the L-band was repurposed for terrestrial purposes when it was supposed to be reserved for satellite uses. This was done over the objections of the entire Administration, especially DoD; (2) a portion of the 5.9 GHz band, the so-called Auto Safety Band, was repurposed for household Wi-Fi over the objections of the DOT; and (3) the current issue regarding the repurposing of spectrum in the C-band very close to the spectrum required by aircraft altimeters, which caused the Federal Aviation Administration (FAA) to suspend and divert some flights at the time that this award was given. These radio altimeters on airplanes are essential to the avionics of aircraft. It is impossible to land an aircraft in situations of low visibility without a working radio altimeter. The altimeter is also a piece of equipment of which other elements of an aircraft's automation depend on. Captain Burns can attest to this. DOT recently announced that a deadline of July 1, 2023, that had been set for upgrading altimeters, will not be extended. Airlines are claiming that they cannot get the equipment necessary to upgrade their altimeters fast enough, because the manufacturer cannot manufacture it in enough quantity fast enough to satisfy the need. Hon. Shane stated that this means, in cases of low visibility, we can expect aircraft to be diverted or flights are going to be cancelled. This is a result of a decision made by the FCC over the objection of the FAA and DOT.



Slide 2

*<Note: *Slide 2 was not displayed for the Board at the meeting>*

The FCC is not doing anything illegal. They are pursuing the legislative mandate that Congress has vested in them. The anomaly is in the structure of the law and the process. Therefore, it is time for the Administration to address the anomaly with Congress to explore if a greater balance can be inserted in the law. The authority that the FCC has to conduct the auction of spectrum has lapsed for the first time since it was granted in 1993. There is now an opportunity to take a hard look at the legislation which authorizes the FCC to conduct those auctions and to make sure that when they are reauthorized, there is some element of balance put back into the law so that the federal agencies that rely on clean spectrum do not bear the burden of proof before the FCC in a proceeding. These government agencies that are objecting to these awards are instruments of government policy in their own right. The idea of treating them as "parties of interest" before the FCC, whose views have to be considered but not listened to, is the wrong way to approach an issue of this kind.

A couple of years ago, this subcommittee submitted to the Board a proposal that was made in 2003, when there was a similar conflict regarding ultra-wide band transmissions. Hon. Shane stated that at that time he was a member of a taskforce run by DOC, which was taking a hard look at the allocation of spectrum. The problem that we had back then is still a problem we have today. DOT proposed to us a system similar to one that it uses when it allocates an international route to an airline. When DOT grants an international route to an airline, whether it's a foreign or domestic airline, that award goes to the White House for presidential review. It is enshrined in law that it cannot become final until the White House blesses it. Today, this process is delegated to DOT and if there are no objections by other agencies, it is assumed to have Presidential approval. Nevertheless, there is still a check because there are national security implications in every award of an international route. Turning to the national security implications of the Ligado award, why is there no Presidential review of awards like that before they become final? If there had been Presidential review, what would have happened? The decision would have been reversed. There was no opportunity to do this because the law does not include any such provision. This is an example of how it could be possible to insert more balance into the law. The idea behind this is not to prevent the FCC from continuing to advance progress. The FCC is a remarkable agency that has done miraculous things for our society. The point is, carrying out the law without finding ourselves with more conflicts of this kind as spectrum gets more and more crowded.

Discussion:

Dr. Parkinson stated that, regarding the burden of proof, he finds is very peculiar that a new service does not have to prove that it does not interfere, rather than have the older services prove that this new service does. He continued, saying that the logic is mindboggling.

Hon. Shane agreed, saying that this would be an easy amendment to make, but changing the Communications Act of 1934 is an uphill battle. There needs to be a concerted effort led by agencies of government who have been disturbed by the extent to which their objections have been overruled. Hopefully then some balance can be inserted into a process that otherwise has served us very well. This is not a criticism of the FCC, which carries out its mandate according to the law. The mandate needs to be tweaked, and that is the recommendation that this subcommittee is making to the Board. Hon. Shane added that his subcommittee had been joined at the hip with the Communications and External Relations Subcommittee regarding the celebration of the 50th Anniversary of GPS. This subcommittee supports the White Paper as well as the idea of a significant recognition of the importance of GPS and PNT using the 50th Anniversary of GPS as the hook. In 1994, we celebrated the 50th Anniversary of the Chicago Convention, which was not technically a U.S. success but an international treaty that became the glue that holds the entire international civil aviation system together. DOT hosted a celebration, including a day-long conference where we celebrated the importance of aviation since the Chicago Convention was adopted. This could be the model for celebrating the 50th Anniversary of GPS.

* * *

Theme 2: Emerging GNSS Capabilities & Alternative PNT – Synergies with GPS?

Virtual briefing - China's Strategic Approach to the Leveraging of its BeiDou System
Dr. Sarah Sewall, Executive Vice President, Strategic Issues, In-Q-Tel

Dr. Sarah Sewall opened her briefing by highlighting that as a political science and national security expert, her role is to draw implications from emerging technologies for the U.S. and allies' position vis-à-vis China, and great power competition. In that way, she believes her presentation may be quite different from some of the other more technical sessions.

She expressed her appreciation for the opportunity to share her thoughts on the broader context for thinking about GPS, BeiDou, and PNT, its future, and why it matters. She highlighted that the conventional understanding of the importance of PNT needs to be augmented by a broader understanding of the role of technology infrastructure, not only in global economics but also in the context of global security and stability, as well as norms, and values.

From the outset, she posited that at least from the American perspective the analogy to think about why the U.S. should care about BeiDou is not dissimilar from arguments about why democratic nations should care about Huawei. A broad and multi-dimensional set of concerns need to be considered. She outlined three broad buckets of them, and then take some time for comments, questions, and discussion.

She noted that China has in a very short period of time moved from being a nation that was dependent on GPS to becoming a nation that has a global system which, some would argue, more advanced capabilities than GPS. It is now using BeiDou as a piece of its digital infrastructure around the world to accomplish a variety of things that fit into a much longer-term perspective about the ways in which connectivity could be used to national advantage. There is an issue that she thinks is important to understand. China has rapidly closed in and in some cases overtaken the West in its thinking about the use of space and its provision of PNT. China still considers these technologies to be nascent capabilities, looking at what they could mean in the future, rather than necessarily what the BeiDou constellation looks like today. She would like to spell out, beyond the technical dimension, the ways in which the Chinese use of PNT provides multiple potential avenues of leverage for their state.

The first has to do with strategic stability and the issues of dependence. When a nation is no longer dependent upon others it has fewer incentives to refrain from disrupting the provision of other nations GPS systems. That is self-evident, but she thinks it is important to articulate it so that it becomes a piece of how the U.S. thinks about PNT and strategic stability. She thinks it creates a greater impetus for those that want to enhance stability to ensure that there is not a significant gap either in terms of vulnerability or capabilities of a GNSS system. She does not think it is just a question of nations wanting to be number one. It is a question of wanting stability. Stability has to do with both the resilience and the capabilities of GNSS. China's success in the number of satellites in its constellation and in the features that are inherent in its system should cause the U.S. to think about global stability. It is an opportunity for nations to broaden the discussion about why they should care about multiple GNSS capabilities

The second dimension is about the ways in which the Chinese have encouraged other nations to rely upon and use BeiDou. How they have talked about military access as well as commercial access and relationships in the context of their PNT capabilities. The U.S. must be mindful of the tensions within the broader system that can lead to a fragmentation of user communities and ecosystems around PNT provision. Obviously, much of what has motivated the drive toward interoperability and the use of multiple different GNSS systems has been a desire to provide global access. It also provides redundancy that can serve a variety of commercial and individual uses worldwide. It would be unfortunate if in the drive for any national system to improve and to be used in the context of bilateral relationships, if that capability were to be seen as something as "either-or", as oppositional, as zero-sum, as opposed to creating a broader integrated set of capabilities that can be used to support PNT uses.

The final point that she wanted to share is the ways in which the BeiDou system is being paired with 5G and embedded within development initiatives. For China, they have been the backbone of its economic, diplomatic, and arguably security policies. Observers have been struck by the way in which infrastructure has scaled and been portrayed as linked to BeiDou. The potential for path dependence can be reinforced by infrastructure development and create dependencies that are purely around one national set of exports. In the context of the Digital Silk Road, the ability to offer highly accurate PNT data to countries becomes part of the argument about why this is the future, about why this is the route to the 21st century, to precision, to self-driving cars, and to everything that might be leapfrogged by more accurate access to PNT. This is something notable and unfortunate to the extent that gaps emerge in terms of what countries understand to be either the visibility or the accuracy of enhanced by-ground-based systems. So, when they use GNSS systems, they feel like there are fundamental choices that they are making that are reinforced through commercial relationships.

Lastly, she highlighted some BeiDou-enhanced capabilities such as Huawei Energy, the two-way satellite messaging system, and the new Huawei Mate 50, a commercial cell phone that can access the two-way system. When thinking about nascent capabilities and the ways in which China is, in a very entrepreneurial way, seeking to provide not just more advanced capabilities, but also commercially available ones. At the moment, this is something that is occurring inside of China, but there is absolutely no reason why this could not become a harbinger of things more broadly. The little that the U.S. knows about Chinese modernization is that they are not just interested in ground-based resiliency and more advanced PNT systems, but also in LEO satellite constellations and what that might mean for developing future capabilities in the context of BeiDou. She thinks this is something that should be watched carefully because it suggests a different paradigm for thinking about PNT. The way she thinks about it is global

connectivity and how states think about the future, not just in the context of GNSS, but in terms of innovation in space, as a whole. She asked about the implications of ensuring the Global South has affordable access to connectivity. These are the questions that from the perspective of the U.S. and its allies, with a broader set of capabilities in terms of open, operable, and accessible global systems, need to ask, particularly about places in the globe, where the U.S. has tended to under-invest in. She believes a multi-dimensional broadening of the conversation about PNT in the future would be fruitful and important for the U.S. and its allies to have.

Discussion:

Dr. Parkinson started with a question of his own and asked whether Dr. Sewall in the course of her distinguished career in a lot of different places had taken her message about PNT elsewhere in the government, and if so what reactions she is getting.

Dr. Sewall answered that In-Q-Tel itself is a 501c3 that does largely strategic investing in a non-profit context. They do not have a robust return or communications arm. They have not typically considered it their mission to convey their analysis to users. They do not have the bandwidth. By virtue of one of the members of the group, she has now convinced In-Q-Tel to be having those conversations with the National Security Council (NSC) Technology Directorate, with the State Department's new Special Ambassador for Emerging Technology, and with some of the other actors of the American administration that are not DoD and not NASA. That uttermost intentional point of view where one looks at the general context of global competition.

Dr. Parkinson expressed his interest in her powerful insights and suggested they could be valuable to at least present to some of the decision-makers.

Dr. Sewall said she was committed to doing that with a handful of them, it is just not what In-Q-Tel is designed to do, but she took his point and will be doing some outreach based on the paper.

Mr. T. Russell Shields thanked Dr. Sewall for a very good presentation and the emphasis on how fast China is moving on these technologies. He then asked whether she had looked into how China is planning on using BeiDou to help export their vehicles. They had already started in Europe, with an emphasis on having better advanced driver assistance and movement towards better automated driving. The Chinese government can and is using BeiDou to support that effort of pushing their automotive industry to be able to successfully export.

Dr. Sewall affirmed that, while she does not have hard data, she concurs with Mr. Shields's assessment. China typically starts by developing products for its internal market using more advanced technology. Then it begins to export them as part of a more integrated strategy. The progress that they've made already internally in terms of the enhancements of the BeiDou system on the ground with core systems.

Dr. Sewall then noted that someone commented in the chat: "It is not true that BeiDou is more accurate than GPS".

Dr. Sewall answered that technically it is indeed not true. However as augmented with core stations on the ground and integrated with 5G, the level of accuracy that BeiDou is able to provide, is higher, in many places in the world, including China, than GPS is in the U.S. What China is doing today, and she emphasized that this is what she means by nascent capability, is as much about where the technology can be going. She recommends that predictions based on ways in which China has acted in the past might be reasonable to predict where it could be going with its export of cars, the Digital Silk Road, train stations, BeiDou, 5G, train infrastructure, and automated cars. This is likely to be the path dependency, where people grow comfortable and get trained with BeiDou. China might export to such a country a variety of advanced infrastructure and then argue that the future of self-driving cars, the future of precision agriculture, will be tied to the most accurate and augmented PNT. In the context of the Belt and Road Initiative, on the ground, there are only probably a dozen spaces where they have already built out the core's infrastructure. But they have plans they say and agreements in some cases to do much more. That sets the stage for the exporting of future technologies, including self-driving cars, that will be very appealing to countries with whom China is already engaged in financing and building fundamental infrastructure.

Gen. Hamel started by thanking Dr. Sewall for a very lucid presentation. He went on to note that in terms of products, and services, the Chinese are trying to promote BeiDou as a centerpiece of some of their political, commercial, and security ambitions. He went on to ask whether there are less well-known areas in Dr. Sewall's studies that could become longer-term threats. Things like the shaping of international standards and how these may interconnect with other areas that maybe get less attention than what is being implemented through the expansion of Belt and Road.

Dr. Sewall emphasized that China's investment in international standards bodies could allow it to dominate standards, unless the U.S. takes a fundamentally different perspective. Again, it is hard to argue now that this is occurring. It is again part of what she sees as a nascent capability that if you look at other areas of technology in which China has moved out to develop some leading-edge capabilities and then paired it with a 100 to 1 ratio of participants in the standards processes. She thinks the U.S. should predict that. The only way to overcome that is for other nations to be doing as much innovation and being as committed to the standards bodies. She thinks that in the same way that the U.S. has tended to not see the signals, not connect the dots based on historical behavior, and then be surprised. I-Q-Tel sees space for American perspectives to include technological standards. She thinks this is an area in which the government is not paying sufficient attention. She cannot speak to all private industry, but much of private industry is not paying attention either.

Mr. Goward thanked Dr. Sewall. He went on to ask for "Not IQT Sarah", but rather "Harvard Sarah or private citizen Sarah", to answer the question of who in the USG should care the most about this problem, be in charge of it, and address it.

Dr. Sewall answered that the problem cannot be addressed unless the DoD is running front and center, but she thinks that DoD's perspective has not been broadened to think about a whole of government approach. This would mean thinking about the economic and diplomatic dimensions, but also thinking less about the equities that have typically been considered to be salient in the context of GPS with the North Atlantic Treaty Organization (NATO) and other allies. Instead, she encouraged the U.S. to think about the broader global South, non-aligned countries, and even countries that the U.S. would have typically been quite close to, Pakistan for example. The Chinese BeiDou data-based relationship has been significant. Pakistan was one of the first places in which BeiDou developed training and assistance programs. The key player is going to be DoD because it is the entity that often can have the most sway in the context of a bureaucratic and budgetary decision-making process. But the people that are not yet engaged in about eight of the U.S. foreign export technology stack are the NSC Tech director, and the new person at State, Nate Fick. They are beginning to think about cables, servers, and telecommunications. They need to also be thinking about how space-based PNT fits into this, and how it undergirds it. What does it mean if the U.S. is not modernizing as quickly? If it is not finding ways to create choices for other nations in the developing world, in particular by helping them match the accuracy of what China is providing to them? How does the U.S. create an alternative and a set of choices for the world so that it is not either creating dependencies upon the Chinese government or separate ecosystems that end up bifurcating and decoupling global connectivity?

Dr. Parkinson concluded the session by thanking Dr. Sewall for the very thought-provoking and excellent presentation.

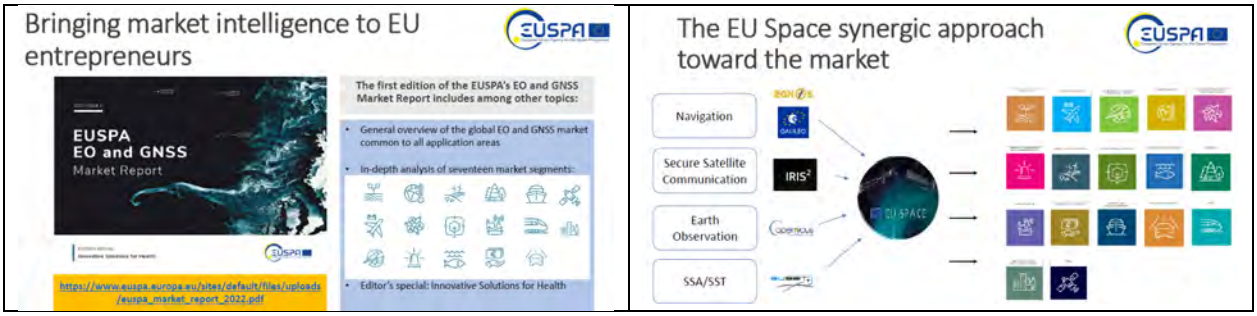
* * *

Virtual briefing - Galileo High Accuracy Service (HAS) & Open Service Navigation Authentication (OSNMA) (View PDF)
Ms. Fiammetta Diani, Head, Market Development, European Agency for Space Program (EUSPA), Prague, Czechia

Ms. Diani introduced herself and outlined the theme of the presentation, which are two new services offered by the Galileo program: the Galileo High Accuracy Service (HAS) and the Open Service Navigation Authentication (OSNMA) (Slide 1). Galileo is part of the European Union's (EU) space program. The EU is quickly becoming the first space investor on the European continent. It covers different domains that are strategic for Europe. Navigation is one, but they have also recently ventured into satellite communication with Iris Program[1]. There is also Copernicus, the number one Earth observation data provider in the world today. They have also started a European contribution to the SSA SST[2]. Their approach is very user- and market-oriented. There are synergies between the components of their space program. They target users ranging from agriculture to maritime, security, surveillance, and more. The EU Agency for the Space Program (EUSPA) is in charge of the services & operations, and navigation of Galileo, but also of the security of the different components of this space program.

Slide 1

Ms. Diani's areas of activity are in market development, applications, and innovation (Slide 2). They have developed a market intelligence report that covers the worldwide GNSS and Earth observation industry (Slide 3). This report analyzes seventeen downstream market segments and forecasts economic growth within them for the next 10 years. This has been a very good tool for companies who need to invest, but also for private investors. She encouraged the audience to pick up the read if they had not already.



Slides 3-4

[1] The Iris Program aims to make aviation safer, greener and more efficient by developing a new satellite-based air–ground communication system for Air Traffic Management (ATM), in partnership with Inmarsat.

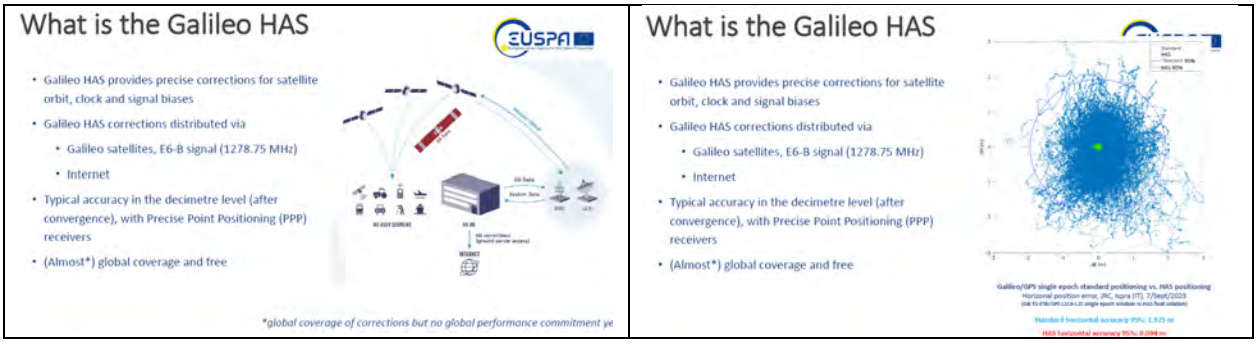
[2] The Space Safety Program (SSP), formerly the Space Situational Awareness (SSA) program, is the European Space Agency's (ESA) initiative to monitor hazards from space, determine their risk, make this data available to the appropriate authorities and where possible, mitigate the threat.

Galileo HAS

The Galileo HAS is already operational (Slide 4). It was decided in 2018 to provide Galileo HAS for free. The idea was to have a service that interprets a trend in GNSS, which over the decades has evolved from GPS Selective Availability all the way to the current possibilities with PPP. The EUSPA wanted to be attentive to meeting user demands. They understood that there was room and demand for this kind of service. It can be used for classic commercial applications, but it can also offer the building blocks to create more innovative and precise services. Beyond the performance that they offer as a provider, they are also generating new businesses and ventures in the field through their own Galileo infrastructure. In addition, the EU wanted to offer a service that is global, free, and with a 24/7 operation guarantee.

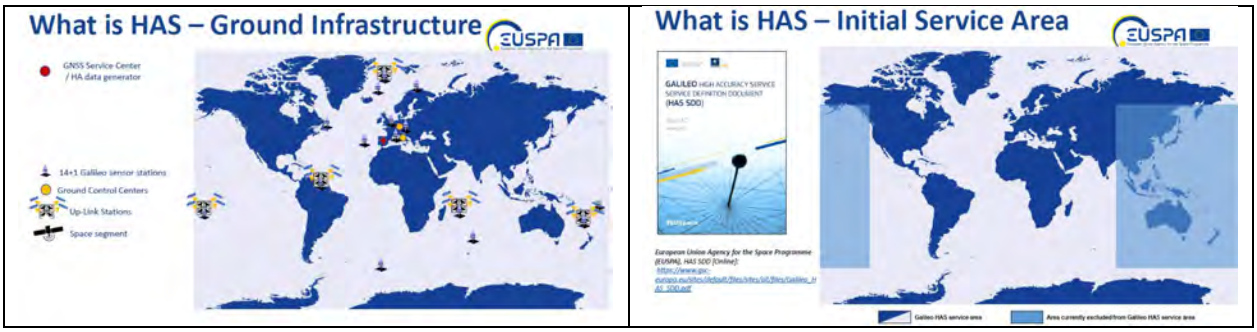
Slide 4

Galileo HAS provides corrections for satellite orbit, clock, and signal biases (Slide 5). These corrections can be provided in two ways: (1) Directly from the satellites via the E6 signal; or (2) Via the internet for connected receivers. They typically target accuracy at the decimeter level, after convergence, with PPP receivers. The service is free, and at this time covers much of the globe. When comparing Galileo to GPS standard positioning with each a high horizontal accuracy of 95% of less than 10 cm. The picture above illustrates the target level of accuracy (Slide 6).



Slides 5-6

Galileo HAS relies on sensor stations around the world (Slide 7). There is a service center in Spain that generates high-accuracy data. The data is then transferred to two control centers, one in Germany, and one in Italy, and is then sent to an uplink station and sent to the Galileo satellites. The initial service area covers much of the globe, but at the moment cannot be guaranteed everywhere (Slide 8). This will be improved upon in the future. All details about performance, performance commitment, and the service area can be found in their service definition document, which can be found in their service center online[3].

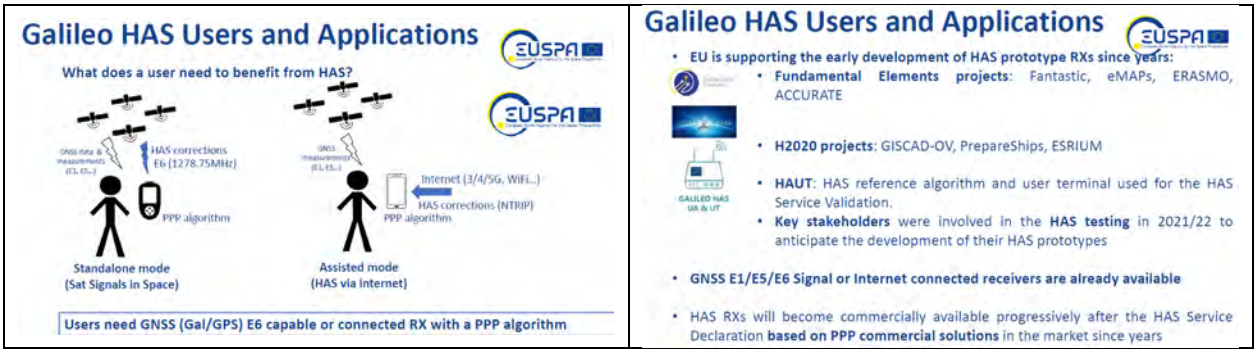


Slides 7-8

[3] https://www.euspa.europa.eu/about/what-we-do/european-gnss-service-centre

There are many applications for Galileo HAS (Slide 9). For example, a better-connected automotive market with automated driving is an emerging case for Europe. There are also other autonomous devices, such as robots. Extensive collaboration is also underway with drone service providers. There already are some examples of mass market applications, but they still have to see wider adoption. There are two modes for using Galileo HAS: the Stand-alone mode (via satellite signals) and the Assisted mode (via the internet). Mobile Communication are required in both cases.

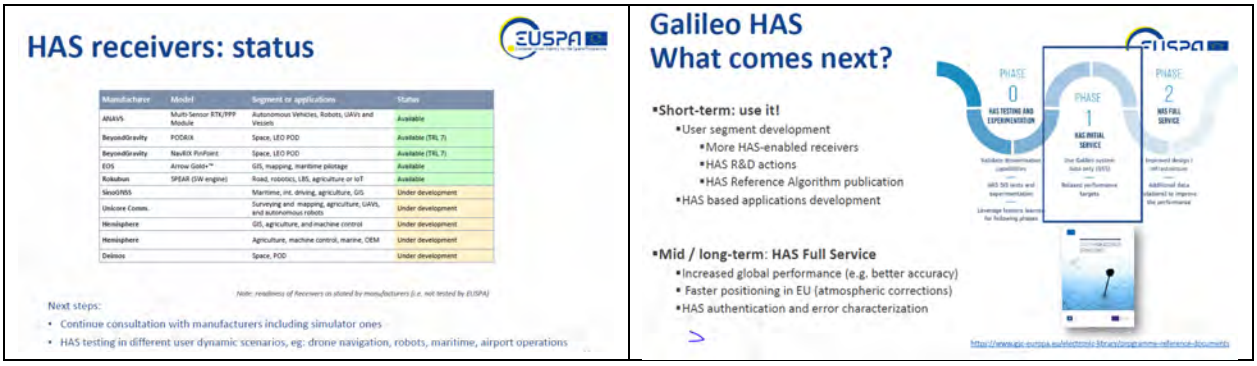
EUSPA has also created a set of tools to be ready with the receivers for when the service is made available (Slide 10). To achieve this, they supported the development of a certain number of receivers, the reference algorithm, and the user terminal for service validation. This was also the opportunity for them to engage the key stakeholders in a testing phase that that took place in 2021 and 2022. It allowed them to be ready for the current phase that is already operational.



Slides 9-10

EUSPA believes that more and more receivers will become commercially available (Slide 11). There already are some receivers on the market. They know that many of them are still under development, but very close for launch into the market. They are supporting the community of receiver manufacturers through consulting, but also technical support in different application areas for quicker and better implementation.

Galileo HAS is already operational in its initial services (Slide 12). In the short term, EUSPA's message is to please start using it or help in building this user community. There will be more and more receivers in the market. They will continue to support and publish their reference algorithm to democratize the HAS. There are also ambitions in the long term. EUSPA would like to have a full service to target increased global performance and better accuracy. For Europe in particular, they will provide atmospheric corrections to have faster positioning. Also, they are thinking about authentication of the HAS and error characterization.



Slides 11-12

Open Service Navigation Message Authentication (OSNMA)

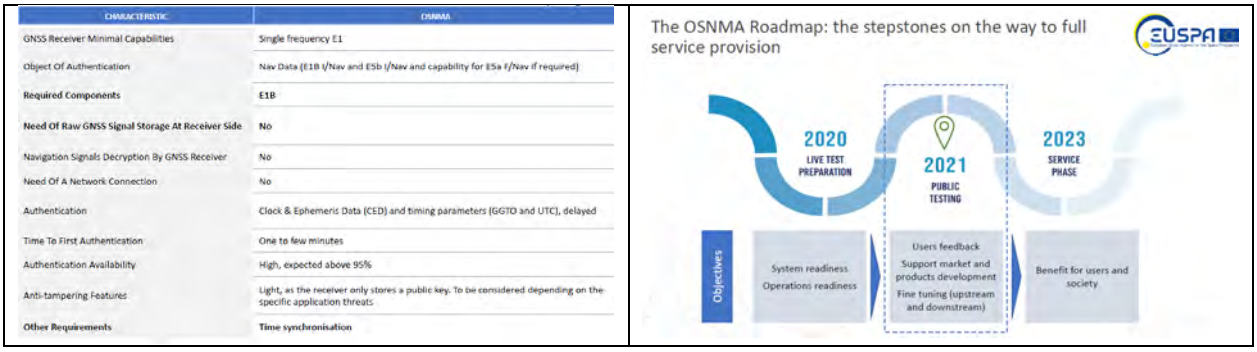
OSNMA is the authentication for the open service of Galileo. This is the first step of the Galileo program to ensure the robustness of user navigation for civilian use (Slide 12). They are already providing a broadcasting signal, even if they have not yet declared it operational.

It uses a digital signature with a key that provides the authentication of the navigation message data (Slide 14). In order to use it, an OSNMA enabled receiver is required. EUSPA is also working with receiver communities and already has many ready to launch when the service becomes fully operational. OSNMA is easy to implement. It is based on a public key and it gives users information on whether the navigation data is coming from a Galileo satellite instead of a spoofer. This is the main information that is given to the user via their operating system or application provider.

Slides 13-14

Slide 15 outlines the minimum capabilities or characteristics a receiver needs to have to use authentication. There needs to be at least a single E1 frequency however, E5 can also be authenticated. It also works for dual-frequency receivers. The required components are in the E1B signal. There is no need for data storage from the receiver side, so it is a rather simple implementation. Time synchronization is required in the receiver. Not all provide this and so they are working with the manufacturers for it to be possible. EUSPA is now targeting the receiver mass-market, receivers that go in smartphones, wearables, etc.

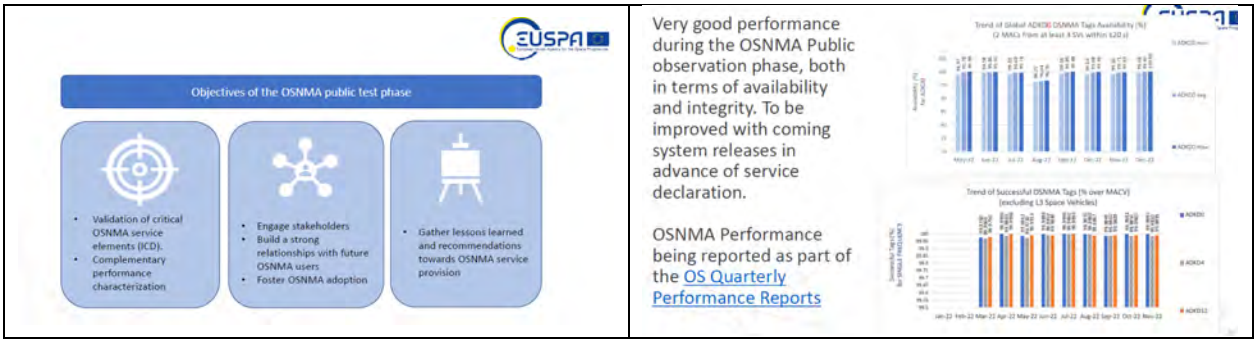
Currently, EUSPA is in a public testing phase (Slide 16). They entered this phase in November 2021, and are already broadcasting the authentication signal, receiving user feedback, supporting application developers, and fine-tuning the service. They expect the official rollout to happen towards the end of 2023.



CHARACTERISTIC	OSNMA
GNSS Receiver Minimal Capabilities	Single frequency E1
Object Of Authentication	Nav Data (E1B I/Nav and E5b I/Nav and capability for E5a I/Nav if required)
Required Components	**E1B**
Need Of Raw GNSS Signal Storage At Receiver Side	**No**
Navigation Signals Decryption By GNSS Receiver	No
Need Of A Network Connection	No
Authentication	Clock & Ephemeris Data (CED) and timing parameters (GGTO and UTC), delayed
Time To First Authentication	One to few minutes
Authentication Availability	High, expected above 95%
Anti-tampering Features	Light, as the receiver only stores a public key. To be considered depending on the specific application threats
Other Requirements	**Time synchronisation**

Slides 15-16

The public testing phase is being used to engage the stakeholders, users, and to be ready for larger adoption (Slides 17-18). They are also gathering lessons learned for the future to improve and create new services. Testing has already been underway for a while. EUSPA believes that the performance they are experiencing is pretty good, in terms of both availability and effectiveness of the authentication signal. Some performances are not ideal, but that is why they are conducting a testing phase. They are still fine-tuning the performance. They also have published quarterly performance reports that can be consulted. They allow a deeper dive into the performance of this phase.



Slides 17-18

It is possible to join this OSNMA test phase on the website of the Galileo service center[4] (Slide 19). EUSPA is targeting informed users, such as manufacturers, application developers, or researchers to participate in the test phase. If anyone at the meeting today wishes to join this test phase, there is still time.

To learn more, EUSPA has a set of public documents that are made available (Slide 20). They have already published the Interface Control Document (ICD). It is meant for the service phase, so it will be in effect through next year. It allows manufacturers to already be building final receivers. EUSPA has also published guidelines for research manufacturers. It is good guidance for implementation if one doesn't know where to start. Finally, there is also an OSNMA Info Note. It is a service description with definitions, a user manual, target users, and instructions on how to create value through the service. EUSPA is now finalizing the testing phase. They do expect to have the service official announcement and rollout at the end of the year. For this reason, the ICD has been published and cryptographic material made available. EUSPA wants to be ready from the start with all the products and are looking forward to the rollout.

Slides 19-20

In summary, OSNMA is already ready (Slide 21). The service acceleration will be achieved soon and they invite the audience to please use it and help build the user community.

Slide 21

Discussion:

Governor James E. Geringer had a question about HAS and its required PPP receiver. He inquired on whether the majority of Galileo receivers in the civil sector were equipped with it today or if that was something they were looking at for the future.

Ms. Diani answered that there are receivers that are already equipped with the PPP algorithm, but of course, not all of them are yet. This is also the reason why they would like to make their reference algorithm available so that it can be used or inspire the development of PPP algorithms at the receiver level.

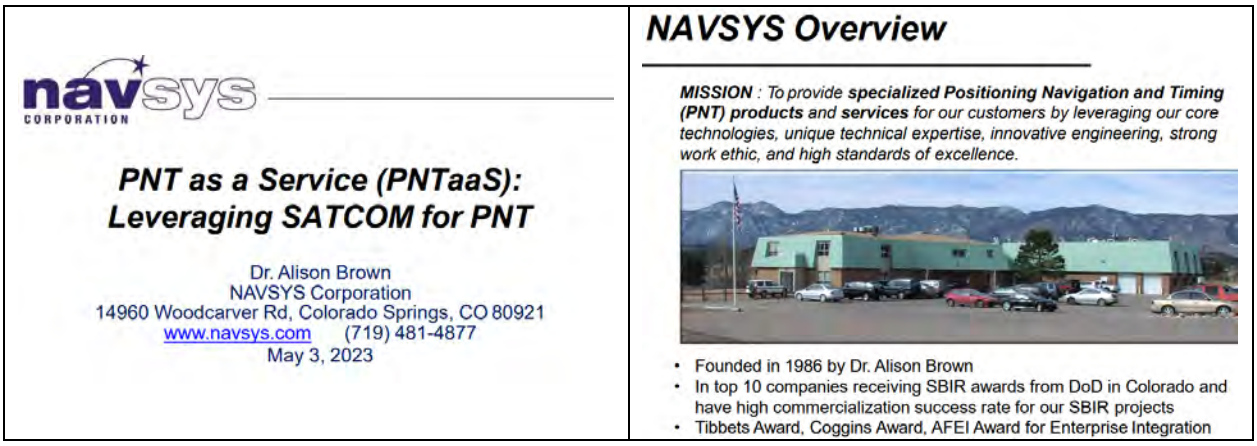
Dr. Bradford Parkinson said the session was very enlightening. In terms of civil authentication, the EU is certainly leading the pack.

* * *

[4] https://www.gsc-europa.eu/support-to-developers/osnma-public-observation-test-phase

PNT as a Service (PNTaaS) Solution Benefits (View PDF)
Dr. Alison Brown, *President & CEO, NAVSYS Corporation*

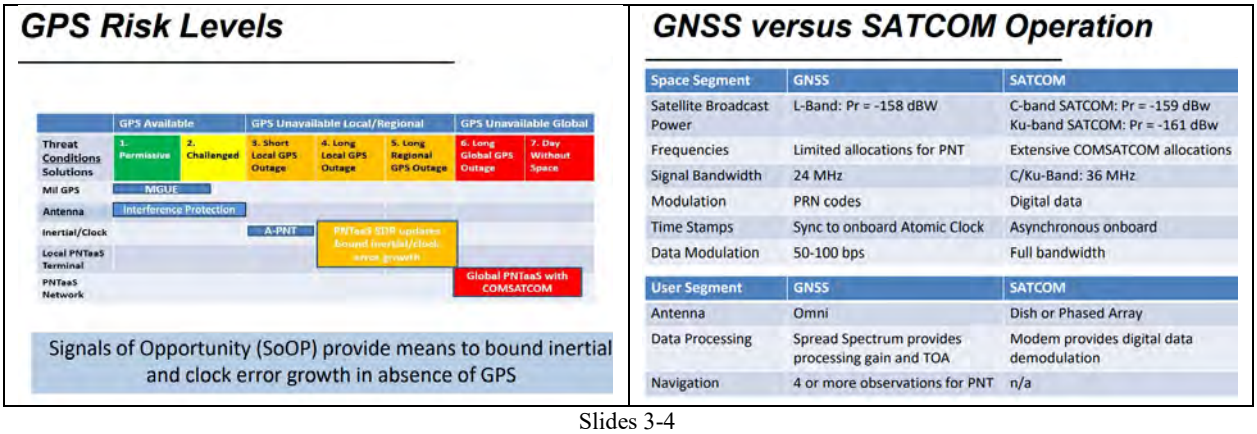
Dr. Brown opened the presentation by noting that NAVSYS has been operating since 1996 (Slides 1-2). Since then, its mission has been to develop advanced PNT technologies. NAVSYS fielded the first GPS cellphone, which is now display at the Smithsonian. The technology developed for it evolved to the standards we have today. Similarly, they developed first implementations of WAAS, which were carried through the first few generations of the program. Today's presentation describes what NAVSYS believes could become the next "big thing" in PNT, which is using Signals of Opportunity (SoOP) to bound inertial and clock error growth should GPS not be available over long periods of time. This project has been developed through Small Business Innovation Research (SBIR) government contracts. This is a capability that can be an open architecture to encourage participation from different partners, including government, industry, and international.



Slides 1-2

The integration [with GPS] of inertial & clock devices can sustain operations for short periods in the absence of GPS, but we need to have solutions that will extend over long periods. (Slide 3). The objective is not to replace GPS, but to supplement it in Assured PNT (A-PNT) devices that are already working with GPS. This would allow such devices to continue to operate over extended periods of time, and through long distances, should GPS not be available. Rather than putting out new signals in space, we are using signals that are already available and primarily used for purposes other than navigation. We are focusing on SoOP, so that rather than putting out new signals in space we are using signals that are already available, such as satellite communication signals (SATCOM).

There are many similarities and differences when operating GNSS signals vs. SATCOM signals (Slide 4). SATCOMs have about the same received power as GNSS signals, but usually have higher bandwidth and are designed to carry digital data. So, whereas a GNSS signals has a known code modulation (a PRN code), SATCOM satellites are broadcasting what is essentially random data. Therefore, to receive SATCOM signals, one needs high gain antennas. GNSS is using spread spectrum and, therefore, can work with an omnidirectional antenna. Another key difference is getting the frequency allocation for new PNT signals, whereas SATCOM signals already have extremely broad frequency allocations.

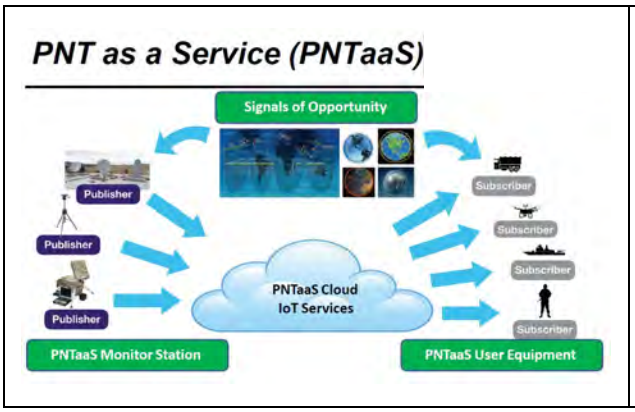


Slides 3-4

The PNT as a Service (PNTaaS) solution is designed to provide an augmentation that would allow any SATCOM signal to be used for PNT (Slide 5). We add the concept of putting a "publisher," or monitoring station, on the ground that is looking at the SATCOM satellites and the time-of-arrival of a segment of the signal. The random content within the signal itself becomes the "code of the

second" for that satellite. By publishing that snapshot (we use an Internet of Things, or IoT, protocol for that) along with the associated time-of-arrival of that snapshot to a reference clock at the monitor station, we now have the same information as we do in a GNSS. That is, we know the code and the timing of that code. Any of these subscribers can access this service over the network and do what we call a "smart data pool" and select which of the SoOP to subscribe from and apply their embedded A-PNT solutions.

Slide 6 summarizes the differences between GNSS and PNTaaS signals. The limitations to this approach, because of the many SATCOM satellites available, is what the capability is at the receiver. We are currently testing this with multiple omnidirectional antennas at different bands to leverage the huge frequency allocations we have access to. Also, to keep the user equipment size, power, and weight down we are using a single-channel software-designed radio that can switch between frequencies at a millisecond level, and by capturing the internal snapshots with very precise time marks so we can synchronize the capture at the user end.



GNSS vs PNTaaS

Space Segment	GNSS	PNTaaS
Satellite Broadcast Power	L-Band: Pr = -158 dBW	C-band SATCOM: Pr = -159 dBw Ku-band SATCOM: Pr = -161 dBw
Frequencies	Limited allocations for PNT	Extensive COMSATCOM allocations
Signal Bandwidth	24 MHz	C/Ku-Band: 36 MHz
Modulation	PRN codes	Monitor publishes snapshots
Time Stamps	Sync to onboard Atomic Clock	Monitor publishes TOA of snapshot
Data Modulation	50-100 bps	Network access to PNTaaS data
User Segment	**GNSS**	**PNTaaS**
Antenna	Omni	Multiple Omni at different bands
Data Processing	Spread Spectrum provides processing gain and TOA	Processing gain from PNTaaS snapshot correlation gives TOA
Navigation	4 or more observations for PNT	Sequencing through multiple snapshots provides A-PNT updates

Slides 5-6

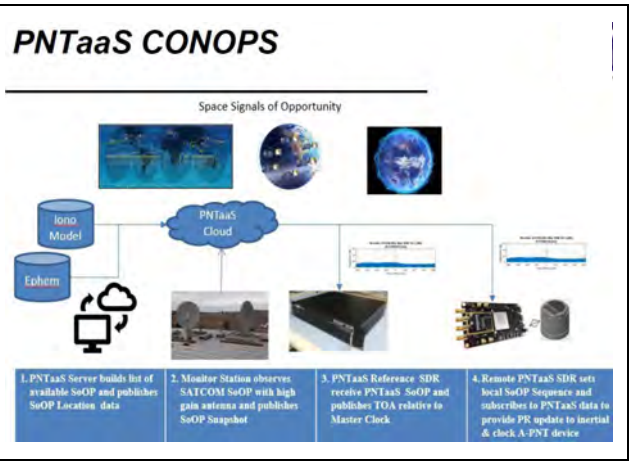
Slide 7 shows examples of the SoOP signal frequencies and satellites they have the capability to use with their radios.

Slide 8 depicts the Concept of Operations (CONOPS). A PNTaaS server has been established, which is the mechanism by which they publish the SoOP location data. The picture shows the monitor location located at NAVSYS, and they are currently installing stations at other locations operated by their partners. The reference Software-Defined Radio (SDR) can be collocated with the monitor stations, but it doesn't really have to be. Currently they are using GPS receivers to provide the master clock, but would like to tie this directly back to the USNO/NIST master time references. Finally, the remote SDR is designed to operate in a decoupled fashion with an inertial and clock device which, as far as the users are concerned, is getting a continuous PNT output.

GNSS versus SoOP Signals

Band	Freq	SoOP	Orbit
L	1 – 2 GHz	GNSS, Iridium	MEO
		Inmarsat	GEO
S	2 – 4 GHz	GlobalStar	MEO
		TDRS	GEO
		COSMIC-2	LEO
C	4 – 8 GHz	Xona	LEO
		Intelsat, Telesat, SES, etc.	GEO
X	8 – 12 GHz	WGS, Skynet	GEO
Ku	10.7–12.7 GHz	OneWeb, SpaceX	LEO
	12 – 18 GHz	DBS, Viasat	GEO
Ka	17.8-18.6 GHz	Telesat, Kuiper, O3B	LEO
		ViaSat, Telesat	GEO

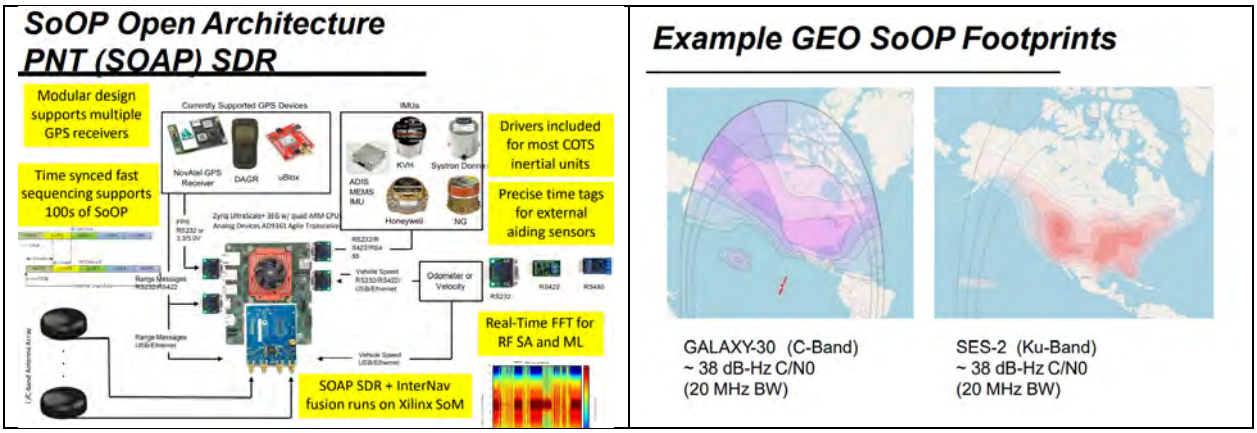
Existing SATCOM systems have many more frequency allocations than GNSS



Slides 7-8

Slide 9 depicts a layout of the SDR. NAVSYS has units it has been using for development and are also providing GNSS development kits to their partners so they can integrate this into their own products. Some of the capabilities of the SDR include the ability to provide time synced fast sequencing through hundreds of signals of opportunity. This is where they can do the "smart pooling" and the smart subscription to the monitoring stations that are published in the PNTaaS data for those particular signals. This is tightly coupled with the inertial device. They also have the capability to do real-time FFT to assist with the correlation and allows gives them the real-time situation awareness, which is tied in with the machine learning algorithm that does the selection of the data.

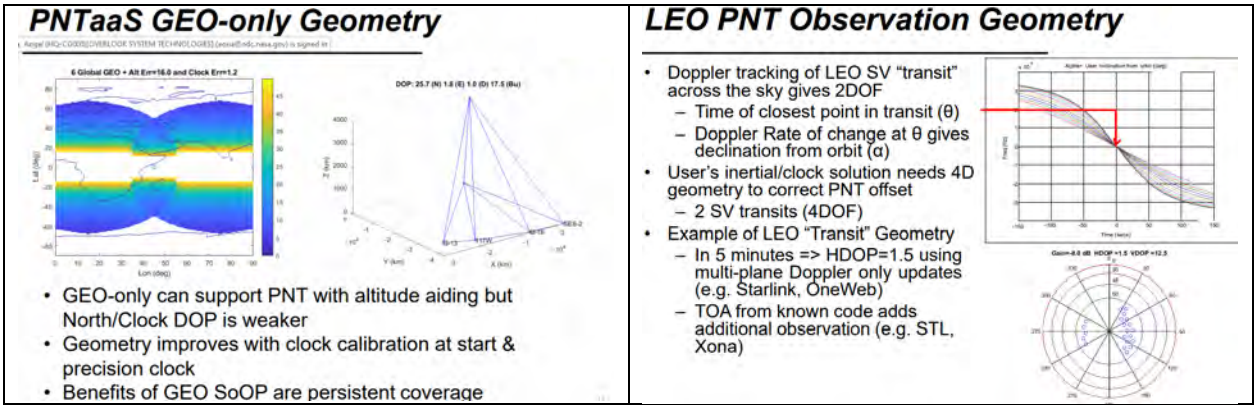
Slide 10 shows an example of some of the signals NAVSYS has been testing with.



Slides 9-10

The geometry of the transmitting satellites is key. Slide 11 shows what the geometry looks like for a constellation of six global GEO satellites with altitude aiding and a calibrated clock. It is possible to get a four degree of freedom update. The geometry does not allow to track over the poles, where GEO signals are not available, and over the equator where the geometry falls apart.

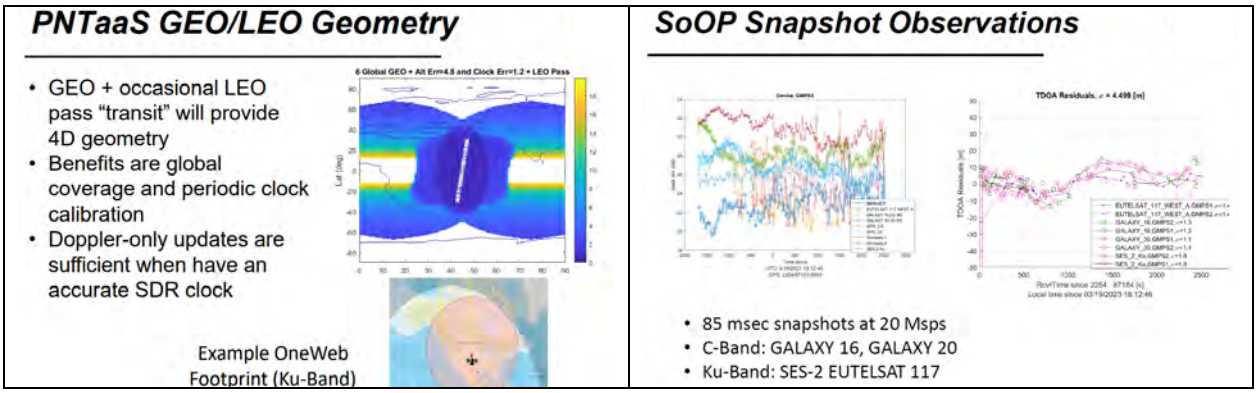
When mixing LEO satelites into this, you get a complementary geometry (Slide 12). A single LEO satellite, as it transits across the sky, can give you a two degree of freedom update. Also, periodically there will be a LEO pass that will be sufficient to calibrate the clock.



Slides 11-12

Slide 13 depicts the geometry when combining GEO & LEO for PNTaasS. When comparing this to Slide 11 (GEO-only), it is apparent how a LEO satellite can fill in the gaps. The slide also shows an example Ku-Band footprint for a OneWeb satellite.

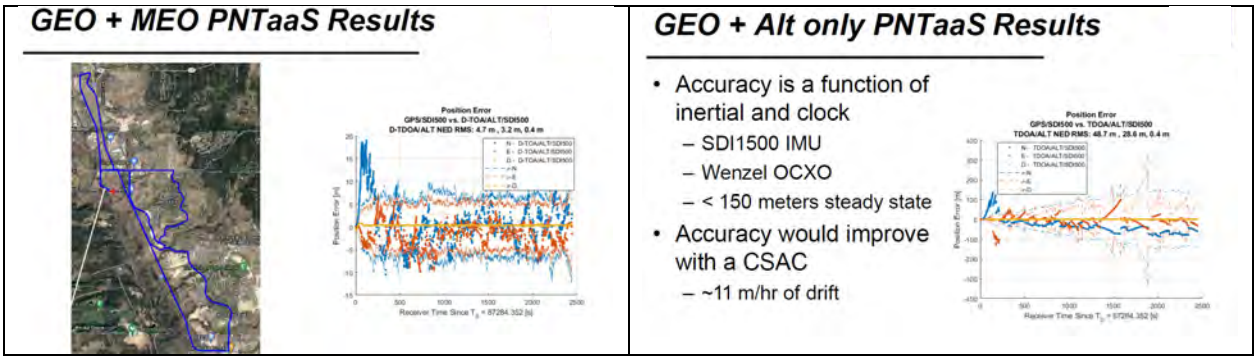
Slide 14 shows actual data. On the left is the signal-to-noise ratio, where we can see the signals are strong. On the right are the Time-of-Arrival observations. Note the clock is drifting, but holding well overall holding. The spread on is only 4 meters (RMS).



Slides 13-14

Slide 15 shows some navigation results when mixing in MEO satellite L-Band signals of opportunity. Once more, we are getting good continuous performance. The inertial and the clock are doing a good job holding the PNT performance between updates.

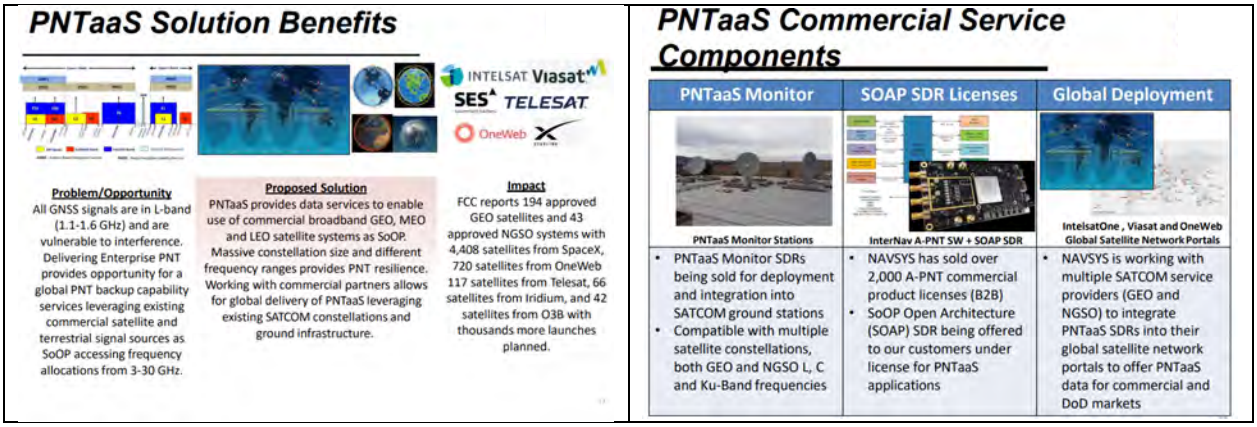
Slide 16 shows what happens when going GEO-only plus knowledge of the altitude. With a reasonable clock it can reach a better than 150 meters steady state. Although inertials are much better than they used to be, they are still the dominant source in the drift.



Slides 15-16

Slide 17 describes the benefits from the PNTaaS solution. Since GNSS signals are in L-Band, its vulnerabilities can be mitigated by leveraging commercial SoOP in other frequency allocations (3-30 GHz). Working with commercial partners enables global delivery of PNTaaS and provides PNT resilience.

NAVSYS has developed a system and tested in live environments to demonstrate interoperability (Slide 18). It has also built monitoring stations that can be integrated into the existing ground Earth stations. NAVSYS has established partnerships with multiple SATCOM vendors to conduct testing and integrate this capability into their architectures. Similarly, they have been developing the user equipment, including A-PNT technology called "InterNav" branded its partner and that is already in thousands of military and commercial systems. The SooP Open Architecture (SOAP) SDR is also being offered under license for PNTaaS applications, and NAVSYS is working with multiple SATCOM providers to integrate PNTAaaS SDRs into their network portals.



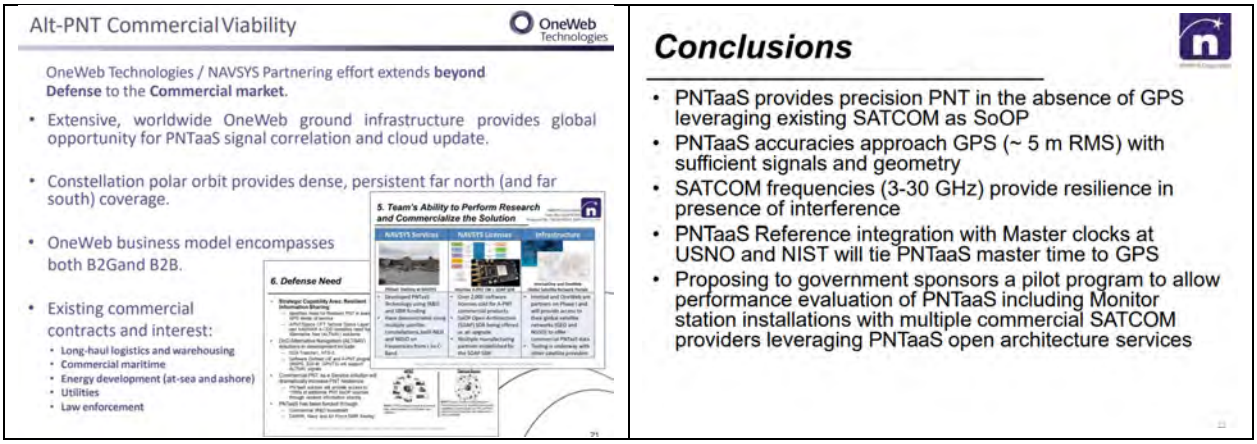
Slides 17-18

Slide 19 describes the extensive IntelSatOne Global Network, which has just installed NAVSYS equipment at one of its network stations and provides access to all their satellites. The equipment can currently handle up to eight PNT satellites at the same time.

NAVSYS is also closely partnered with OneWeb (Slide 20). Since they rely on GNSS to operate their satellites, they are considering alternatives to mitigate its vulnerability.

Slides 19-20

Slide 21 describes what OneWeb is offering. In conclusion (Slide 22), PNTaaS provides PNT without requiring additional space infrastructure. It uses existing satellite commercial services as signals-of-opportunity. The accuracies can approach GPS. Also, by integrating this architecture with the master clocks at the U.S. Naval Observatory (USNO) and NIST, it can get a robust master time even in the absence of GPS. NAVSYS would like to see the government stand up a pilot program to allow performance evaluation of PNTaaS.



Slides 21-22

Discussion:

Dr. van Diggelen asked what is the latency between the sampling of signals of opportunity and the user being able to correlate the data?

Dr. Brown responded that it depends on the network. It can range anywhere from seconds to minutes.

Mr. Logan Scott noted that it appears the key limitation is getting from the local reference station to the field. Any thoughts on how you might choose which bandwidth you want to operate with?

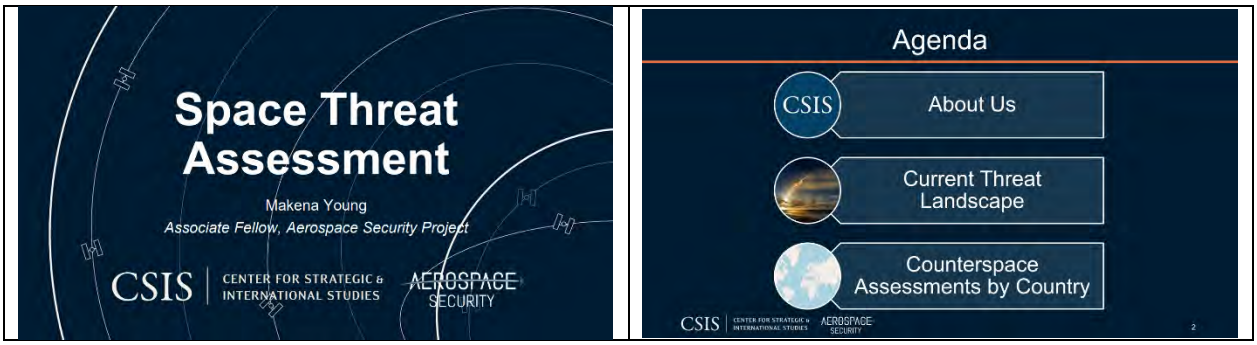
Dr. Brown noted that what they do with the monitoring stations is to publish the data. They allow the user equipment to basically do an intelligent pull. That's one of the advantages in the internet protocol NAVSYS uses. The subscriber is in control, not the publisher. There is a trade between power and bandwidth. We can work with very short signal snapshots if the signal has enough receiver power. Also, this can be done in both cooperative and non-cooperative modes.

* * *

Theme 3: Protect, Toughen, and Augment – Ensuring Access to GNSS Service

2023 Space Threat Assessment: Trends in Development, Testing, and Use of Counterspace Weapons
Ms. Makena Young, *Associate Fellow with the Aerospace Security Project, Center for Strategic and International Studies (CSIS)*

Ms. Young thanked the Board for inviting her to present and introduced herself as an associate fellow at the Aerospace Security Project at the Center for Strategic and International Studies, which is a think tank located in Washington DC. She stated that she'd be discussing the organization in more detail, the current threat landscape, and a counter space assessment by country which comes from their recently published Space Start Assessment 2023 (Slides 1-2). This is the sixth iteration of this report that details counter space capabilities from China, Russia, India, Iran, North Korea, and some other countries.



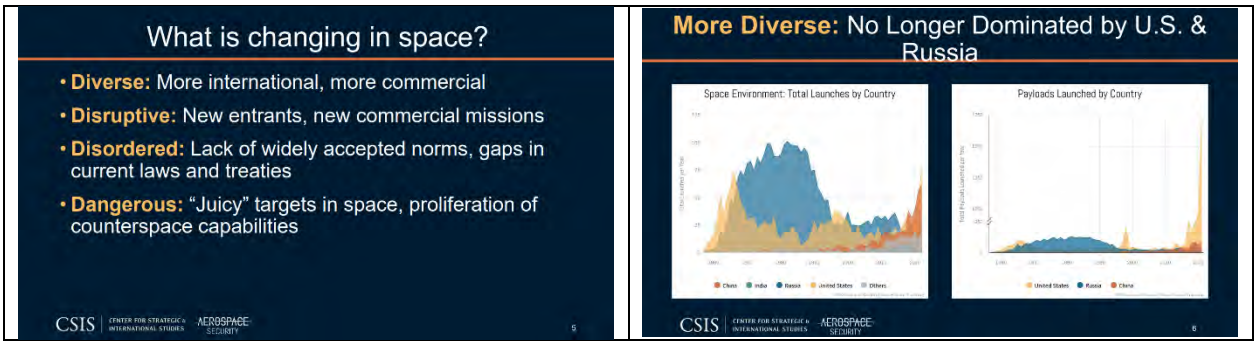
Slides 1-2

CSIS is a non-profit, bipartisan think tank with over 200 scholars focusing on regional and functional issues spanning the globe (Slide 2). The team at the Aerospace Security Project focuses on space issues that span national security space, civil space, and commercial space, as well as air power and cross-domain integration. CSIS's mission is to educate and inform the public largely by producing in-depth analysis as can be seen in their most recent reports. Notably, all published work at CSIS is unclassified. Ms. Young stated that the deputy director and herself do not hold clearances. While Scholars at CSIS can have clearances that are held elsewhere, all the work that is done at CSIS is based on open-source research and is unclassified. As shown on the left in Slide 3, CSIS published a report in December of 2022 called Low Orbit, High Stakes on the LEO broadband competition, which looks at Starlink, Kuiper, One Web, as well as what China is doing within the LEO broadband sector. The report in the middle on Slide 3 is the Space Threat Assessment 2023, which was published on April 14. Ms. Young stated that this will be her focus for her presentation today. On the right in Slide 3 is a paper called Defense Against the Dark Arts in Space which is a follow-on to CSIS's annual Space Threat Assessment giving a broad overview, largely focused towards policy makers, on initial steps to protect space assets from counter space capabilities.

Slides 3-4

Space is becoming more diverse, more international, more commercial, more disruptive with new entrants and new commercial missions, and more disordered with a lack of widely accepted norms and gaps in current laws and treaties which all makes it more dangerous (Slides 4-5). As leaders like to say, there are "juicy" targets in space and a proliferation of counter space capabilities which threaten them.

Space is no longer dominated by just the U.S. and Russia. Slide 6 depicts two charts of data analysis that can be found on CSIS's website. The chart on the left it looks at the space environment for total launches by country and the right is payloads launched by country. China is an orange, Russia and blue, and the U.S. in yellow. This shows that up until about the mid-1990s, space launch and space payloads launched were dominated by Russia, and to a smaller extent the U.S. In the late 1990s, China began to ramp up their launches. There is a very large spike in U.S. launches at the tail end of the payload launch graph. This comes from Starlink, who have placed almost 4,000 satellites in orbit.



Slides 5-6

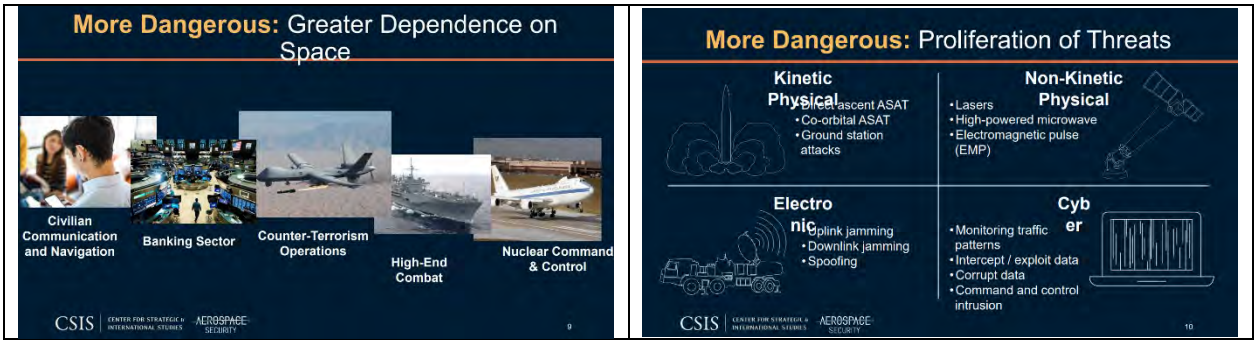
This has caused space to be more disruptive (Slide 7). In the 1950s and 1960s, launches were conducted exclusively by government, largely military missions, from the U.S. and Russia. At that time, even commercial satellites were heavily subsidized and drew on technology from the government. During the 1990s, commercial space started to pick up with commercial remote sensing and commercial communication satellites being launched, but a lot of these systems were still very much dependent on the government for various reasons. Today, the center of innovation is arguably in the commercial market and commercial companies are leading the way. This is brought down the size of satellites, the speed at which they are able to be produced, the cost of launch, and the number of satellites that can be launched at once. As of today, almost 85 percent of all satellites in orbit are commercial. An example of commercial dominance can be compared to this image on the top right in Slide 7. These are Planet Dove Earth Imaging Satellites, which are about the size of a shoebox, can be launched by the dozens and have a resolution of about three to four meters. They're not exquisite systems but because they have so many satellites, they can get a much higher revisit rate to get a fuller picture. These can be compared to the image in the top left in Slide 7 which is of the now declassified Corona Spy Satellite which, also has a resolution of about three to four images and is about the size of a school bus. These use wet film that had to be sent back down to be developed. This is an example of how far the commercial sector has been able to iterate from these early systems. The commercial sector has also been working on future technologies, such as 3D printing in space, on orbit servicing and refueling, as well as asteroid mining.

Laws and regulations are not keeping up with these technological innovations. For example, SpaceBee nano satellites are about the size of a Rubik's Cube and include four satellites stacked on top of each other (Slide 8). The FCC denied their license, not because anything was wrong with the radio system on the satellite, but because they thought the satellites were too small to be tracked. Unfortunately, SpaceBee went through an intermediary who notified that everything was okay with these satellites, and they later launched on an Indian space launch vehicle. This was not the government of India's fault because it is not their responsibility to confirm that U.S. companies have been properly regulated. They simply got bad information. On the right side in Slide 8, there are two pictures from SpaceX missions: the Falcon 9 second stage video feed and the Falcon Heavy/Spaceman car launch. These videos both included cameras that look down on the Earth as the satellites were launching. National Oceanic and Atmospheric Administration (NOAA) regulates all cameras that are on board satellites or launching systems. SpaceX was not aware of this and just launched these rockets with cameras on them (they did this nearly a dozen times before NOAA was made aware). Once NOAA was made aware of this, they shut down their video feed in the middle of a launch. This is another example of how easy it is to misread or ignore regulations.

Slides 7-8

The U.S. and its allies and partners have become much more dependent on space across the full spectrum of combat operations, as well as everyday civilian uses (Slide 9). Our adversaries know this, and it can become an Achilles heel. If the U.S. wants to be able to project power over long distances, there is no substitute for the capabilities that space provides. Our adversaries have developed and are proliferating a wide range of counter space weapons, which is what CSIS focuses on in its annual Space Threat Assessment.

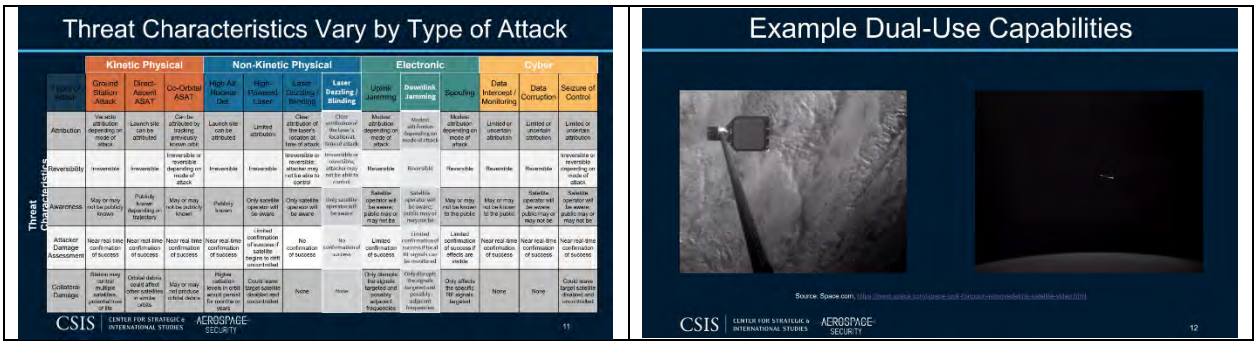
The counter space threats are split into four main groups (Slide 10). First, on the upper left-hand side in Slide 10 is Kinetic Physical, which include direct assigned Anti-Satellite (ASAT) tests or ground station attacks that destroy a segment of a satellite or a ground station. The upper right in Slide 10 is Non-Kinetic Physical, which include lasers and high-powered microwaves which can disrupt parts of the satellite without physically destroying them. The bottom left is Electric counter space capabilities that deal primarily with uplink and downlink jamming as well as spoofing. On the bottom right, Cyber capabilities regard the corruption of data, command, and control.



Slides 9-10

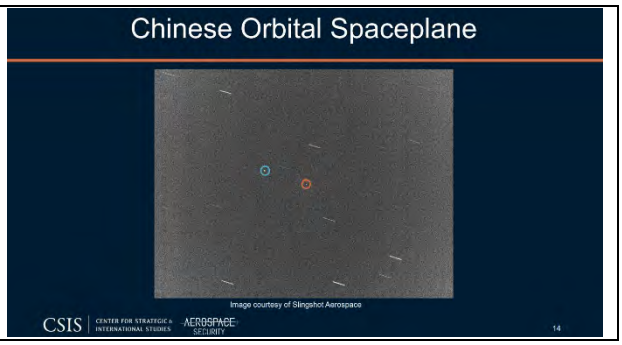
Each report includes a chart which depicts the threat characteristics (Slide 11). Ms. Young highlighted two columns in Slide 11: (1) Non-Kinetic Physical includes dazzling and blinding. Only the satellite operator may be aware of an attack. It's hard to get a confirmation of success and it may be reversible; and (2) Similarly, an electronic with downlink jamming can be reversible. The satellite operator will be aware, but they may not have to make the public aware and there is limited confirmation of success. CSIS details the different characteristics in these four categories.

CSIS also analyzes the dual use capabilities (Slide 12). For example, a commercial company based in the UK is working on orbital debris mitigation. On the left side in Slide 12 is a harpoon that reaches out and grabs onto an object in space and then reels it in. The right side in Slide 12 shows a net that goes after a spiraling satellite. Both are fine when considering that this is a UK-based company, but if countries such as China or Russia were to develop these capabilities, it would warrant greater concern.



Slides 11-12

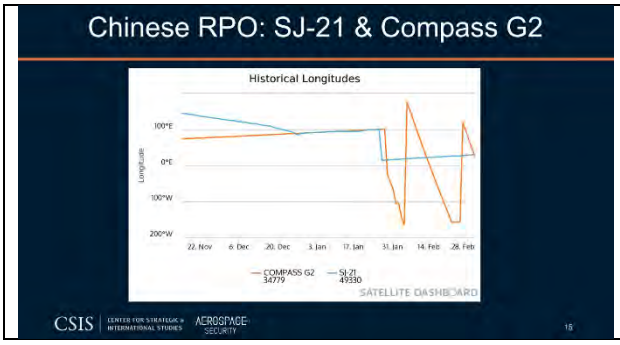
In CSIS's annual report, activities from China, Russia, India, Iran, and North Korea are detailed (Slide 13). China continues to make progress towards its goal of becoming the world leader (Slide 14). CSIS categorizes China as the second most capable space nation behind the U.S. in space. They had 64 launches this year, which broke their record of 55 launches from last year, and they continue to grow their space capabilities in every category. In August of 2022, China launched two different spaceplanes: one orbital and one suborbital. This was the second test of each of these systems following tests in 2020. On August 4, 2022, almost after two months in LEO, the spaceplane raised its orbit on October 23 and then released an object. Although it's not clear from publicly available data when exactly the spaceplane released the object, the USSF space tracking database recognized the object on October 31, 2022. The image in Slide 14 is from commercial company Slingshot Aerospace. The spaceplane can be seen in the blue circle and the object it released is in the orange circle. CSIS focuses on highlighting commercial data in their reports emphasize how far the commercial market has come and how much information is available.



Slides 13-14

China has a long history of producing satellites capable of performing on-orbit Rendezvous and Proximity Operations (RPOs) commonly in GEO (Slide 15). This was a highlight in last year's assessment where SJ-21 was launched in October 2021 as an experimental debris mitigation satellite which separated from its upper stage apogee kick motor. It's unlike most satellites in GEO. The Apogee Kick-Motor (AKM) stayed near the satellite for a while in which SJ-21 performed a rendezvous and proximity operations around the AKM before it separated into GEO. The graph shows SJ-21 in blue come close to the orbit of Compass G2, which was a defunct beta satellite that was in GEO. China publicly stated that this was a debris cleanup mission to take this defunct Compass G2 satellite and move it into a graveyard orbit. In late December SJ-21 comes very close to Compass G2—possibly even docking with it—stays in a very close proximity for about a month until January 22, 2023, where it raises its latitude and moves Compass G2 into a graveyard orbit almost 3,000 kilometers above GEO, drifting in a westward direction. This maneuver lasted about three days with SJ-21 releasing Compass G2 into the graveyard (disposal orbit above GEO altitude) on January 26. Updated information from this year showcases that SJ-21 took Compass G2 significantly higher than a typical graveyard orbit, which is highly unusual for these debris removal missions and shows that Chinese capabilities have continued to develop every year.

CSIS's 2020 report included incidents reported throughout 2018 and 2019 of GPS signals for automatic identification systems (AIS) were being inaccurate in the main port of Shanghai (Slide 16). The image is from a resource organization called Skytruth, which found that two GPS interference locations around an oil terminal were active and had a dramatic effect on scrambling vessel positions in the area. Some vessels were even shown to be far inland and going 25 to 103 knots on the mainland, which is a clear indication that that this is inaccurate data. On the water many positions are also appearing with very high speeds to be over 25 knots. It's not possible to distinguish true or false locations. Skytruth has not found a responsible party. Some experts have claimed this to be non-state actors while others believe that this technology was so advanced it had to have been a part of the government.



Slides 15-16

One of the most notable and visible counter space activities of 2021 was the Russian anti-satellite test performed on November 15 (Slide 17). An interceptor was launched and successfully hit and destroyed defunct Russian satellite Cosmos 1408 that had been in orbit since 1982. Russia has possessed this kinetic ASAT capability for years. From 2015 to 2020, Russia tested this capability ten times—the last eight of which were successful. Though they did not hit their targets in orbit, these eight successful tests showcased the full capability of this system which made this debris-creating test a surprise to many space analysts around the world. Russia has taken great pride in being on the cutting edge of space technology from the 1960s, but in recent years the country has launched significantly fewer space objects and this ASAT test may have been a way to loudly remind the space community that Russia is still a major space power with meaningful military capabilities and to ensure that Russia was not left out of any norms-building discussions surrounding ASAT weapons.

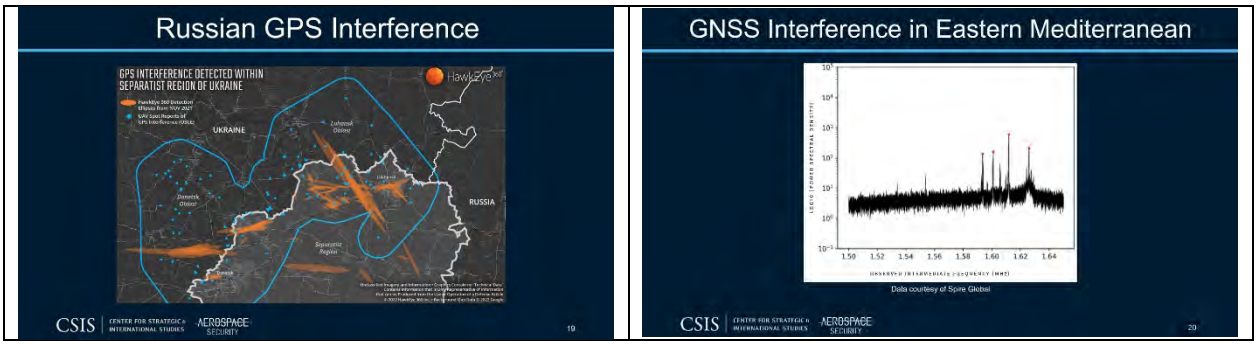
Before the invasion of Ukraine, the Organization for Security and Cooperation in Europe (OSCE) was monitoring the Ukrainian-Russian border using Unmanned Aerial Vehicles (UAVs) to perform overflight missions (Slide 18). The fleet of UAVs operated by the OSCE uses the unprotected civilian GPS signal to aid in their navigation. Throughout March and April of 2021, over 60 percent of their UAV flights encountered GPS signal interference, including areas near the OSCE base. These events were

corroborated through RF signal sensing from a commercial space company which confirmed detection of GPS interference in the areas.

Slides 17-18

Emissions from the GPS jammers were detected and geolocated by a commercial company called Hawkeye 360, as can be seen in Slide 19. The orange ellipses in the figure indicate the estimated locations of the RF interference and overlapping emissions from multiple satellite passes can be used to precisely locate a jammer. Russian employment of GPS jamming devices has continued throughout the conflict.

In addition to confirmed interference to ViaSat and Starlink services in March of 2022, the European Union Aviation Safety Agency released that, during the current Russian invasion of Ukraine, GNSS jamming and or spoofing has intensified in four key areas: Kaliningrad, Eastern Finland, the Black Sea, and the Eastern Mediterranean. These four locations have all experienced significant interference with PNT systems such as GPS and Galileo. Data from commercial RF company Spire Global corroborated this GNSS interference over the Eastern Mediterranean in the February 2022, which can be seen in Slide 20. These spikes indicate unusual GNSS interference in the Eastern Mediterranean where higher frequency signals have been converted into lower frequency signals to expedite at their processing.

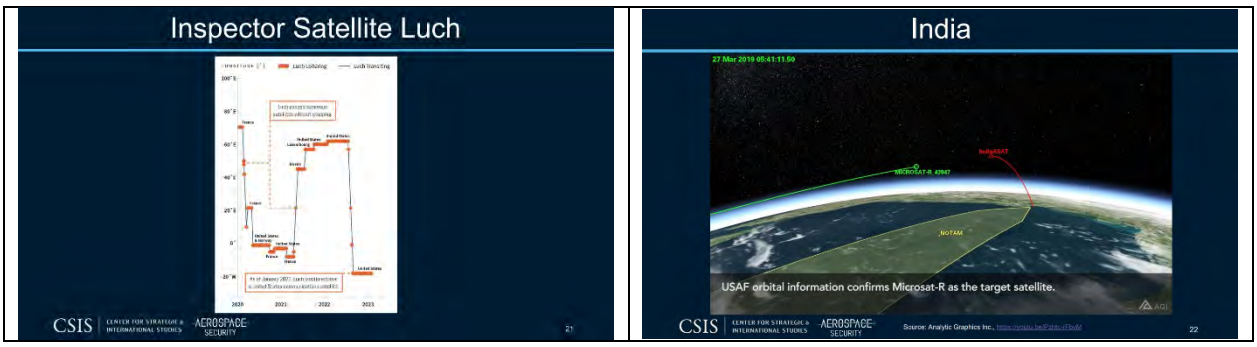


Slides 19-20

Russia's inspector satellite, Luch, may also be supporting the war in Ukraine through signals intelligence gathering in GEO (Slide 21). At the beginning of 2020, Luch made a significant maneuver westward covering about 60 degrees in longitude, as can be seen in the slide. As it moved, Luch had the opportunity to conduct multiple close approaches with other satellites. Just a year later in March 2021, after Russia began its initial military buildup near the Ukrainian border, Luge made a significant maneuver back eastward to visit another Russian satellite in GEO. Luch then maneuvered and loitered near Intel Satellite 33E from October 21st through January 22nd. Luch then moved to rendezvous with another Intel Satellite 39, a high throughput communication satellite with European coverage, just one month before Russia invaded Ukraine. Since the war began, Luch has been performing proximity operations near intel satellites and loitering nearby for about 150 days at each satellite, which is a significant departure from its normal operations. Notably these intel satellites are transmitting K, U, and C-band frequencies, often used for secure military communications over Ukraine. Although it is unclear if they are supporting any operations in this region. The only system that we have seemingly missing from Russia's counter space arsenal is directed energy. Despite much boasting of capability, there are no independently verified open-source reports of Russia deploying directed energy capabilities against satellites and its war in Ukraine. CSIS poses some questions in their report as to why this may be.

In 2019, ASAT catapulted India onto the global counter space stage as it became only the fourth country besides the U.S., Russia, and China to successfully demonstrate a direct descent ASAT capability (Slide 22). After this test, officials announced that they do not have specific plans for another ASAT in GEO, but they may test in higher orbits. The Indian space sector continued to grow throughout 2022 with a particular focus on military and private satellite imagery. Prime Minister Modi announced a new mission defense space program where they highlight 75 defense-based mission areas for private companies to focus on, proving that they

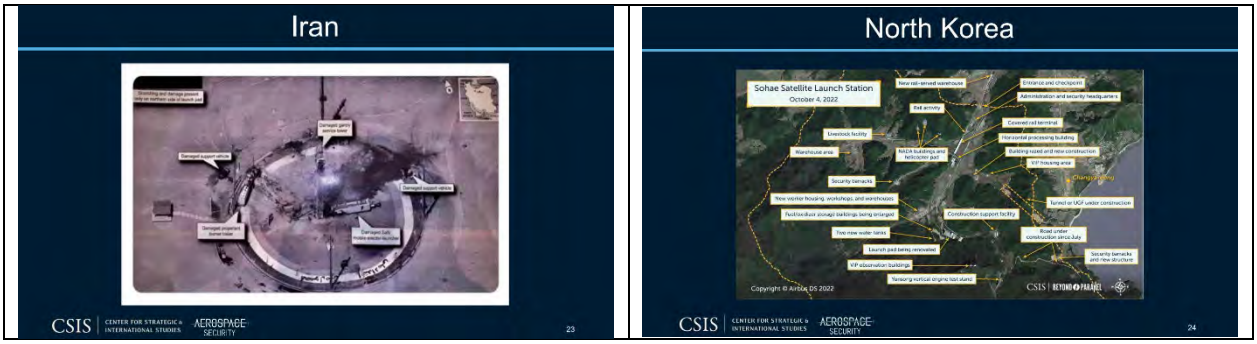
are also focusing on injecting money and enthusiasm into their commercial sector. These 75 missions focus on satellite launch software, ground systems, communications, and payload.



Slides 21-22

The Iranian Space Program has become one of the largest in the Middle East, and the country's leaders regularly invoke the program as a symbol of national strength and progress. After a series of launch failures in recent years (Slide 23 shows an image of from an explosion on an Iranian launch) they have shown great signs of progress in 2022. Although their other capabilities are nowhere near as robust, there seems to have been a significant shift in mission success and overall government support of space capabilities over this past year. Iran still appears far from developing kinetic ASAT weapons or non-kinetic physical counter space capabilities. They continue to develop electronic and cyber capabilities and they have shown success in jamming and hacking particularly against foreign government and commercial satellite communication systems. Iran is also developing relationships with other space capable nations, particularly Russia. The Russian invasion of Ukraine solidified a military alliance between Iran and Russia. In exchange for Iran's support, particularly through the supply of UAVs. Russia is likely returning the favor with military and technical support. In December of 2022, the Iranian Space Agency and Roscosmos signed an agreement to design and build remote sensing and communication satellites, develop infrastructure, and hold joint trainings which may bolster Iran's space capabilities in the near future.

North Korea reported a space launch test on February 26, 2022, for a spy satellite, although U.S. DoD officials have refuted these as disguises for intercontinental ballistic missiles (Slide 24). This claim remains constant with a confirmed test B satellite that was launched in December of 2022 at one of their two Satellite launching stations in Sohae to prepare for a full satellite system in the coming weeks. Supreme leader Kim Jong-un visited the satellite Sohae launching station in March of 2022. This is an image (slide 24) from CSIS that show the upgrades to the satellite launching system over the past year, indicating that they plan on having a lot more launches here. Very Important Person (VIP) lot watch areas at this location prove that this will likely be a popular destination.



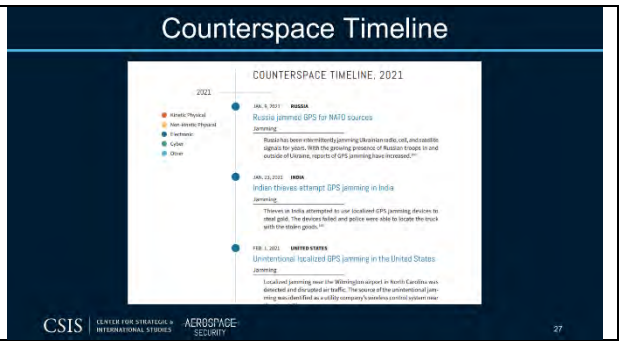
Slides 23-24

Allied nations have also conducted activities related to space defense. Australia set up a defense-based command within the Royal Australian Air Force, which was formally established in January of 2022. They also released a defense-based strategy last year. French officials have continued to be outspoken about investing in counter space technologies and they're underway of achieving bodyguard satellites with a potential satellite named Yoda. Publicly available information states that Yoda will have an intelligence, surveillance, and reconnaissance (ISR) capability to detect incoming threats to GEO satellites. Israel continues to make progress in testing its iron beam capability, a directed energy system that will complement the iron dome missile defense system. In December of 2022, Japan released a new national security strategy, national defense strategy, and a national defense buildup program, which all emphasize the importance of capabilities in the space domain. South Korea is also injecting millions into its commercial sector, and they reached a major milestone in 2022 with their first successful satellite launch with an indigenous liquid-fueled rocket. Lastly, the UK established a Space Command in 2021 followed by a Defense Space Strategy in February of 2022.

Ms. Young concluded her presentation with CSIS's "what to watch" from this year (Slide 25). Lessons learned from Russia's invasion of Ukraine include the reliance on commercial data and communication services, as well as the amount of electronic and

cyber counter space capabilities that come from Russia. Additionally, CSIS discusses the direct-ascent ASAT test ban that the U.S has started. In the UN, 155 countries voted in support of this. Notably, all five countries that we cover in this report did not vote in favor of this resolution. CSIS also emphasizes space situational awareness and its ability to track counter space weapons targeting and on-orbit activities, which make reports like ours possible.

Finally, a counter space timeline can be found on CSIS's website and has all prominent counter space tests from these countries, including the U.S. since the 1950s (Slide 26).



Slides 25-26

Discussion:

Dr. Brad Parkinson thanked Ms. Young for the informative presentation and opened up the floor for questions.

Dr. Powell asked, regarding Russia's Luch satellite and its loitering, is there any way to determine how close it was loitering?

Ms. Young stated that she would have to look into that further and the CSIS may be able to get some better numbers.

Dr. Betz stated that attacks on satellites in space are exotic and interesting, but it's good that Ms. Young discussed attacks on the ground segment of space systems because they're not moving at kilometers per second and are not as far away. He asked, are there similar threats against systems that are only terrestrial and does CSIS look at those as well so there's a balance across different flavors of systems: some space and some terrestrial.

Ms. Young answered, "yes, absolutely." Threats to ground stations are as critical as threats to on-orbit activities, so CSIS looks at those as well. However, CSIS does not highlight those in this year's report, but they are tracking those as well.

Dr. Parkinson said that the focus of this presentation tended to be on the high-altitude satellites. What about the LEOs? Does CSIS delve into that in any depth?

Ms. Young stated that CSIS will be focusing on that in the coming years, particularly as China launches its own mega constellation of satellites in LEO. A lot of open-source information regarding counter space capabilities seem to be threats to GEO satellites or larger military satellites. But CSIS is also seeing a lot more in LEO, so that will be something that they look at in future years.

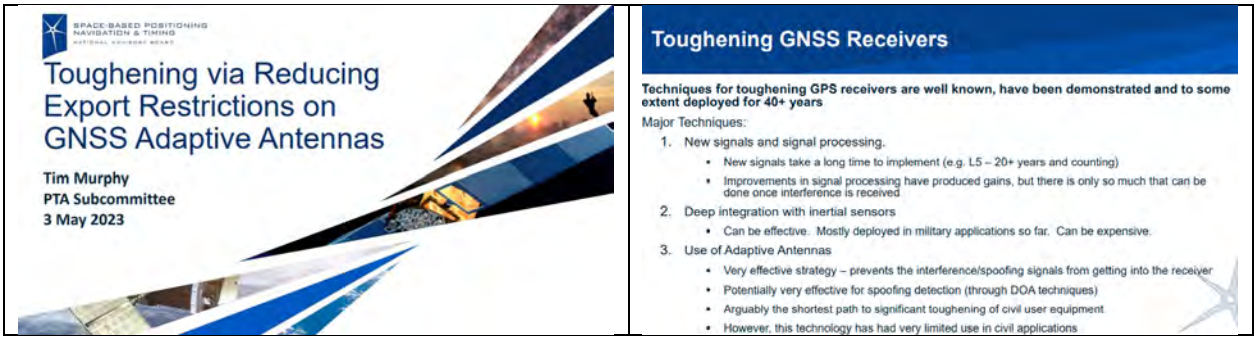
Dr. Parkinson stated that, regarding augmentation of GPS, people are increasingly, and with good reason, looking at LEOs. But regarding directed energy or direct ascent, a LEO is a lot easier problem than a GEO. So, from a vulnerability standpoint of an individual satellite, it would be an interesting exercise. The other side of the coin is that many of those satellite systems are greatly proliferated and one of the defenses against direct ascent is it is such an expensive attack to take out a whole constellation that it's not profitable to do that. The MEOs are not that proliferated.

Ms. Young stated that there have been discussions from Chinese Scholars, particularly on ASATs or how to take out large Slots of Starlink satellites, but CSIS hasn't seen that get a lot of traction in actual documents from the Chinese government, or that they have any plans to grow those. Another trend that CSIS has observed is that China has become just a bit more dependent on space, as well. They have their own space station and citizens on orbit. Notably, they didn't denounce Russia's ASAT test but did mention that it posed a threat to their citizens on orbit. So, they are taking a new newer approach to looking at these threats and realizing that they have a lot to lose on orbit.

* * *

Toughening via Reducing Export Restrictions on GNSS Adaptive Antennas (View PDF)
Mr. Tim Murphy, *Member, PNTAB*

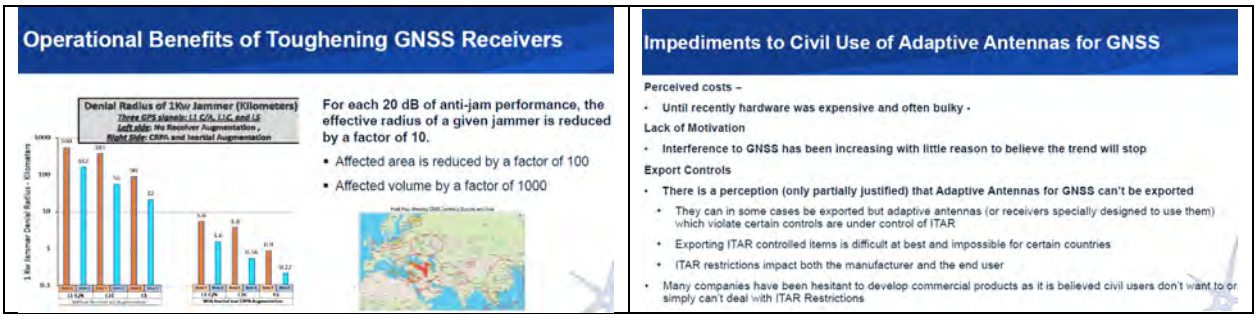
Mr. Murphy introduced himself (Slide 1) and noted that the techniques for toughening GNSS receivers are well known and have been explored and demonstrated for well over the past 40 years. They follow three major categories: (1) implementing more sophisticated signals and signal processing, (2) integration with inertial sensors; (3) and use of adaptive antennas. The implementation of new signals take a long time to implement, as mentioned earlier today when discussing the implementation of the GPS L5 signal. We have seen a lot of improvements in signal processing over the years, but there is only so much you can do other than a few dB in improvement. The second major bucket is deep integration with inertial sensors, which can be very effective. In fact, we do this in civil aviation, but it mostly only allows you to coast through outages and can be expensive. This briefing focuses on the use of adaptive antennas. This is a very effective strategy for toughening a GPS receiver because it prevents the interfering energy from getting into the receiver at all. You are eliminating it before it can get into your receiver and affecting the tracking loops. This approach is also very effective for the detection of spoofing through techniques to determine the direction of arrival (DOA) and whether the signal is coming from the direction you believe the GPS satellite to be. Arguably, this is the shortest path to get significant toughening of civil user equipment, with anti-jam capabilities in the order of 30-40 dB. Also, there is nothing left to invent here as these techniques are well understood and have been demonstrated over the past 40 years. However, we've only seen limited use of this in civil applications.



Slides 1-2

Slide 3 shows the operational benefits of toughening GPS receivers. For every 20 dB of anti-jam performance, the effective radius of a given jammer is reduced by a factor of ten. This really ups the ante for a jammer to be effective. If you force a jammer into the kW range to become effective, you're also making it easier to locate and shut down.

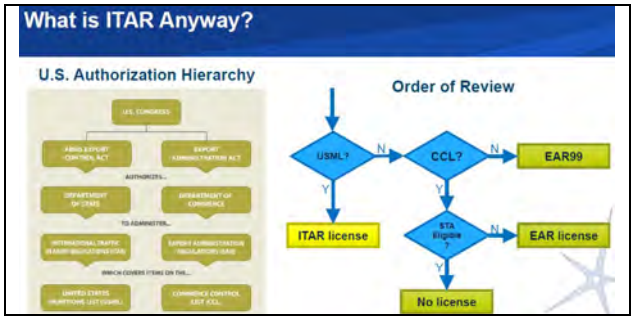
The use of adaptive antennas for civil applications has been limited due to a number of impediments (Slide 4). First, it's the perceived cost. Until recently hardware has been quite expensive and often bulky. However, advances in electronics have made these antennas much easier to make and improvements in signal processing have brought the cost down. Second, there has been a lack of motivation due to its perceived complexity, but that is also going away since interference to GNSS has been increasing and there is little reason to believe that such trend will stop. This, and I think is one of the primary impediments, are the export controls. There is a perception, which is only partially justified, that adaptive antennas for GNSS can't be exported. In fact, in some cases they can be exported, but the adaptive antennas and the receivers specially designed to use them violate certain controls under ITAR. Exporting ITAR controlled items is difficult at best and impossible for certain countries. Also, these ITAR restrictions impact both the manufacturer and the end user. So, many U.S. companies have been hesitant to develop commercial products as it is believed civil users don't want to or simply can't deal with ITAR restrictions.



Slides 3-4

So, what is ITAR anyway (Slide 5)? In the U.S. there are two domains for export controls. One is the export control regime for military equipment (International Traffic in Arms Regulations, or ITAR), which is run by the Dept. of State. The military equipment that falls under this is described in the U.S. Munitions List. The other domain is export control for anything else (Export Administration Regulations, or EAR), including dual-use technology like GPS. This is administered by the Dept. of Commerce.

It has its own list (Commerce Control List), which defines what does and does not require an export license. So, as shown on the right side of Slide 5, if you are a manufacturer you have to go through this flowchart to decide what kind of a license you need. First you have to make sure what you are planning to export isn't covered by the U.S. Munitions List (USML) and requires an ITAR license. If it's not, then you have to check the Commerce Control List (CCL), and it its there then you can see if there are some exceptions that would allow you to export to certain countries without a license. Failing that, then you need a license under EAR. If the item is not on the CCL, then it becomes what is known as EAR99 which is basically export with no license required.



Slide 5

So, what's the big deal about getting an ITAR license (Slide 6, on the left)? First you must register with the Directorate of Defense Trade Controls, which then send you a long list of things you have to comply with. Then you have to obtain a license, which includes all kinds of restrictions and also has substantial liability for showing compliance. Also, if a single ITAR component is included in a system, then the entire system becomes controlled by ITAR. This is often referred to as the "see through" clause. There are also restrictions when moving the product, for example an airplane or a ship, from one country to another. The penalties for violations are substantial, up to $500,000 per event, and there is a potential for what is known as inadvertent or deemed exports, where even just sharing information with a non-U.S. person in the U.S. can be deemed as an export. This has ramifications on the ability of a company to support its product even if the people that bought it have a license authorizing them to have the product. Let's contrast that now with licensing under EAR (Slide 6, on the right). As noted earlier, EAR controls everything that is not already under ITAR. EAR restrictions depend on the Export Control Classification Number (ECCN). GNSS adaptive antennas are already covered ECCN, and there is a general requirement that any adaptive antenna must have an EAR license. The bottom line is that there are some adaptive antennas (for example the ones with more than three antenna elements) that fall under ITAR, but even if you build an antenna that doesn't run afoul of ITAR you would still need to get a license under EAR.

ITAR vs. EAR Licensing

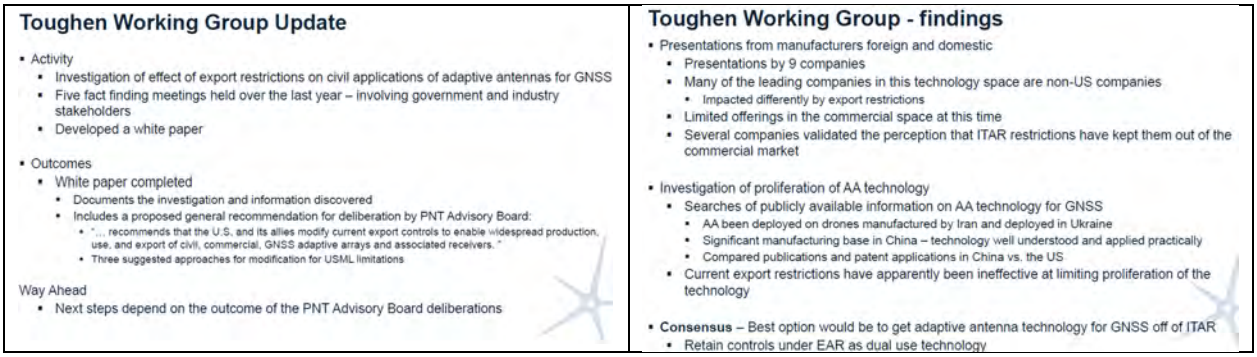
ITAR – Controlling Defense Items	EAR – Controlling Dual Use Items
Must Register with Directorate of Defense Trade Controls • DDTC provides guidelines on the type of controls to implement within the organization. The guidelines include information on the creation of a compliance manual, recordkeeping, audits, and management commitment. • Registration alone does not grant the registrant authority to export. **Must obtain a license** • Several types of licenses - all include restrictions on which individuals in which countries can have access to the items or data. • Substantial liability and responsibility for tracking and showing compliance **ITAR components included in systems results in the entire system being controlled by ITAR** • The product inherits all the restrictions of the components **Restrictions on retransfer** • Recipients of items or data are restricted from re-exporting without DDTC approval • Restrictions on retransfer to dual nationals and third country nationals **Substantial Penalties for Violations** • **Up to $500,000 per event** • **Potential for inadvertent or "deemed" exports**	**EAR essentially controls everything not ITAR** • Commerce Control List (CCL) - is a limited list of items which could potentially have a military use in addition to commercial use. (i.e. "dual use.") • The overwhelming majority of things that fall within the scope of the EAR are not listed on the CCL; instead, they are given the designation "EAR99." – marked NLR (No License Required) **EAR export restrictions depend on the ECCN (Export Control Classification Number)** • ECCN designates that an item, which can be a tangible or intangible (i.e., software or technology), is controlled because of its specific performance characteristics, qualities, or designed-end use. **Bureau of Industry and Security (BIS) is the regulating authority** • Recordkeeping and reporting may be required for some licenses. • Some licenses do not require reporting of reexporting GNSS Adaptive antennas • Covered under - ECCN - 7A005.b and 7A105.b.3 Licensing under EAR is less onerous than ITAR • Some improvements in EAR licensing criteria would also be beneficial

Slide 6

Slide 7 provides an update of the Protect, Toughen, and Augment (PTA) Subcommittee Toughen Working Group activities since the last board meeting. The working group has been investigating the effect of export restrictions on civil applications of adaptive antennas for GNSS. Over the last year the subcommittee has held five fact-finding meetings involving government and industry stakeholders and developed a White Paper to support the recommendation on modifying export controls for GNSS adaptive

antennas that was approved at the Nov. 16-17, 2022, board meeting. The White Paper documents the working group's investigation and information discovered and includes a general recommendation for deliberation by the Board.

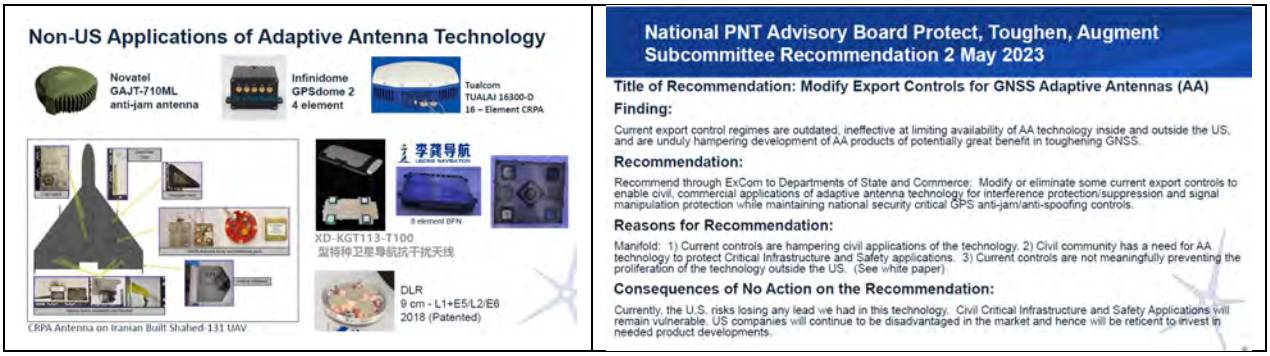
The fact-finding meetings included presentations from nine foreign and domestic manufacturers (Slide 8). Many of the leading companies in this technology space are non-U.S. companies. Ironically, if I were to purchase a CRPA (Controlled reception pattern antennas) antenna outside the U.S., and brought it into the country I would suddenly have to treat it as an ITAR device and cannot re-export it. It was also found that at this time there are limited offerings in the U.S. commercial market as current restrictions impact their markets and product development decisions regarding the development of civil systems, and those being offered only have two or three antenna elements to avoid ITAR restrictions which in turn limits their anti-jamming performance. Another area studied by the working group is the proliferation of adaptive antenna technology outside the U.S. to demonstrate how current technology controls have not been successful in mitigating the spread of this technology. Publicly available information shows that GNSS adaptive antennas have already been deployed on drones manufactured by Iran and deployed in Ukraine. There is also a significant manufacturing base in China. In summary, current export restrictions have apparently been ineffective at limiting proliferation of the technology. The working group consensus is that the best solution would be to get adaptive antenna technology for GNSS off ITAR while retaining controls under EAR as dual use technology.



Slides 7-8

Slide 9 shows a few examples of non-U.S. applications of adaptive antenna technology. The Novatel GAJT is a seven-element CRPA antenna. Other offerings include Infinidome's four-element antenna and Tualcom's 16-element antenna. However, even if we purchased these for use in the U.S., once imported they would become ITAR items and we would not be able to re-export it. The picture on the bottom was taken from a news article showing an Iranian UAV bought by Russia that was found to have a four element CRPA that was cobbled together from components bought in the West. So, again, the proliferation of this technology was not adequately contained by current U.S. export restrictions. The pictures on the bottom right are from a Chinese company called Ligong Navigation that builds four and eight -element CRPAs.

Slide 10 shows the recommendation that was approved by the board in November, with minor tweaks to the language based on the learnings in the White Paper developed by the working group. So, again, our recommendation is for the Departments of State and Commerce to get together and modify or eliminate some current export controls to enable civil, commercial applications of adaptive antenna technology for interference protection/suppression and signal manipulation protection while maintaining national security critical GPS anti-jam/anti-spoofing controls. The reasons for this recommendation have been validated by the additional fact-finding work done by the working group.



Slides 9-10

Discussion: Dr. Parkinson thanked Mr. Murphy for the briefing.

* * *

DOT System-of-Systems Interference, Detection, and Mitigation (View PDF)
Mr. James S. Aviles, *DOT OST-R Office of the Assistant Secretary for Research and Technology*

Mr. Aviles thanked Ms. Karen VanDyke for tasking him with supporting the "Protect" aspect of the Board's PTA program (Slide 1).

Slide 1

Their strategy comes from the Interference, Detection, and Mitigation (IDM) requirements outlined in SPD-7 (Slide 2). They are primarily tasked with actively detecting and identifying L-band interference emissions, with focus on in-band and adjacent band interference. This is done in partnership with other Federal departments and agencies. To accomplish this, they want to leverage space, ground, fixed, transportable, and mobile devices. This can be achieved with sensor equipment already in operation on the Federal as well as other civil and commercial assets.

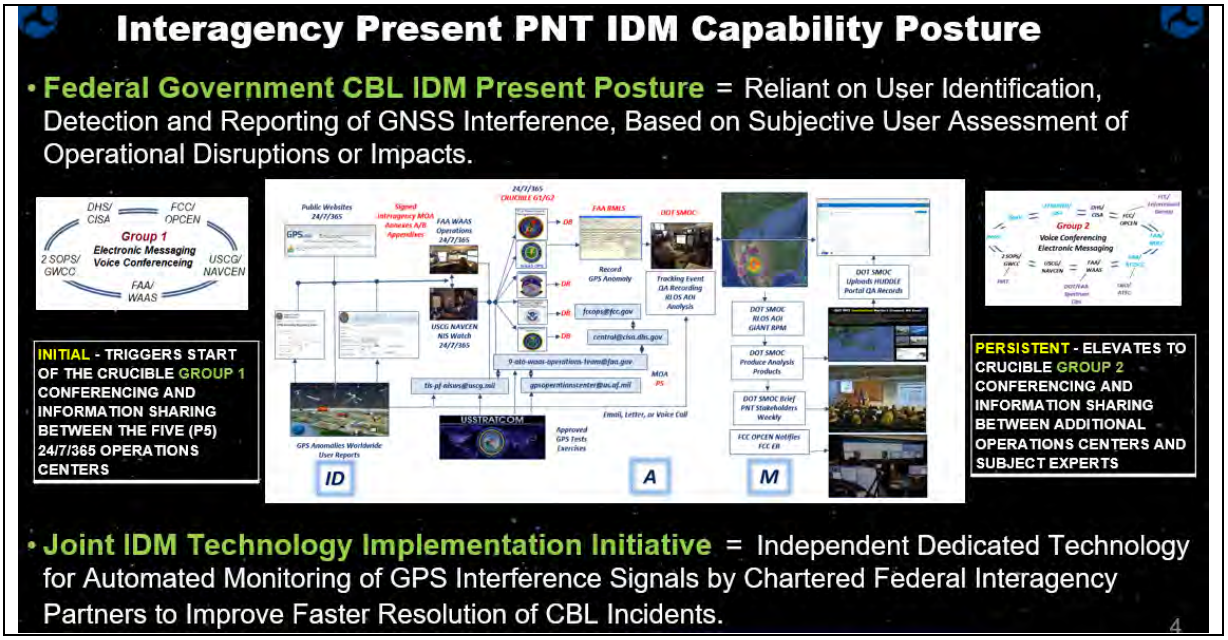
Slide 2

Slide 3 depicts the nine high level IDM requirements, where DOT is working on all of them. Requirement number 6, "Leverage Fixed-Mobile Assets & Sensor Technology Innovations," is what Mr. Aviles is working on. The photos on the right depict the assets DOT is actively using for on-going in-band and adjacent band interference detection. DOT wants to establish a multilayered

approach in this systems-of-systems, including the space layer, ground/airborne layer, and cyber layer. In the end, we want to centralize the reporting capability to enable regulatory enforcement.

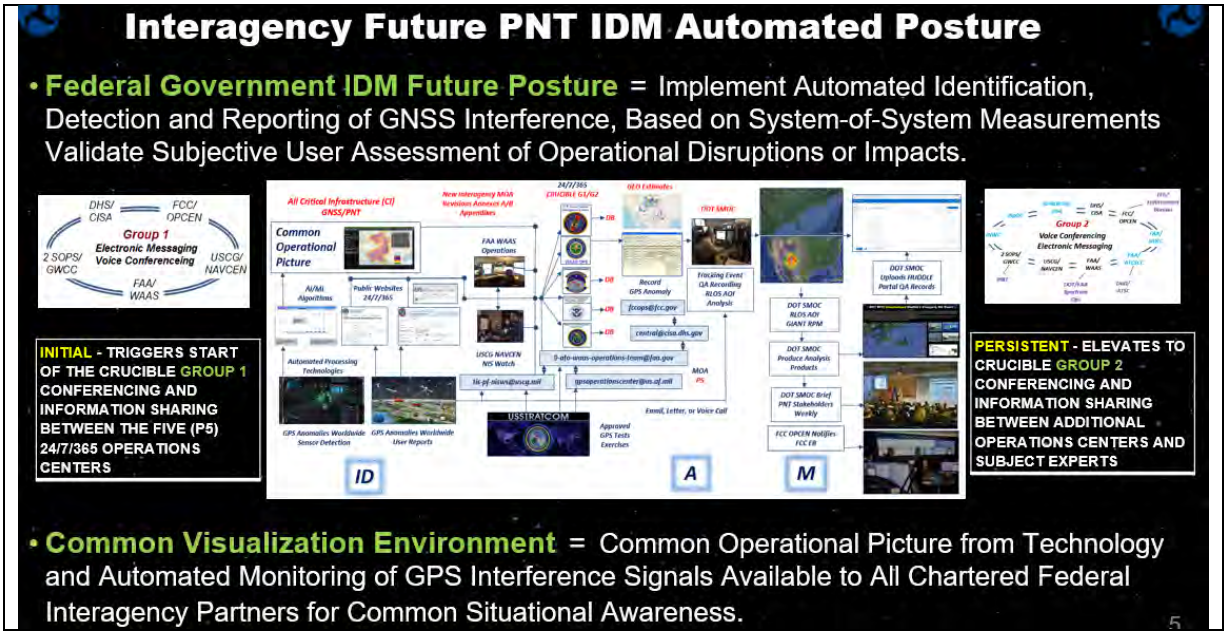
Slide 3

Slide 4 depicts their current posture. It shows what the Federal government currently has for dealing with interference in the homeland. The process is called "Crucible," which was established in 2008 by the Purposeful Interference Research Team (PIRT). It's a user-based reactionary process. Once a report is received and analyzed, there are two active escalation processes in place. What they now want to do is introduce technologies to improve the current reactionary, and manual, process.



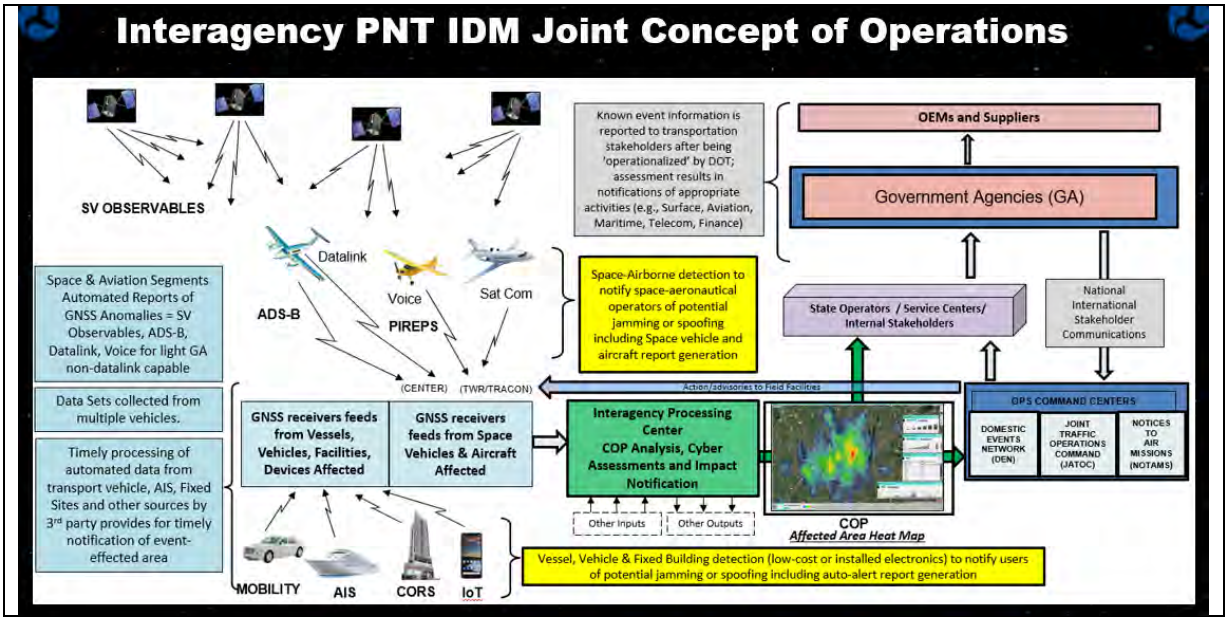
Slide 4

They are not going to get rid of the current process but want to augment it with automation (Slide 5). This will include artificial intelligence, machine learning, crowdsourcing, etc., as part of a system-of-systems. The objective is to incorporate automation, create a common operational picture from this automation to validate what users are reporting or even alert users before they even know something is happening. If we can get to the source quicker there will also be cost savings since we will be spending less time looking for it and, in turn, will help law enforcement be more effective to shut them down. Once all this is in place, we want to create this "common visualization environment" so, perhaps, in a not-too-distant future one could see in a smartphone app what the "GPS weather" [GPS interference levels] is.



Slide 5

The overall Concept of Operations is to create a "fusion center" where we will have all these feeds (space, ground, airborne, and cyber) come in for processing, project a common operational picture, and provide this "GPS weather" product to the users (Slide 6).

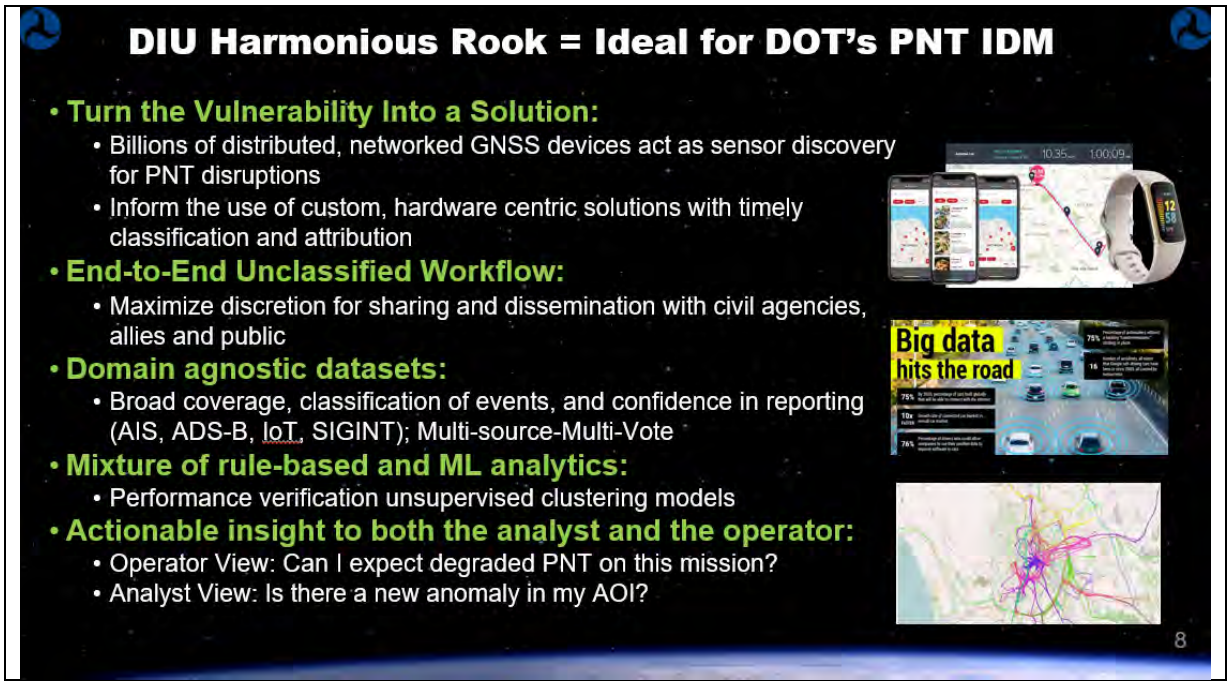


Slide 6

The Defense Innovation Unit (DIU) is a DoD organization that is implementing a program called Harmonious Rook (Slide 7). This program leverages commercial companies to create a capability to solve national security problems.

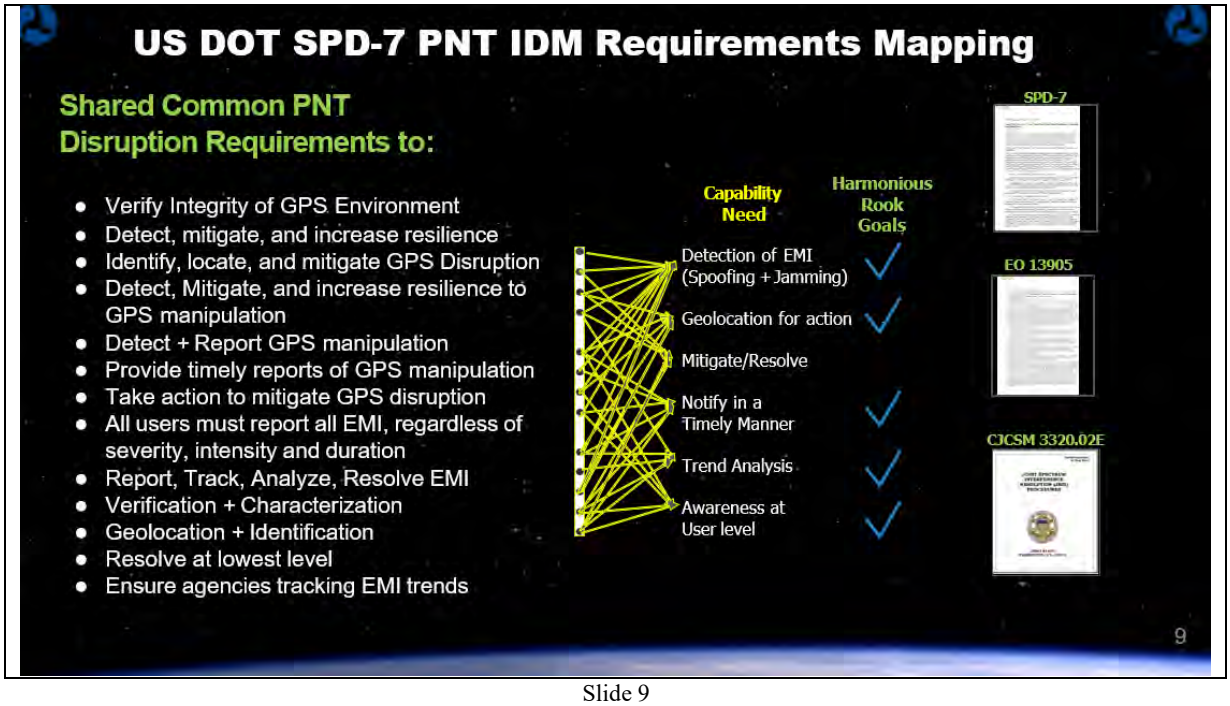
Slide 7

The objective of Harmonious Rook is to turn PNT vulnerability into part of the solution (Slide 8). That is, users can provide billions of distributed sensors, such as our GNSS-capable smartphone, to detect PNT disruptions. It creates an end-to-end workflow that is unclassified but can be kept under tight civil control. The resulting datasets are domain-agnostic, and then machine learning analytics are used to process the data and create actionable insights.



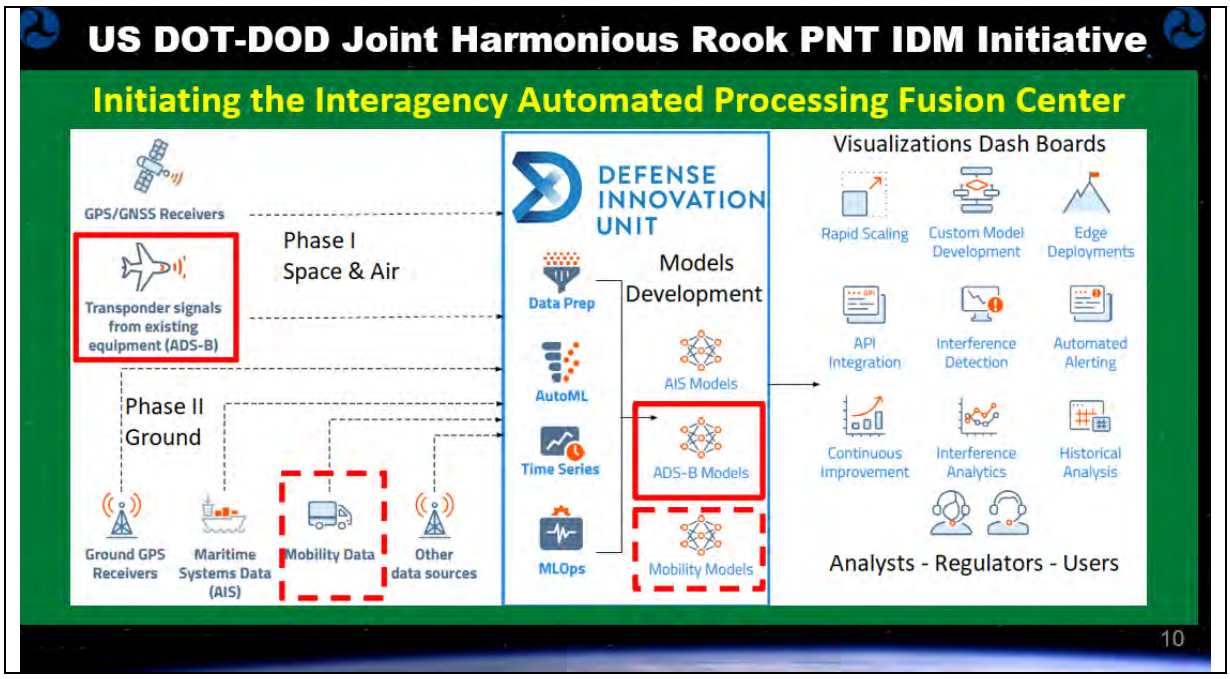
Slide 8

The Harmonious Rook program has a number of requirements that fit into the DOT's overall nine requirements for PNT IDM (Slide 9). In slide 9, the "capability need" column shows what the program is seeking to do jointly. The only aspect not covered by Harmonious Rook is that of regulators and enforcers to take down a source of harmful interference.



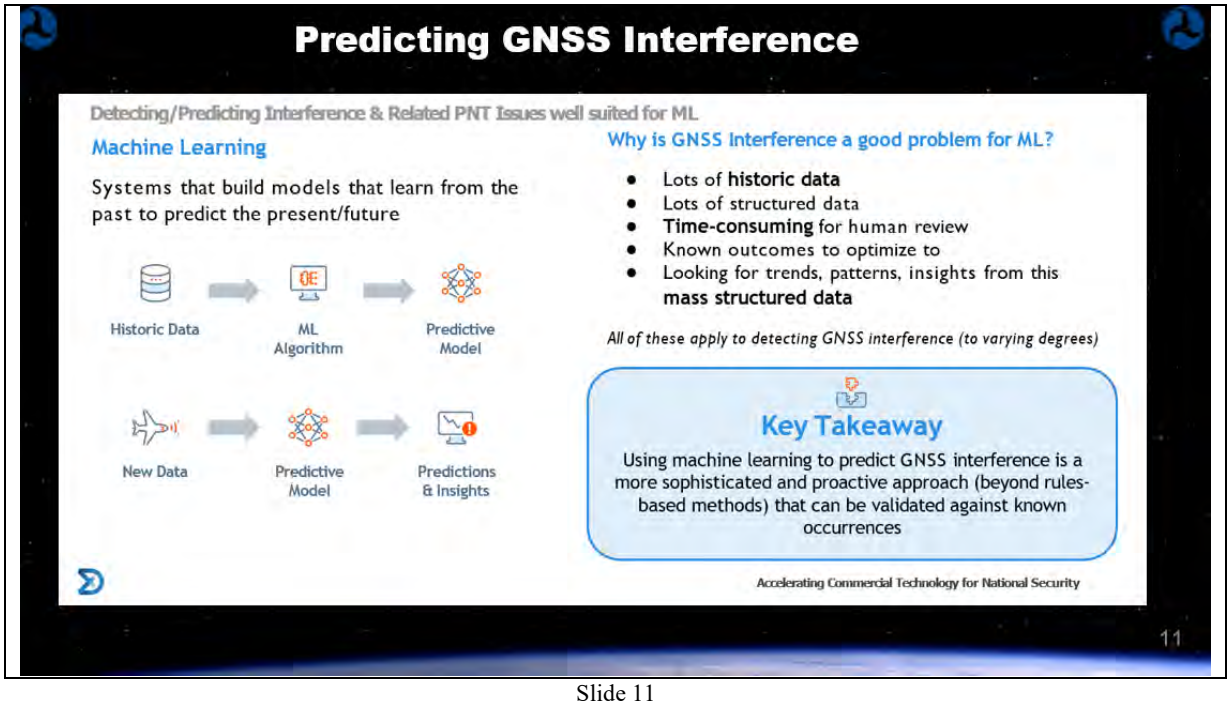
Slide 9

So, DOT invested into the program and started with Phase 1, which covers the space and air segment, and then moved on to Phase 2 to also pick up information coming from the ground mobility segment (Slide 10). The objective was to begin to develop models to process all this information and bring it into a fusion center where the machine learning and artificial intelligence will do all the work to provide products to enable analysts to go to the next level and shut down the sources of interference.



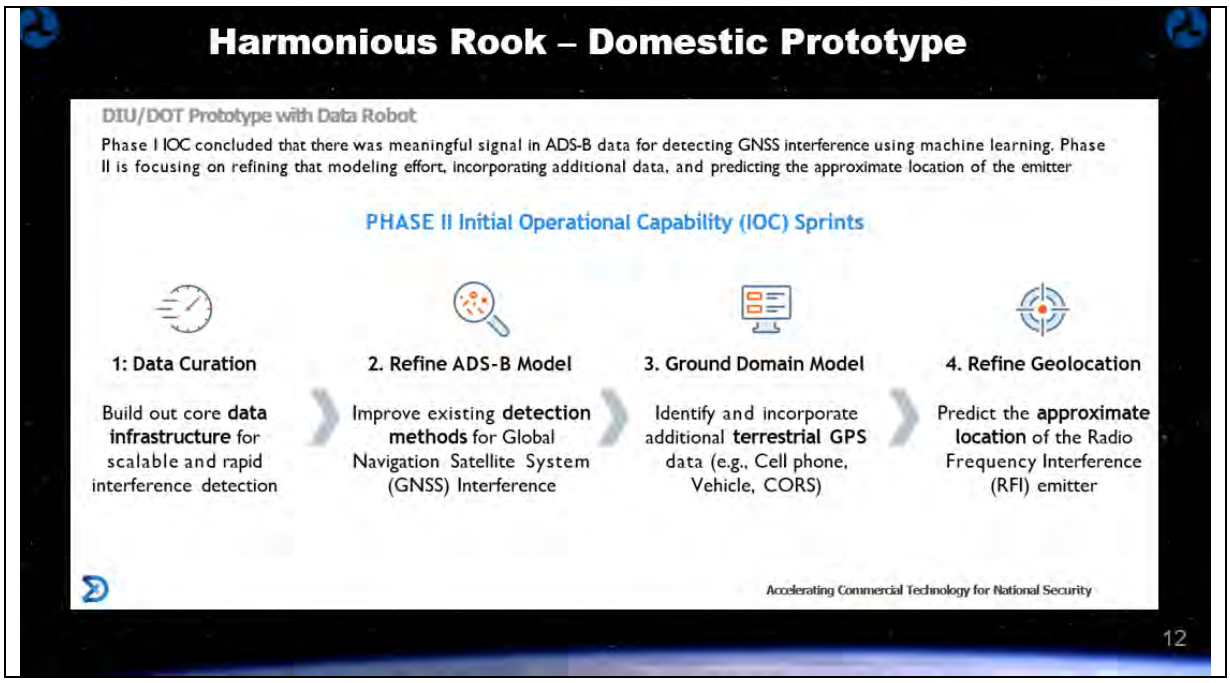
Slide 10

The workflow is one where you use historical data and build algorithms for the machine to learn and build predictive modeling (Slide 11). Then you add new data to the predictive modeling in order to get insights into those predictions. The key takeaway is that machine learning can predict GNSS interference.



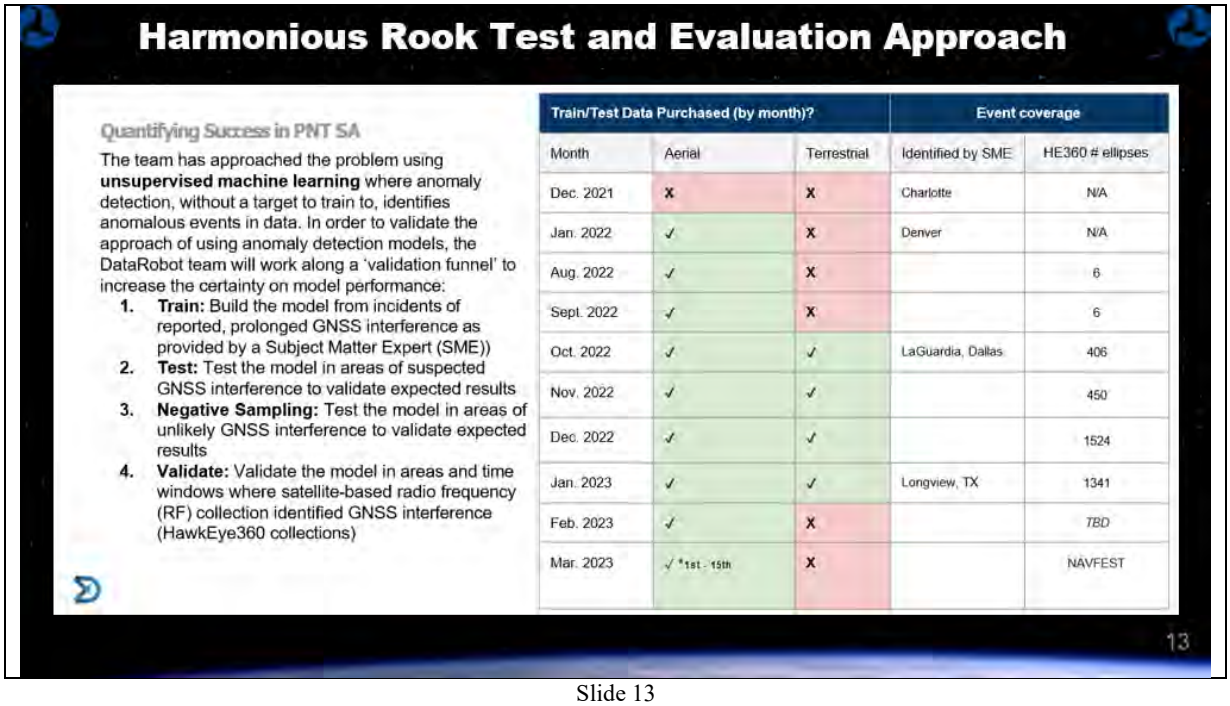
Slide 11

Our joint venture with Harmonious Rook is at the stage of having developed a domestic prototype (Slide 12). We have been doing data curation and refining the Automatic Dependent Surveillance-Broadcast (ADS-B) model we started under Phase 1. We are now moving to having the models work on the ground domain (using data from ground sources), and we'll then refine those to perform geolocation.



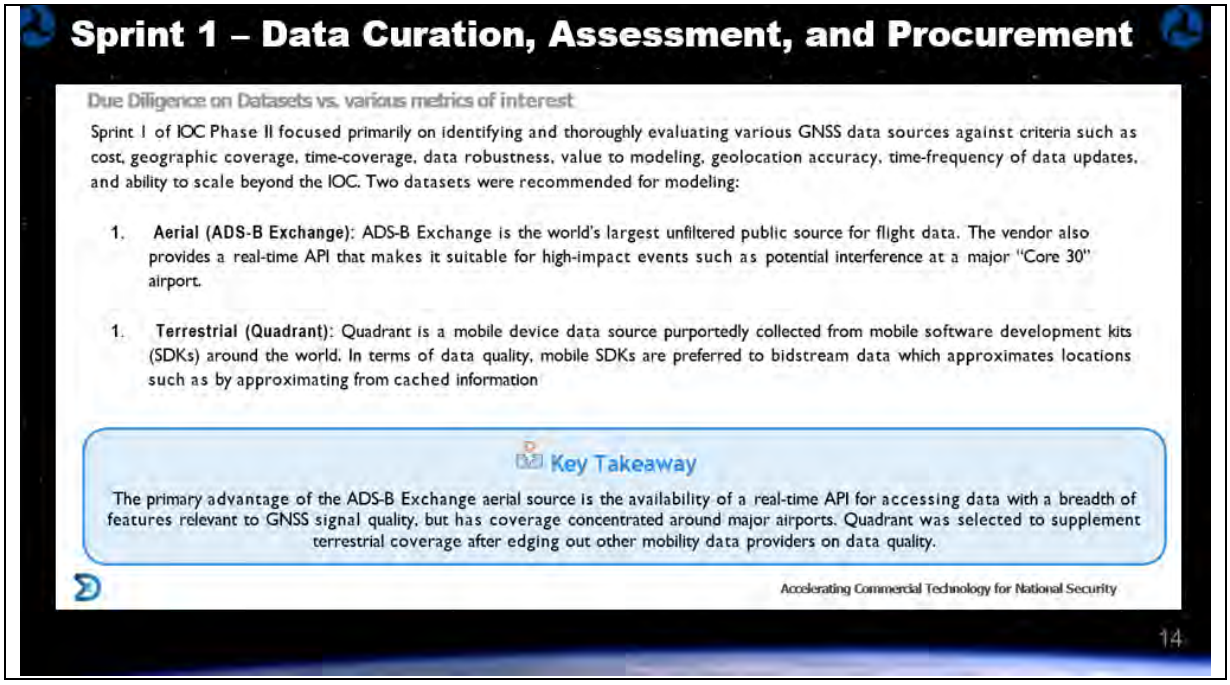
Slide 12

Slide 13 describes the Harmonious Rook test and evaluation approach, which includes the following steps: train, test, negative sampling, and validate. The column titled "Identified by SME" describes the real-life events against which the models were run for validation.



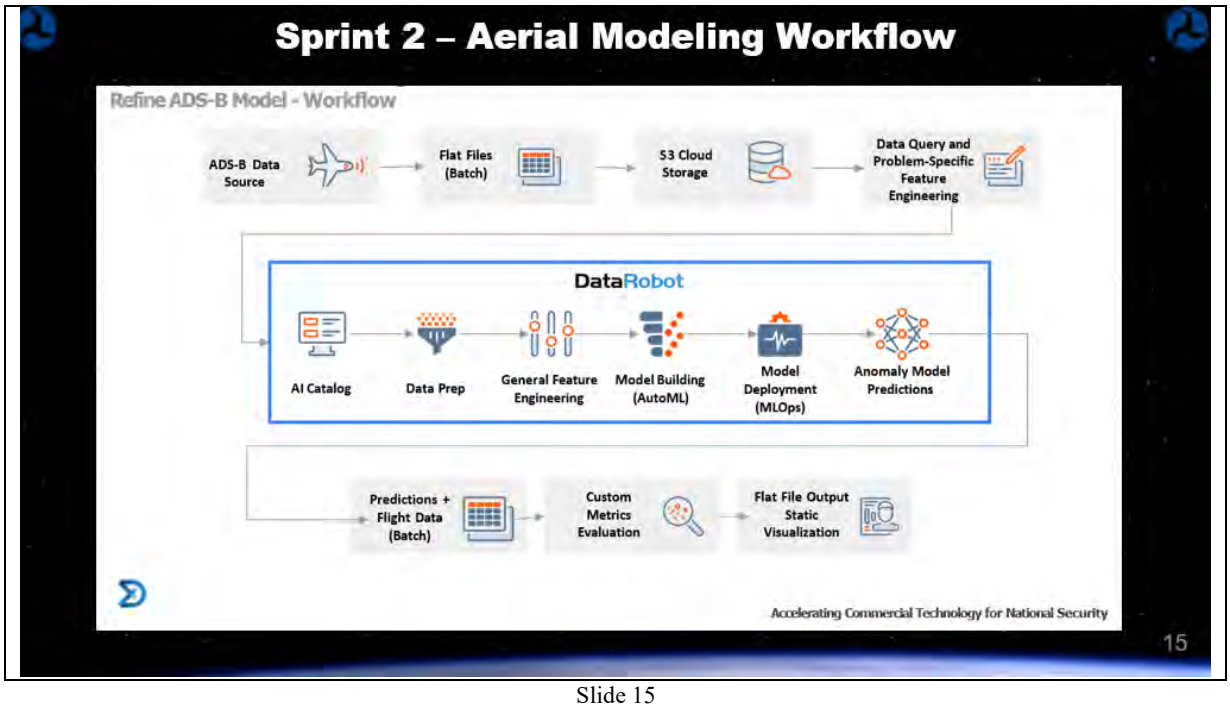
Slide 13

Slide 14 describes where the project currently is, which is data curation, assessment, and procurement of the data. Under Sprint 1, the ADS-B exchange was selected as the data source provider for the airborne feed, and Quadrant was selected for the terrestrial feed. Both feeds are needed to ensure the geolocation of interference is accurate. As the program progresses, more datasets will be added.



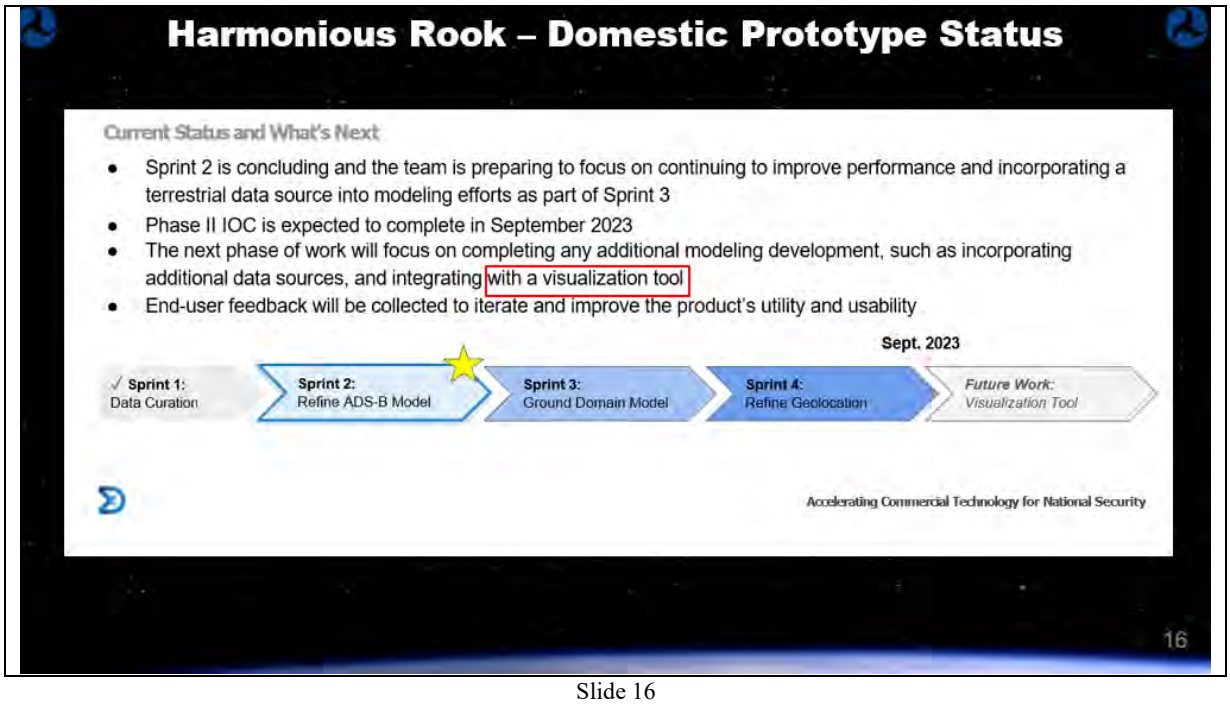
Slide 14

Slide 15 describes the workflow for adding new data to the ADS-B model.



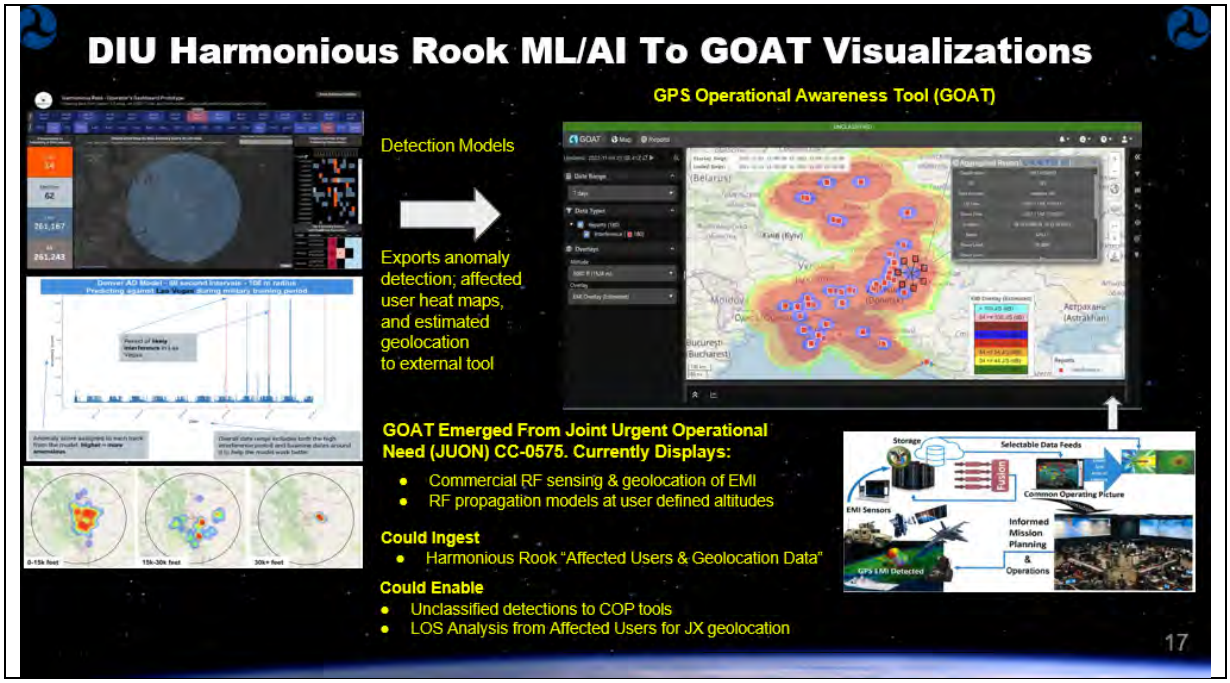
Slide 15

Slide 16 summarizes the progress in developing the domestic prototype for Harmonious Rook. Sprint 2 has just been completed, and they are now into Sprint 3. Later this year they expect to enter Sprint 4 to refine the geolocation and then to integrate all this into a visualization tool. The team has started to experiment with the visualization tool.



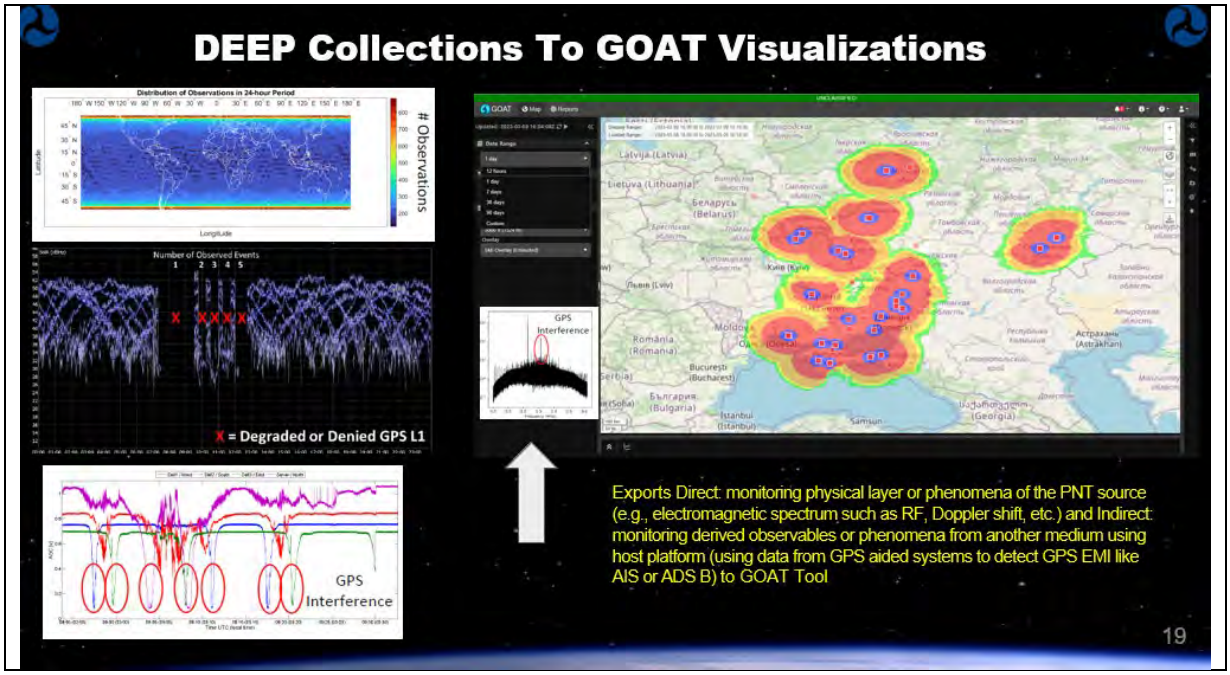
Slide 16

Slide 17 describes the visualization tool, called GPS Operational Awareness Tool (GOAT), that is most appealing to their team. It was developed by the Joint Navigation Warfare Center for an urgent in-theater need. This application was originally in the classified environment but has now been set in an unclassified environment. This tool is very appealing because it does not only provide geolocation, but it also enables the application of propagation tools to scope out the radiation pattern. This is very useful for us to alert users as to the scope of the area impacted.



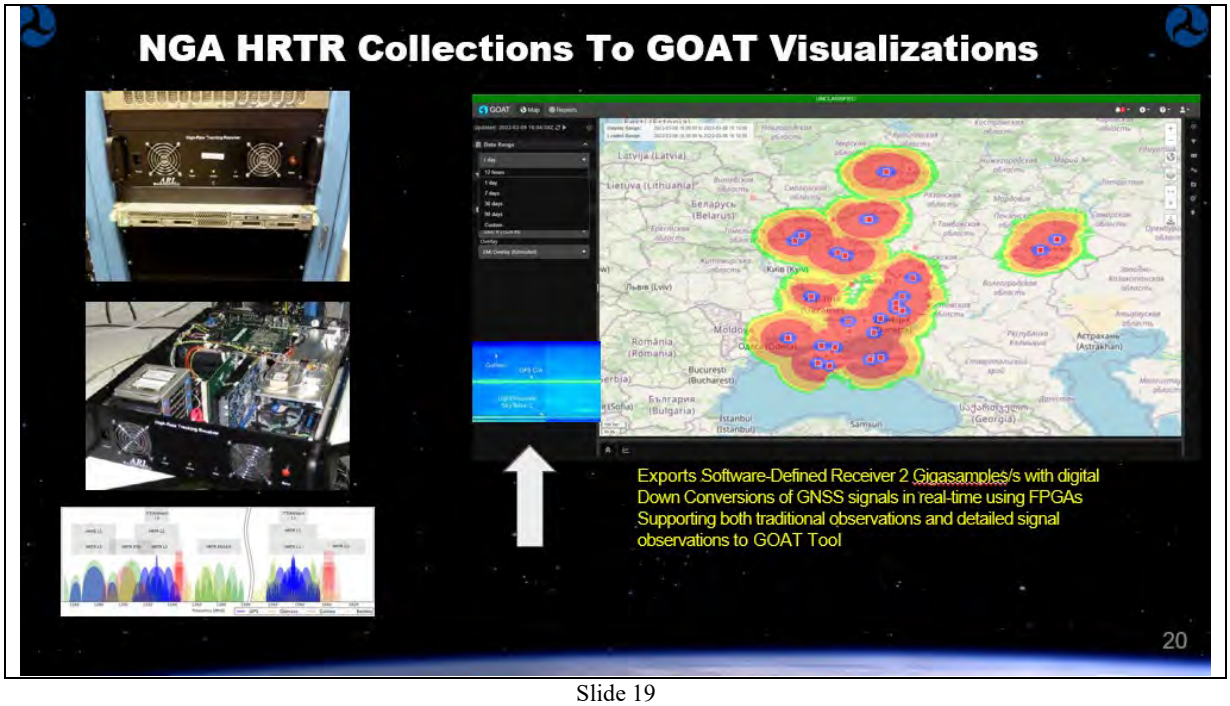
Slide 17

Slide 18 shows a conceptual visualization derived from other PNT-GNSS interference collection efforts. There is another program called "DEEP" that does collections of observables from space service providers, and its outputs are being considered as inputs to the GOAT visualization tool.



Slide 18

Finally, slide 19 depicts the National Geospatial-Intelligence Agency (NGA) High-Rate Tracking Receivers (HRTR) data collections that are also used as inputs to GOAT. These receivers can very accurately measure and predict the effects from space weather (for example, geomagnetic storms caused by coronal [Sun] mass ejections).



Slide 19

Discussion:

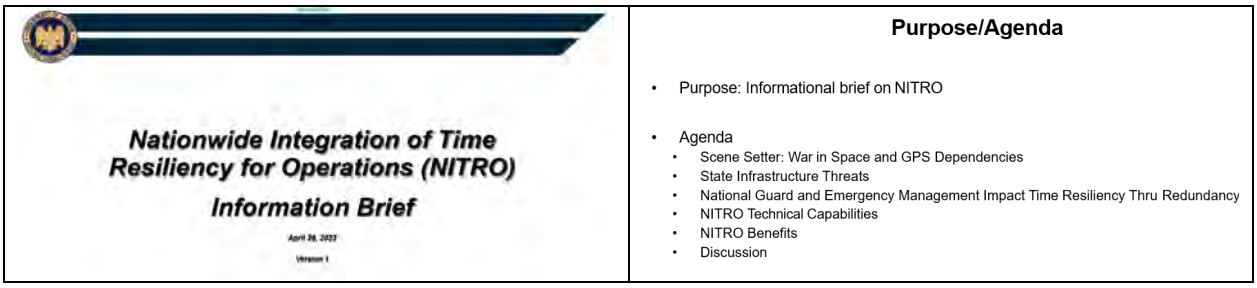
Dr. Parkinson thanked Mr. Aviles for his presentation and the concrete examples he presented.

Ms. Van Dyke thanked Dr. Hampshire for championing this effort.

* * *

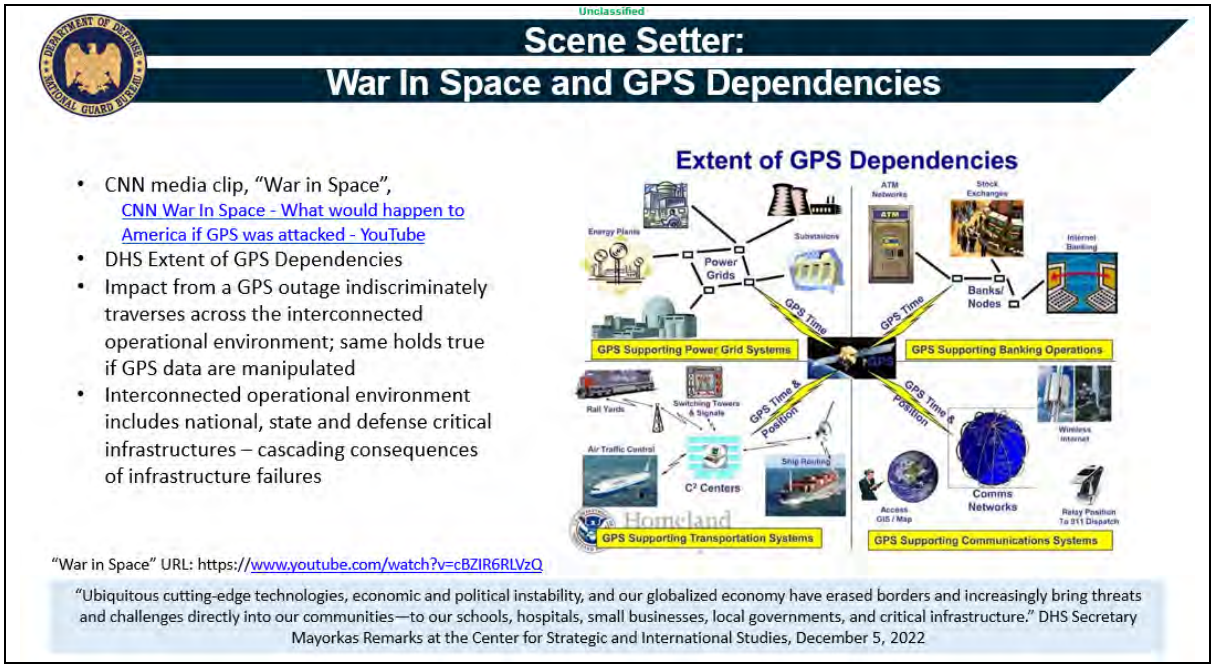
Nationwide Integration of Time Resiliency for Operations (NITRO) (View PDF)
Dr. Laura Callahan, *Special Advisor to Vice Chief, National Guard Bureau*

Dr. Callahan introduced herself and, on behalf of Maj Gen Hogan (Joint Force Headquarters, National Guard), thanked the Board for the opportunity to share their work on bringing in a combination of activities across domains so that in a domestic operational environment we can understand what is going on and prevent emergencies, and should prevention fail, we can respond and recover. This briefing focuses on a specific capability, Nationwide Integration of Time Resiliency for Operations, also referred to as NITRO (Slide 1). It covers topics such as: state (and U.S. territories) infrastructure threats and how we leverage NITRO capabilities to respond to domestic emergencies (Slide 2).



Slides 1-2

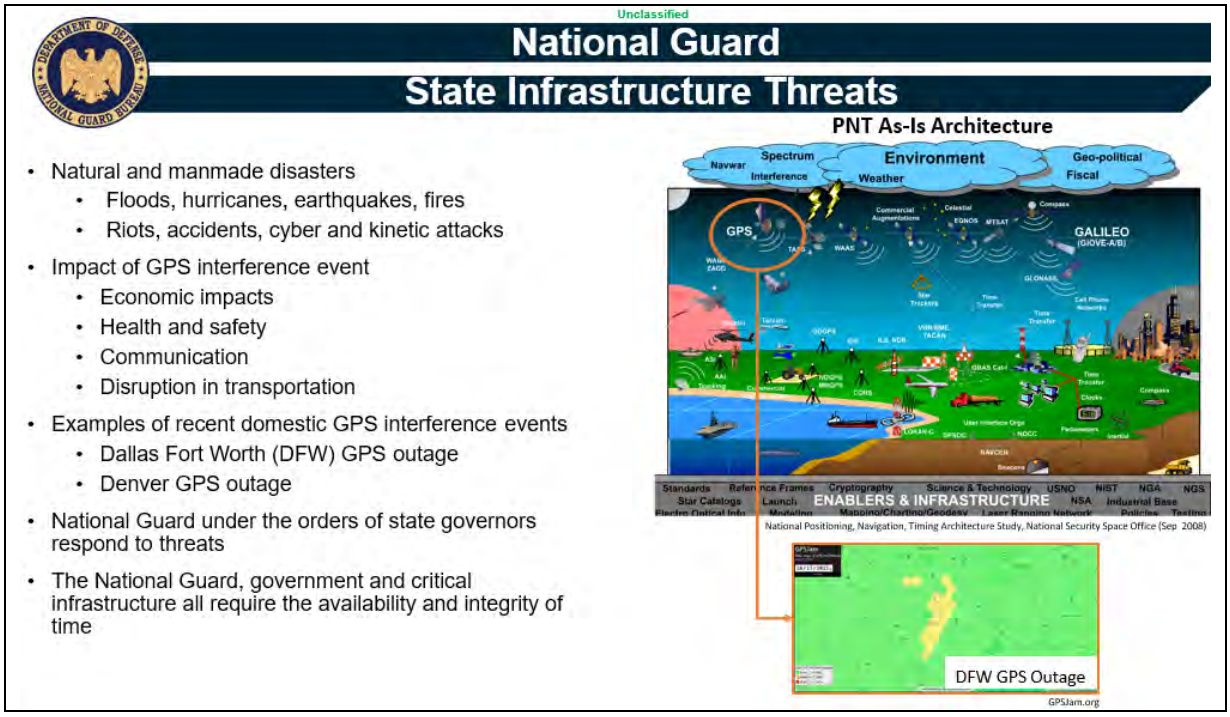
Slide 3 provides a scene setter. In our operational environment we assume variation. For us this means that GPS dependencies flow through the highly interconnected state and local infrastructures that know no boundaries because of the interconnectivity in critical infrastructure. It is interconnected as one system-of-systems. Thus, if there is a GPS outage somewhere it will indiscriminately traverse across that interconnected operational environment. This is how we set the scene as we work through at the local., state, and regional level with a lot of our emergency management personnel and national guardsmen as we deal with the challenges to prevent domestic emergencies, and if that fails then with the ability to rapidly respond and restore normal operations. As noted by the Dept. of Homeland Security (DHS) Secretary Mayorkas, the ubiquitous cutting-edge technologies, economic and political instability, and our globalized economy have erased borders and increasingly bring threats and challenges directly into our communities. This is why we step into the scene and "glue together" both local communities and country when responding to emergencies and, even better, in trying to prevent such emergencies from happening.



Slide 3

Slide 4 provides an overview from the National Guard's perspective. They have ~ 440,000 personnel in over 3000 locations across states, territories, and the District of Columbia. With its dual authority, serving both the community and country, they have some unique capabilities to help local authorities. The National Guard has traditionally focused on addressing natural and man-made disasters, but there are over 4000 guardsmen working as cyberwarriors to respond in the non-kinetic world, such as spectrum, where we need to know how to respond so that civil authorities can maintain normal operations as we figure out how to resolve a situation.

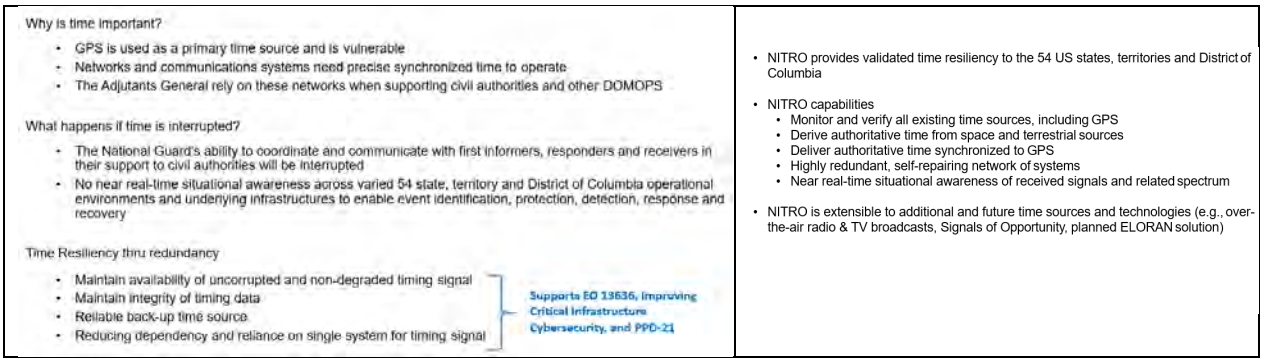
With GPS interference, they have noticed such events not only have economic impact, but also impacts to health and safety, communications, and transportation. During the Dallas Fort Worth event, despite extensive searching they were unable to find the source of GPS interference. Ideally, they would not just react to an event, but develop a proactive posture. This is what they are working towards and leveraging their capabilities to do. This is not just to support the community and country, but one third of their force at the adjutant general level are dual-hatted and work as emergency management leaders for the local state governors. In addition to GPS, they are looking at emerging technologies, including advances in Galileo and its approval for use in the U.S.



Slide 4

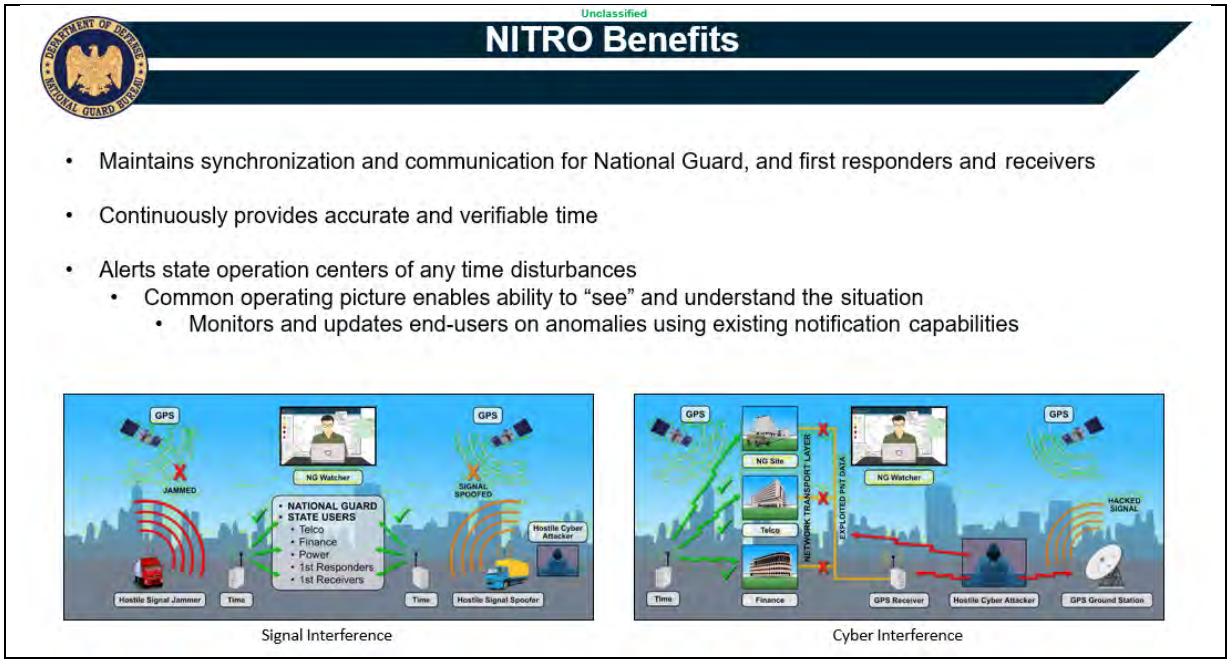
As noted in Slide 5, time is the fundamental source of data that flows through this interconnected and inseverable environment of state, city, and critical infrastructure system-of-systems. When we looked at that, we saw that time is the key value that all critical infrastructure systems need, and that it flows with a dependency on GPS. Networks and communications systems need precise synchronized time to operate, and the adjutant generals rely on these networks when supporting civil authorities and other Domestic Operations (DOMOPS). So, why is time important to the National Guard? If time is disrupted, they lose their ability to coordinate and communicate with first informers, responders, and receivers. They would also lose situational awareness across the U.S. Therefore, they need to have resilience through redundancy, and leverage what is already out there. With that, they came up with four guiding principles: (1) maintain availability of an uncorrupted and non-degraded timing signal, (2) maintain integrity of timing data, (3) have a reliable back-up time source, and (4) reduce dependency and reliance on single system for timing signal. By focusing on these key areas, they were able to move forward with NITRO.

As shown in Slide 6, they realized the following would be needed for NITRO: (1) monitoring and verifying all existing time sources including GPS, (2) deriving authoritative time from both space and terrestrial sources, (3) delivering authoritative time synchronized to GPS, (4) implementing a highly redundant and self-repairing network of systems including artificial intelligence and machine learning capabilities, and (5) having near real-time situational awareness of received signals and their related spectrum. This is important to the National Guard because they are not only fusing space, land, and cyber domains, but are also looking at also how PNT data flows. Such data tells us what part of the spectrum is affected and whether the data can be trusted. In their operation centers they can deliver the common operating picture in near real-time so they know, at a moment's notice, if there is an anomaly in the environment, what type of anomaly that is, and be able to inform the emergency operations personnel and local leadership so they can take action. At the discretion of the civil authority, they can elect to receive the accurate time from the National Guard as a failover so operations and services to the public remain normal while they work to resolve the anomaly. Also, NITRO is purposedly built with an open system architecture to make sure it could be extensible to additional and future time sources such as over-the-air radio & TV broadcasts, other signals of opportunity, and potentially the proposed eLORAN capability.



Slides 5-6

Finally, slide 7 provides an overview of benefits of NITRO. It provides the ability to maintain synchronization and communication for the National Guard, first responders and receivers, and with the recent addition of TV signals also our first informers. NITRO continuously provides accurate and verifiable time, and alerts state operation centers of any time disturbances. Having a common operating picture provides the National Guard with the ability to "see" and understand a situation. From there, NITRO monitors and provides updates to end-users on anomalies using existing notification capabilities. The graphics in the slide provide an OV-1 view [Note: this is DoD jargon for high-level operational concept graphic], of how we are tackling GPS interference (on the left) and cyber interference where false timing data is being inserted into the system (on the right).



Slide 7

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Session of Thursday, May 4, 2023

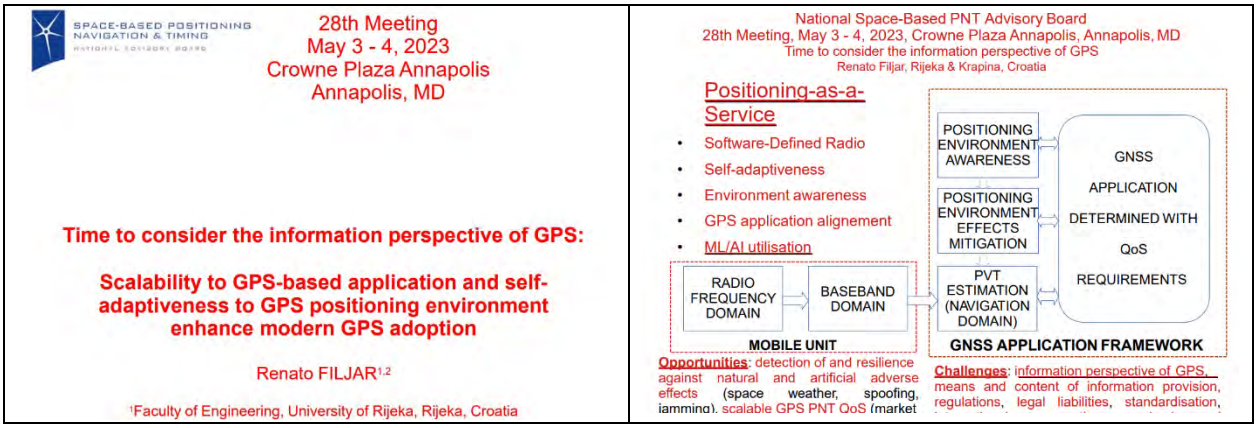
Updates from International Members & Representatives

1) Croatia: Dr. Renato Filjar

Dr. Filjar thanked Dr. Parkinson and the Board. He apologized that he could not make it to Annapolis, MD to attend this Board meeting in person, and stated that he would be presenting some activities that he has encountered since the previous meeting.

Regarding the presentations yesterday from Dr. Alison Brown and Ms. Fiammetta Diani, Dr. Filjar stated that he'd like to emphasize the importance of the consideration of the information perspective of GPS (Slide 1). Especially for the scalability to GPS-based applications and self-adaptiveness to GPS positioning environment, which provide us with the opportunity to sustain GPS as the gold standard. Dr. Filjar said that he believes is it a good idea to consider the advantages of the other GNSS systems, but it is not a good idea to merely follow in their footsteps with hopes of becoming comparable to them. As Dr. Parkinson presented yesterday, GPS began as a fantastic technological marvel, and it should stay on that same trajectory in the future by providing something unique in comparison to the other GNSS systems.

The Positioning-as-a-Service is a result of the perspective and consideration of the information within the GPS positioning process (Slide 2). Enriched with software-defined radio, we all enjoy or mobile phones with self-adaptiveness and environment awareness. PNT may be easily aligned with a particular GPS application. The mobile unit has become more prevalent of a concept. We understand that a GPS receiver splits its tasks into two domains: (1) The Mobile Unit, and (2) GNSS Application Framework. The Application works closely with the estimation of the position, velocity, and time, so the PNT service has gradually become the information perspective of the environment framework.



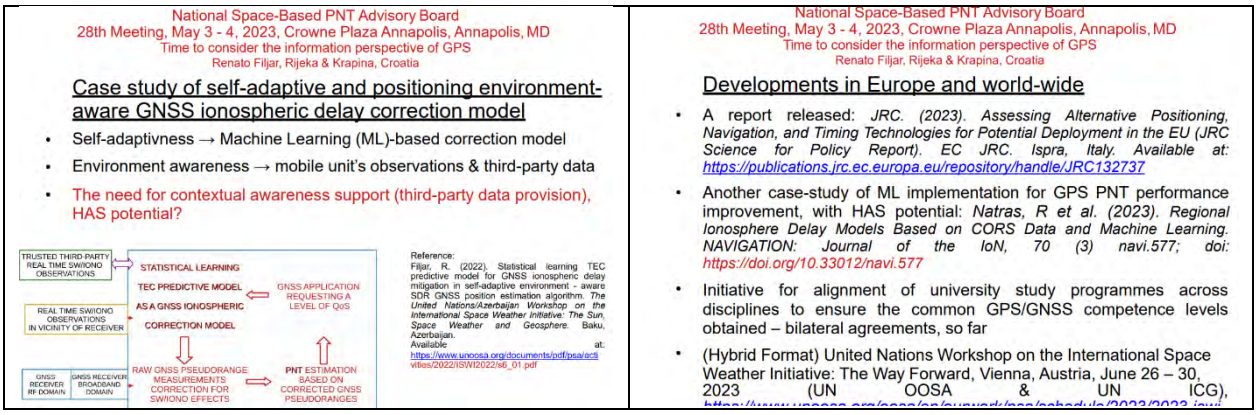
Slides 1-2

Detection and resilience against natural and artificial adverse effects can provide us an opportunity to collect the crowdsourcing data from the regulated applications, such as those in telecommunications or air traffic control. This is also an opportunity for the GNSS application to be scalable, or to scale the PNT quality of service regarding the needs and requirements of the particular application. Dr. Filjar stated that he referred to this in his previous presentations when referring to the work of the European Space Agency (ESA), which developed a library of books which outlined the requirements of particular GNSS applications in regard to the PNT performance. A question that arises from the challenges of implementation is what the U.S. government should do about this. Dr. Filjar stated that he believes that the U.S. government should do a lot regarding the new concept of Positioning-as-a-Service. There are perspectives of the content and means of information provision, the regulation of certain parts of the segment, and legal liability standardization because the receiver is no longer defined in the traditional way. There is a new perspective of the GNSS and GPS PNT services. There is also a quest of international cooperation because the awareness of PNT disruptions may be collected internationally for the benefits of all.

Regarding academic and educational information, Dr. Filjar emphasized that we need a better understanding of PNT across various disciplines. Mathematics is needed for geodesists, computer scientists, electrical engineers, etc. in such a way that people in all industries, including lawyers and medical staff, should learn the essentials about PNT in order to utilize modern technology.

Dr. Filjar showed a case study of the self-adaptiveness and positioning environment-aware GNSS ionospheric delay correction model (Slide 3). Specifically, Dr. Filjar's group studied the ability of certain mobile devices, such as smart phones equipped with GPS receivers and geomagnetic sensors. The work that has been published at one of the ICG events shows that simple awareness of the geomagnetical conditions may serve in the development of the self-adaptive, machine-learning based correction model for the ionospheric effects. This opens an opportunity to integrate the mobile unit observations with data, which will be more imminent to the GNSS receiver ability to mitigate atmospheric effects, and potentially other natural effects. There is an opportunity to include contextual awareness of this data in the proposed concept of HAS.

There are some developments in Europe and world-wide (Slide 4). The Joint Research Center of the European Commission in Ispra, Italy has issued an interesting report on alternative PNT technologies for potential deployment in the EU. This document is available to the public, and Dr. Filjar has included the link to the publication on the slide. Another publication within the Navigation Journal of the Institute of Navigation discusses the utilization of the machine learning for the development of the regional ionospheric delay models. Machine learning and artificial intelligence are playing a larger role in GPS, and this should be considered in the Board's future meetings. University study programs are beginning to align across disciplines. This opens up to opportunity for the EU to collaborate with the U.S. elsewhere in the world. Bilateral agreements have been reached regarding this topic. Additionally, there will be a United Nations Workshop on the International Space Weather Initiative in June in Vienna, Austria.



Slides 3-4

In June, the Baska Spatial Information Fusion Forum (SIF) will be held in Croatia and will address a number of topics related to this Board (Slides 5-6). These topics include satellite navigation; machine learning; predictive modeling; and spatial data/information description, identification, modeling, and prediction. Dr. Filjar stated that this Board has the opportunity to attend this forum and thanked the Members who have shown interest in this event.

Slides 5-6

* * *

2) Australia: Mr. Matt Higgins

**There were no slides for this presentation.*

At the last meeting Mr.Higgins presented on the development of a national roadmap for PNT, as one of the seven space priority areas identified in the Australian Civil Space Strategy. The roadmap is now complete and has been signed off by a Steering Committee involving senior management in the Australian Space Agency, Geoscience Australia, Department of Defense, and Department of Home Affairs. The roadmap now needs to be approved by the Head of the Australian Space Agency and then by our Minister. So, it is hoped that the roadmap will be published in coming months and Mr. Higgins stated that he hopes to be able to present it in detail at the next Board meeting.

Mr. Higgins also presented on the SouthPAN SBAS project to the last meeting of the Board. The project is progressing well.

Some may have seen some press about so-called "GPS outages" in Australia and reports about tractors stopping in the fields. That was not actually a GPS outage but an outage on a comms satellite used for delivering GNSS corrections. Inmarsat experienced an outage on its 4 F1 satellite, which provides L-band services for East Asia and the Pacific region. That Inmarsat outage did affect SouthPAN and a number of commercial Differential GNSS service providers. In some ways, it was useful to have outages because it raises awareness of how reliant we are on these services.

It is important to note that SouthPAN is currently offering what are referred to as early open services, which are not intended for safety of life applications. Future stages of SouthPAN will introduce new and redundant satellite comms capabilities and it will not be until then that SouthPAN will move to operational phases and ultimately to certification for safety of life applications.

Mr. Higgins also addressed the European Commission (EC) Joint Research Centre (JRC) on "Assessing Alternative Positioning, Navigation and Timing Technologies for Potential Deployment in the EU". He stated that it was gratifying to see Locata Corp from Australia as one of those solution providers and it performed very well against the testing criteria for both positioning and timing.

Finally, Mr. Higgins stated that he wears the hat as President of the IGNSS Association in Australia during Board meetings. The next IGNSS conference will be held in Sydney in February 2024. He said that if anyone is interested in speaking or attaching meetings to that event to please let him know. Both he and Rick Hamilton are currently working on the possibility of having a CGSIC meeting attached to this conference.

Discussion:

> Dr. Parkinson commented that he is always struck by how well the Australians have adopted GPS, but then realizes that Australian is a vast continent that this may be a marriage made in heaven.
>
> Mr. Higgins stated that Australian can be considered a country that GPS was designed for.

* * *

3) United Kingdom: Professor Terry Moore

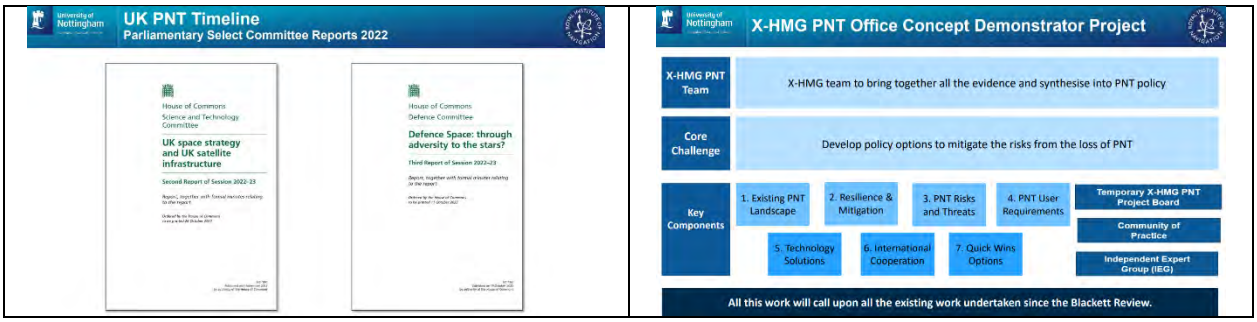
Prof. Moore noted he would provide a brief report on aspects that have been happening in the UK regarding the cross-government activities in PNT as well as what has been happening within the Royal Institute of Navigation (RIN) (Slide 1). Prof. Moore also stated that he is not presenting as an official government spokesperson. He has consulted with the cross-government team, and they have approved the slides that he will present.

There has been activity in the UK leading to the publication of several reports, including the Blackett Review which was published in 2018 (Slide 2). This report stresses, for the first time, to the UK government the vulnerability of PNT and out reliance on it. Additionally, the study on the Space-Based PNT Program came out in 2020. These reports all lead to the drafting of a PNT strategy, which was titled the Draft Cabinet Office Strategy and was never formally published. Later, the UK Integrated Review and the National Space Strategy were published in 2021. These reports highlight the criticality and the need for developments of PNT.

Slides 1-2

In 2022, two Parliamentary Select Committees, one for science and technology and one for defense, considered various aspects of space infrastructure and its uses (Slide 2). PNT was a key part of this discussion.

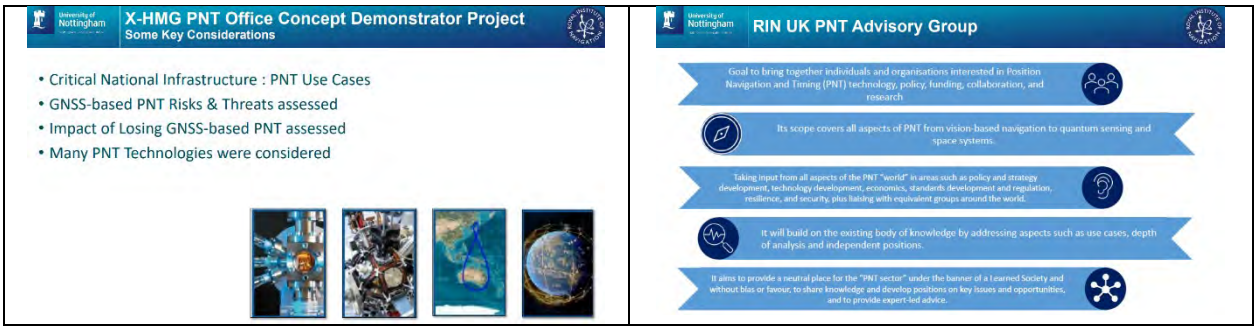
Regarding the Cross-His Majesty's Government (X-HMG), a PNT Office Concept Demonstrator Project, a team was established within a government department that was then called BEIS, which is now called the Department of Science, Innovation, and Technology (DSIT) (Slide 4). This team aimed to bring everyone together who is involved in PNT across all aspects of government to try to come up with a clear strategy and policy that could be implemented within the government. Aspects of this discussion include: (1) Existing PNT landscape, (2) Resilience and mitigation, (3) PNT risks and threats, and (4) PNT user requirements. This team visited the U.S. in December of 2022. A critical group within the X-HMG Board talked with representatives from government and stakeholders, and an independent expert group made up of about 15 to 20 experts from industry and academia across the country (this is where Prof. Moore sits).



Slides 3-4

The team looked at critical national infrastructure and how that mapped onto the various departments that were represented, PNT use cases and its criticalities, risks and threats and the impact of losing GNSS-based PNT, and a wide range of PNT technologies for possible solutions in addressing those threats including quantum, LEO, global or regional satellite constellations, augmentations, different aspects of timing, etc. (Slide 5). This work has been concluded and the team had produced its final report, which is still being considered by the government. Therefore, although there are clear policy recommendations within the report, Prof. Moore stated that he is not allowed to discuss those at this time. It is hopeful that by the end of the summer, this report will be approved, and the actions can be implemented. Then at the next Board meeting, Prof. Moore will hopefully be able to discuss the actions taking place within the UK government.

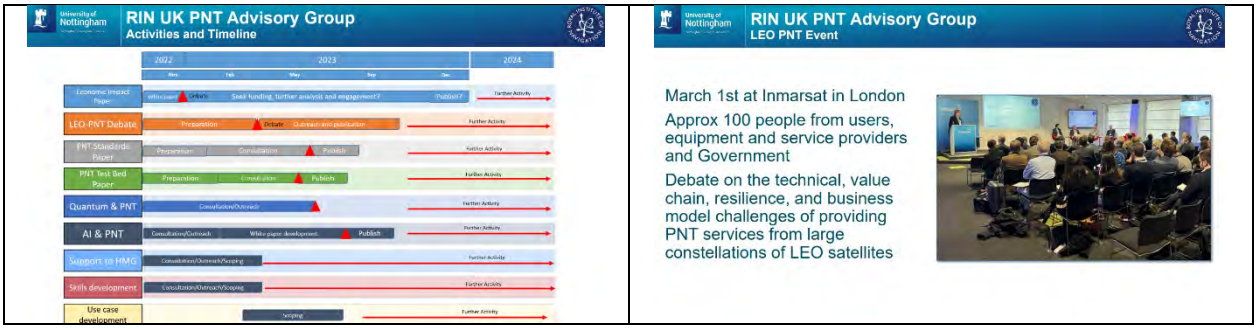
Within the RIN, a PNT Advisory Group has been created (Slide 6). This group aims to help the apparent stagnation within government in terms of PNT policy and implementation. This Group brings people together to put things in place such as studies, workshops, forums, and white papers to help advance the developments of PNT within the UK.



Slides 5-6

The Economic Impact Paper was published in November (Slide 7). There may be a need to continue working on it, so the Group is seeking funding to further develop the work. The LEO PNT aspect has advanced significantly. There was a workshop on March 1, 2023, where over 100 people attended and helped significantly advance the debate regarding LEO PNT. The Group has also been looking at the needs and roles of advancing standards in the UK. Relating to that, a PNT Test Bed Paper is being developed to address validation and certification against standards. The RIN is not going to put the testing into place, but the Group is drafting a white paper to recommend what should be done in that regard. Yesterday, Prof. Moore recommended that the Board consider quantum and AI technology's relationship with PNT. The Advisory Group will be holding a workshop in the UK looking at quantum and PNT. There is a significant amount of funding coming from the UK government towards quantum advancements relating to PNT. Work has also been continuing work regarding skills development relating to the work of the Board's ESI Subcommittee. Additionally, a refresh of the work that has been done so far in support of the government was reported.

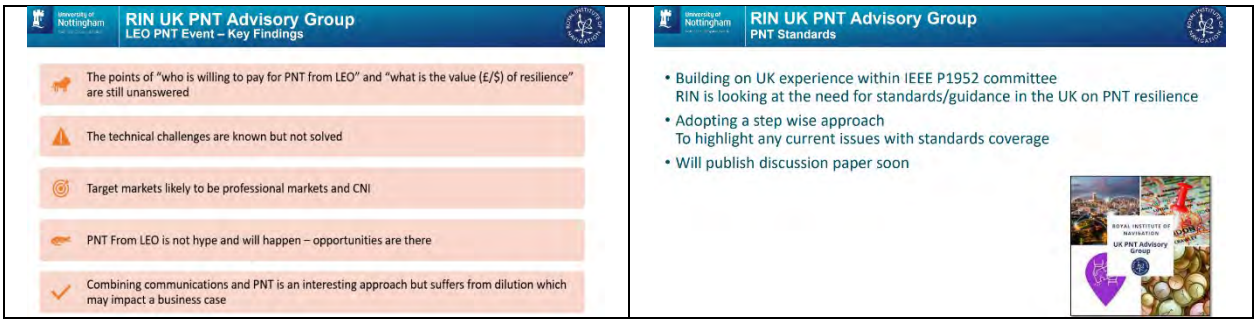
The LEO PNT event was held in March in London (Slide 8). Over 100 people, including users, equipment and service provides, and government representatives attended this event. Each session held was based around debates relating to technology, business models, etc., instead of presentations.



Slides 7-8

As shown on Slide 9, key findings included: (1) The question of "who is going to pay for LEO PNT?" is still unanswered; (2) A number of technical challenges are still unsolved; (3) Although the markets are not clear, there is likely to be professional markets and critical national infrastructure; (4) Is PNT from LEO all hype? There is reality that things will be happening, but not yet and not in all market areas; (5) The synergy between PNT and communications as well as the benefits work between the two could have significant impacts on some of the business cases.

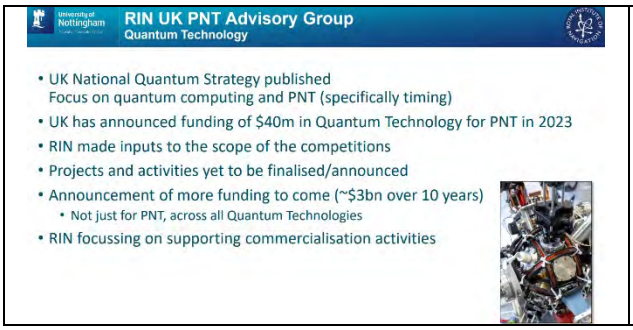
The Group has also been building on the work done within the IEEE P1952 committee by looking at the need for standards, advice, and guidance within the UK and addressing PNT resilience (Slide 10). A discussion paper of this is now drafted and will be published within the next few weeks.

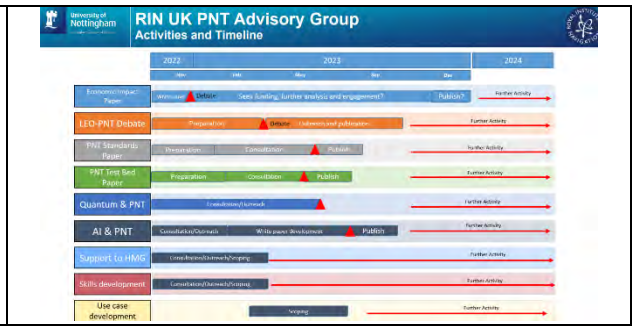


Slides 9-10

Regarding quantum technology, the Quantum Strategy has been published, and highlights PNT, specifically timing (Slide 11). Funding from the UK government for quantum technology for PNT will be announced within the next few weeks. The RIN was activity involved in the process of deciding where these awards will go, and an additional three billion pounds in funding is estimated to come over the next ten years.

The RIN has set aggressive timescales (Slide 12). It is The Group is publishing white papers, holding forums, and stimulating the discussion while trying to help the UK government move forward.





Slides 11-12

Discussion:

Mr. Miller thanked Prof. Moore for an informative and concise presentation. He noted that Dr. Parkinson has presented serval times to the ICG on the value of other nations having citizen-based user advisory boards such as this one. The Board highly values the perspective of its international members. Now that several nations such as the UK have put up their own advisory boards, is there any thought to inviting U.S. personnel so we can continue the cross-pollination at the user level?

Prof. Moore said that within the official cross-government work there have been recommendations that there should be user advisory groups. This consideration has gone forward in the report. There are many U.S. members of the RIN and we have been considering expanding the membership of the Advisory Group to include U.S. representatives and others, as well.

Dr. Parkinson asked Prof. Moore to give a brief summary of where the UK stands relative to Galileo.

Prof. Moore stated that the UK is no longer involved in any way to the Galileo Program. As a result of Brexit, they have been excluded from many parts of the Program including the Galileo Publicly Regulated Service (PRS). Critical national infrastructure is one of the main reasons why the UK needs to do something nationally about PNT. The Ministry of Defense, as a member of NATO, has access to GPS and the M-code. But regarding other access of critical national infrastructure, we would not have that access, so now without any access to PRS within Galileo, there is a need to address the critical national infrastructure aspects. Relating to this, the UK also no longer subscribes to the European Geostationary Navigation Overlay Service (EGNOS). This means that EGNOS cannot be used for the certification of movements in airspace within the UK, which is steering the considerations of PNT policy within the UK. The question is, how does the UK address the requirement for a certifiable augmentation for GNSS in UK airspace if we are not using EGNOS. These are all drivers that are being considered.

Dr. Parkinson clarified with Prof. Moore that he could not tell the Board whether the UK is contemplating a parallel development to Galileo along the lines of GPS/GNSS.

Prof. Moore stated that this is correct.

The Hon. Shane asked Prof. Moore how often the Advisory Group meets within the RIN, and if there are other elements of similarity or difference that might inform the work of this Board?

Prof. Moore stated that the Advisory Group is working under the umbrella of the RIN, which is a charitable body similar to the Institute of Navigation (ION) in the U.S. This constrains what we can and cannot do, for example, the Group cannot lobby. We are there to have independent discussion and provide expert advice. The UK Space Agency has a PNT committee, who do not have the same independence that the Advisory Group has, and therefore the government listens to them in a different way. The Group is very conscious about remaining independent to provide balanced advice. The Group meets every month to every six weeks. The PNT workshop is the next main action item, and the Group has been discussing that every few weeks. There are fewer than ten on the Advisory Group and can therefore respond an work fairly quickly.

* * *

4) Resilient Navigation and Timing (RNT) Foundation: Mr. Dana Goward

**There were no slides for this presentation.*

Mr. Goward stated that the RNT Foundation is a 501-C3, a public science and benefit charity, and while they do have corporate members and supporters, IRS regulations state that they support our mission as opposed to us supporting their interests.

1996 was the year of the "Unforgettable Humiliation". China was outraged by Taiwan's efforts for international recognition as an independent nation. China had amassed 150,000 troops in Fujian Province along the shores of the Taiwan Strait. There were artillery exercises, amphibious landings, and naval maneuvers. The U.S. immediately became concerned and sent two aircraft carrier battle groups to the straight in order to monitor the situation. This became known as the Third Taiwan Strait Crisis. As part of intimidating Taiwan, the People's Liberation Army fired three missiles aimed about 16 km off the Keelung Taiwanese Military Base. One of these missiles landed on target in the water and the other two went missing. The People's Liberation Army (PLA) stated that this was because the USAF was diddling with the GPS signals that were guiding the missiles. This event became known to the PLA as the "Unforgettable Humiliation". This spawned a 24-year effort by China that eventually resulted in BeiDou: a satellite navigation system that China claims is second to none and exceeds that of the U.S. Along the way, BeiDou birthed an entire Chinese space industry including satellites, rockets, receivers, landings on the far side of the moon, the PLA strategic support force, the Rocket Force, and a new inventory of cruise, ballistic, and hypersonic missiles.

BeiDou was China's declaration of technological independence from the west. China's military and civilian population no longer needed to rely on Western PNT from space. For over 5,000 years, China had been the most advanced and sophisticated civilization in the world. Then it was interrupted by oppression from the West for 150 years by unfair trade practices and opium wars. Now with BeiDou, the great rejuvenation of the Chinese nation had taken a giant a giant leap forward. China was back.

Now here we are, with 70-year-old President Xi who, like his 70-year-old friend, Vladmir Putin, is aware that leaders don't create legacies in their 80's. Like President Putin, Xi is very desirous of bringing a prosperous, breakaway province back into the sphere of governance.

2024 will be the Year of the Dragon in China, and the dragon is the symbol of power, honor, luck, and success. President Xi very much wants to be China's modern-day dragon. China also has, arguably, the world's most resilient PNT architecture, while that of the U.S. is relatively fragile. 2024 could be a very propitious year for one of China's perpetual critics and adversaries; to have its own Unforgettable Humiliation. The RNT Foundation believes that the U.S. should be very concerned and have a sense of proficiency in all of its PNT endeavors.

Mr. Goward stated that as a 501-C3, the RNT Foundation is required to hold an annual meeting so that the directors may hear from members and others regarding the course of the foundation. This year's meeting will be immediately after the conclusion of this Board meeting. Members and other attendees are invited to participate in the discussion regarding best ways forward for our non-profit.

* * *

5) Consumer Technology Association: Mr. David Grossman

**There were no slides for this presentation.*

Mr. Grossman greeted the Board and apologized that he could not attend in person. He is the Vice President of Regulatory Affairs for the Consumer Technology Association (CTA). CTA represents about 1,500 companies and 18 million jobs across the consumer technology industry.

Mr. Grossman stated that he would be providing an update on five issue areas that have relevancy to the Board.

First, this morning, the White House is convening a summit on the U.S. National Standard Strategy for critical and emerging technology. Veronica Lancaster will be representing CTA at this event, where she will deliver the message that standardization supports innovation. CTA strongly believes in the importance of private sector engagement and standards development, which is critical for ensuring that standards are timely, relevant, practical, effective, and progressive. The U.S. will need to remain engaged in these efforts in order to remain competitive and maintain its leadership in technological innovation.

The National Standards Strategy addresses a list of critical and emerging Technologies, and PNT is included in that list. The strategy focuses on four key objectives to prioritize critical and emerging technology standards development, including: (1) Bolstering investment in pre-standardization research to promote innovation, cutting edge science, and transnational research to drive U.S. leadership, (2) Committing the USG to engage with the broad range of private sector, academic, and other key stakeholders including foreign partners, (3) Investing in education and training stakeholders, and (4) The USG will harness the support of like-minded allies and partners around the world to promote the integrity of the international standards system and to ensure that international standards are established on the basis of technical merit through fair processes that will promote broad participation from countries around the world. Notably, the White House recently issued that several U.S. agencies have demonstrated their commitment to the Strategy, including the DOT, NTIA, NIST, and FCC. This announcement is available to the public at whitehouse.gov along with the Strategy, which is about a 14-page document.

The second topic regards the lapse of the FCC spectrum auction authority. Congress initially established the FCC's auction authority in 1993, and until this March that Authority had never lapsed. During its 30-year history the auction authority process enabled the FCC to raise more than $233 billion for the U.S. Treasury, which has helped unlock thousands of megahertz (MHz) of spectrum and, in turn, powered each new generation of wireless technology. - Mr. Grossman stated that he authored an op-ed on this topic a few weeks ago highlighting why spectrum auction authority is so important for consumers. Regarding the World Radio Conference later in 2023, U.S. leadership has been important to the wireless community and a lapse of this authority is a detriment to our leadership. There is no update on where Congress stands on this issue. There have been attempts to either get a short or long-term extension, but at this point Congress has not been moving this issue and the authority has lapsed.

The third issue surrounds receiver performance. At the previous Board meeting, he discussed the FCC's Notice of Inquiry, which they issued last summer seeking comment on the role of receiver performance in the agency's management of spectrum. While GPS is not directly mentioned by name, the item that was just recently voted on, it's clear that GPS is at the forefront of the high-level pre-principles that were adopted by the FCC at last month's meeting. I n their statement, the FCC notes that the property of receivers and their immunity to out-of-band interference offer an increasingly promising pathway to managing spectrum needs. Receivers authorized for a use and a service should be designed to mitigate interference from emissions from outside of their services, as well as assign frequencies or channels.

When the Notice of Inquiry (NOI) was published last year, CTA record noted that "it's clear that a voluntary industry-led approach to enhancing spectrum performance is most likely to be successful and that the Commission should focus its efforts on promoting participation in voluntary, industry-led approaches, which are succeeding to increase spectrum efficiency." CTA also noted the need for additional dialogue before such guidance is issued. The Commission recently approved, 4-0, a high-level set of principles on how they intend to manage spectrum moving forward. The policy statement outlines guidance within three categories: (1) The physical realities of interference that apply to transmitters and receivers in all spectrum-based services, (2) The Commission's expectations about the shared responsibility of transmitter and receiver systems to coexist with other services in approximate bands, and (3) The role of reliable data in the FCC's technical analysis of spectrum issues.

Mr. Grossman noted that this statement is not a regulatory, legally binding document. FCC Commissioner Simington recently indicated that he would like the FCC to move to a notice of proposed rulemaking uh related to receiver performance.

The fourth topic is in regard to NTIA's National Spectrum Strategy. In March of this year, NTIA announced that it would seek comments in support of a National Spectrum Strategy with the goal of identifying at least 1,500 MHz of spectrum to study for potential repurposing. Comments were due on April 17, and over one hundred organizations filed in the docket. CTA's filing discussed the growing demand for new and innovative wireless services; the importance of wholistic approach to spectrum policy; embracing licensed, unlicensed and hybrid models; and the need for better federal coordination between agencies.

Mr. Grossman also addressed the filing of the GPS Innovation Alliance in response to the spectrum strategy. His former organization discussed the need for NTIA to recognize the critical differences between communications and navigation systems and support the maintenance of the spectrum environment. They also encouraged NTIA to endorse the 1 dB metric for evaluation of harmful interference to navigation services and to rely on the expertise of federal stakeholders responsible for the operational management of these spectrum service.

Lastly, FCC Chairwoman Rosenworcel recently announced the launch of the agency's Space Bureau and Office of International Affairs. Notably, the Space Bureau's mandate includes serving as the FCC's focal point for coordination with other USG agencies on matters of space policy and governance. Additionally, the Bureau will collaborate with the Office of International Affairs for consultations with other countries, international and by multilateral organizations, and foreign government officials that involve spectrum, satellite, and space policy matters. - The Bureau is being led by Julie Kearney who has a long history in the tech and telecom community. Mr. Grossman stated that the Board could invite the Space Bureau—Ms. Kearney or another representative—to speak at a future Board meeting.

Discussion:

Dr. Parkinson asked Mr. Grossman if he has gotten any response regarding his op-ed and if he is hearing anything from Congress or anyone with power and as to how they're reacting from the FCC's lapse of auction authority.

Mr. Grossman stated that Members on the House Committee on Energy and Commerce and Senate Committee on Commerce have talked about the need to get this authority reauthorized. One of DoD's objections regard the lower three GHz band. CTA and other organizations continue to push Congress for a resolution, but it doesn't appear that anything is imminent in terms of uh an extension at this point.

The Hon. Shane thanked Mr. Grossman for bringing to the Board's attention the work that's being done within the FCC and elsewhere regarding the question of spectrum receiver quality. He stated that it's good to know that these issues are rising to a national level of attention and he share's the hope that the FCC's auction authority is re-established as quickly as possible. He continued, "the recommendation of that it be accompanied by some greater deference to other agencies of government who rely on spectrum and who, unfortunately, may be having to deal with legacy receivers for some period of time is not inconsistent with the need for a renewal of the auction authority."

Mr. Miller stated that amongst all the Board Members, Mr. Grossman is the most plugged into what the FCC is doing with their new Space Bureau and asked if Mr. Grossman would be comfortable inviting Julie Carney, on behalf of the Advisory Board, to the next meeting this winter. He stated that, "it would be really appreciated if you can continue to stress how important and how much we would appreciate if she could join us."

Mr. Grossman said he would be pleased to invite her to the next Board meeting.

* * *

6) International Air Transport Association (IATA): The Honorable Jeff Shane

**There were no slides for this presentation.*

The air transport industry is a major beneficiary now of GNSS, and GPS in particular. The default navigation technology in the air transport industry is ADS-B (Automatic Dependent Surveillance-Broadcast), which is entirely dependent on GPS. Therefore, all of the recommendations that this Board has made at this, and at previous meetings are important to the aviation industry. Clean spectrum is essential to reliable navigation.

The conflict over 5G that erupted as a result of the auction of C-band spectrum a couple of years ago is a poster child for the importance of taking a very hard look at the way we allocate Spectrum. There was no need for confusion about the allocation of spectrum for 5G purposes. It ended up disrupting the aviation industry and the wireless industry because the wireless industry paid $80 billion for the spectrum that was being auctioned. They are not able to use all that they paid for now because they were insufficiently informed of potential restrictions on the use of that spectrum. This conflict was with radar altimeters, which are an essential piece of avionics on every aircraft. This underscores the importance of ensuring, in the future, that we have a process that does not lead us inadvertently into confusion of that kind because it's much too costly and it's avoidable.

* * *

Roundtable Discussion

Dr. Parkinson opened the floor for subcommittee chairs to present their updated and/or new recommendations for deliberation by the full board.

* * *

1) Communications & External Relations (CER) Subcommittee

Mr. Goward (Chair, CER Subcommittee) explained that since the last PNTAB meeting, the subcommittee has developed a

White Paper in support of the recommendation for a celebration of the 50th anniversary since the approval of the GPS program. The draft has been sent to board members for comment. Mr. Goward suggested that the board adopt this White Paper for use as a tool for informing USG leadership in support of the recommendation that was approved at the last board meeting.

Dr. Parkinson asked whether the board would be out of line in also suggesting with agency should lead this?

Mr. Goward noted that the subcommittee didn't want to be too prescriptive.

Dr. Parkinson expressed concern about this recommendation falling on the cutting room floor if it does not clearly state who should lead this.

Mr. Shane underscored what Mr. Goward said about the White Paper being a tool. In his view the administration is starting to "get it", and what we need is to reinforce the ask.

Mr. Goward said the White Paper was constructed to go to Mr. Chirag Parikh (Executive Secretary, National Space Council) first. In his view, there is enough substance in the White Paper for tailoring when briefing different audiences.

Gen Hamel said this goes back to an earlier point of what should be the board's routine order. We have an EXCOM which is supposed to be chaired by the DoD and DOT deputy secretaries. This is an issue that should be elevated to both principals. If we can get cabinet secretaries to support this, then the recommendation will blow through any concerns the White House may have. We cannot motivate this recommendation unless there is strong consensus, which is we need to get forcefully in front of the deputy secretaries.

Dr. Parkinson said he'd like to be able to stand in front of the principals and asked them to choose who will lead this.

Gen Hamel suggested reworking the recommendation to make it an explicit short-term action for the two EXCOM co-chairs.

Dr. Parkinson asked Gen Hamel to work with Mr. Goward to update the recommendation approved at the PNTAB-27 meeting as well as the White Paper.

Mr. Miller noted that while the White House is interested in this, the issue is whether they can get the Vice President to show up. Mr. Miller noted he has a call with Mr. Parikh on Monday and will bring up this issue.

Mr. Goward said he'd be happy to update the recommendation and include wording to emphasize that the EXCOM should assign someone to act as lead.

<Dr. Parkinson polled the board by asking if anyone disagreed with this approach. There were none, so the motion was approved>

Mr. Goward presented a proposed new recommendation from the CER subcommittee, which calls for the EXCOM to provide within 90 days of submission written feedback to recommendations from the board, and for the National Coordination Office (NCO) to prepare a list of all the recommendations from the board since its inception in 2007.

<Dr. Parkinson polled the board by asking if anyone disagreed with this approach. There were none, so the motion was approved>

Mr. Goward asked about the status of the recommendation at the PNTAB-27 asking the DOT to provide public announcements of GPS interference incidents. He noted that there have been a number of recent incidents which, to the best of his knowledge, have not been reported.

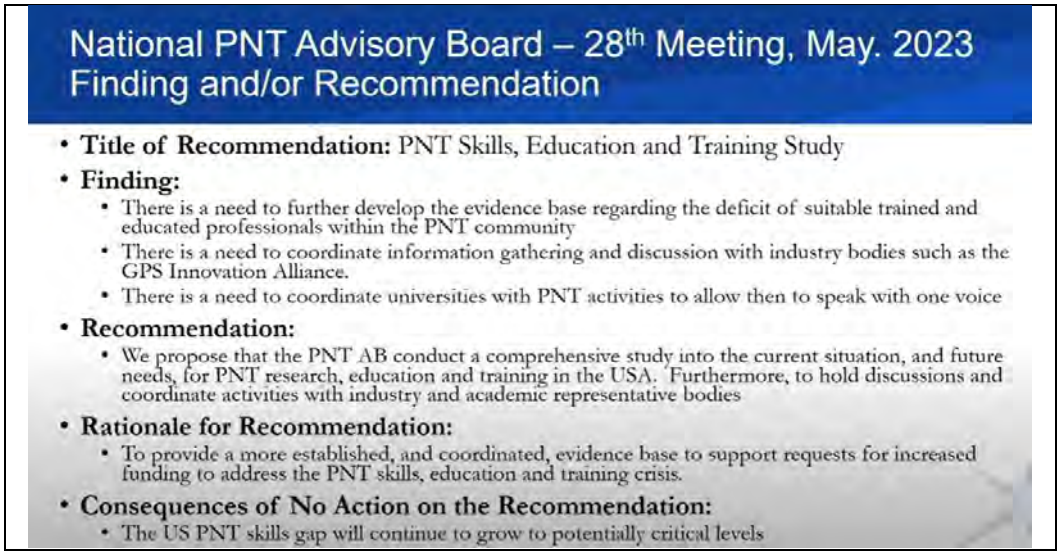
Dr. Parkinson asked Ms. VanDyke if she had any comments about the recent interference events.

Ms. VanDyke noted that the FAA has a process for issuing a Notices to Air Missions (formerly Notice to Airmen). She explained that in March DOT reviewed all of the board's recommendations and is working on drafting a response. With respect to reporting incidents, DOT is working with its operations centers on how to issue warnings and/or notifications. DOT is also working on how to get the GPS interference "heat maps" out to the public.

* * *

2) Education and Science Innovation (ESI) Subcommittee

Prof. Moore (representing Dr. Morton, Chair, ESI Subcommittee) noted the subcommittee just framed a point to raise into two recommendations. The first recommendation is related to education, and calls to make the recommendation on funding more specific. The ESI subcommittee also proposes that it be allowed to work with other bodies, academia, GPSIA, etc., to fill the pace of evidence to strengthen this recommendation (Slide 1). Dr. Morton would head that study.



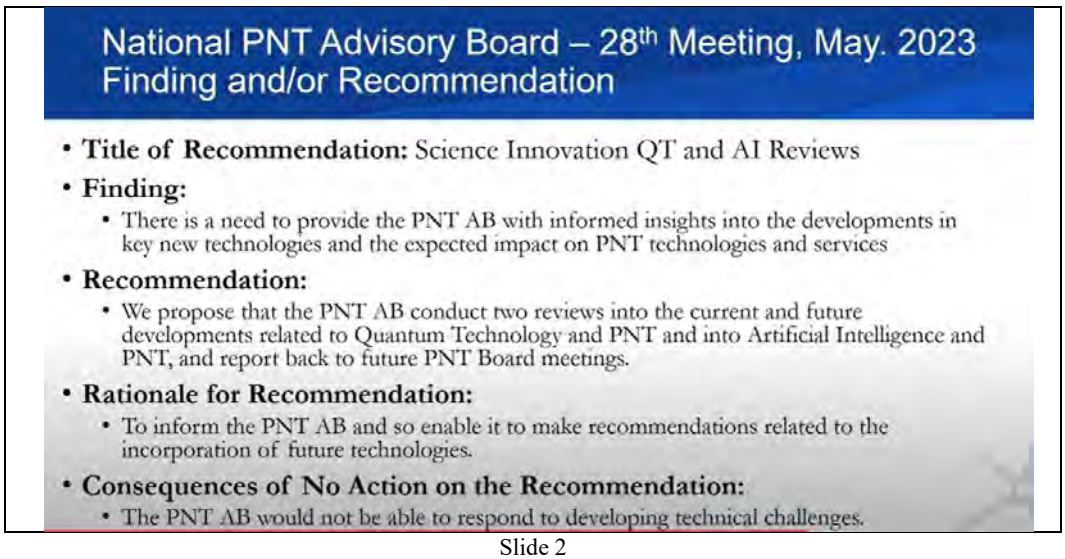
Slide 1

Dr. Parkinson asked about the status of the supporting White Paper agreed at the last board meeting.

Prof. Moore noted the subcommittee has not yet developed that White Paper.

<Dr. Parkinson polled the board by asking if anyone disagreed with the approach proposed by Prof. Moore. There were none, so the motion was approved>

Prof. Moore then explained that the second recommendation is related to science innovation, and the "Science Innovation" part. It proposes that the ESI subcommittee conduct two studies, one looking at Quantum Technology and the on Artificial Intelligence (Slide 2). That study would be led by Prof. Moore.



Slide 2

<Dr. Parkinson polled the board by asking if anyone disagreed with this recommendation. There were none, so the motion was approved>

* * *

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

Mr. Diggelen (Chair, ECAS Subcommittee) noted that he does not have more to add to the recommendation for USG to fund the High Accuracy and Resilience (HARS) service, other than it has completed the supporting White Paper.

Dr. Parkinson asked Mr. Diggelen to go back to the recommendation submitted at the PNTAB-27 meeting and make sure it is harmonized with the latest view.

Mr. Goward noted that, based on today's deliberations, it seems that the board is in a position to accept this white paper.

<Dr. Parkinson polled the board by asking if anyone disagreed with accepting the White Paper. There were none, so the motion was approved>

* * *

4) International Engagement (IE) Subcommittee

Mr. Higgins (Chair, IE Subcommittee) noted that in his briefing on the previous day he reported on the work the subcommittee plans to do over the coming months. This includes pulling the various fact sheets developed by the subcommittee into a White Paper for distribution and comment by the board. Based on the responses, the subcommittee will prepare a recommendation for deliberation at the next board meeting. The key objective is to present to the UGS the capabilities offered by other GNSS and obtain a response on what the future plans are for GPS.

<Dr. Parkinson polled the board by asking if anyone disagreed with this proposed approach. There were none, so the motion was approved>

* * *

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

Dr. Betz (Chair, PTA Subcommittee) explained that they are working to make more actionable a previous recommendation by the subcommittee. The proposal was for the USG to promptly remove any source of significant interference to GPS, and the revised text would include a timeframe for this to happen.

Ms. VanDyke noted that DOT is driving towards detection. Following detection, removal of the source of interference is not within DOT's authority and instead we need to rely on regulators, such as the FCC, and law enforcement.

Dr. Parkinson asked how this proposal could be re-worded to help DOT solve the problem of eliminating the interference source.

Dr. Betz suggested identifying the legal obstacles for prompt removal of the interference sources. While it is interesting to know GPS interference is happening, what really matter to users is knowing that such interference source is no longer there. Dr. Betz noted he'll be happy to reword the recommendation along these lines.

Dr. Parkinson asked whether we could modify the recommendation to ask DOT to work with relevant authorities, like the FCC, to enable the process to remove the interference source. Since this is going to the EXCOM, the recommendation should be clear on what it is we're asking them to do and not just to "figure out what to do".

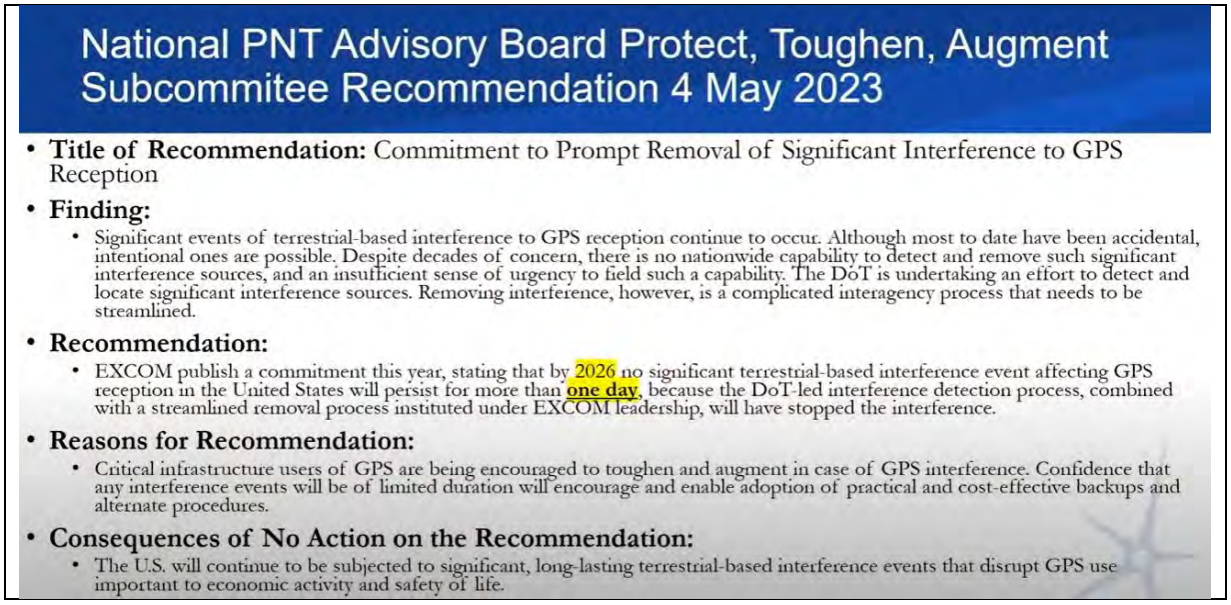
Mr. Goward noted that this issue was raised on the previous day when discussing the lack of a whole-of-government approach. This could be done much better, and within hours rather than weeks or even months. It is the lack of priority that is hampering a USG response.

Dr. Betz suggested wording this so that the EXCOM can publish the recommendation, and then let the PNT interagency process figure out how it can be best resolved.

Ms. VanDyke: That could work.

Dr. Parkinson noted we need to clearly acknowledge this is an interagency issue that probably involves the Dept. of Justice (FBI) and the FCC, and not just DOT who has the job to locate the source of interference.

Dr. Betz noted he will provide an update by the end of the morning (Slide 3).



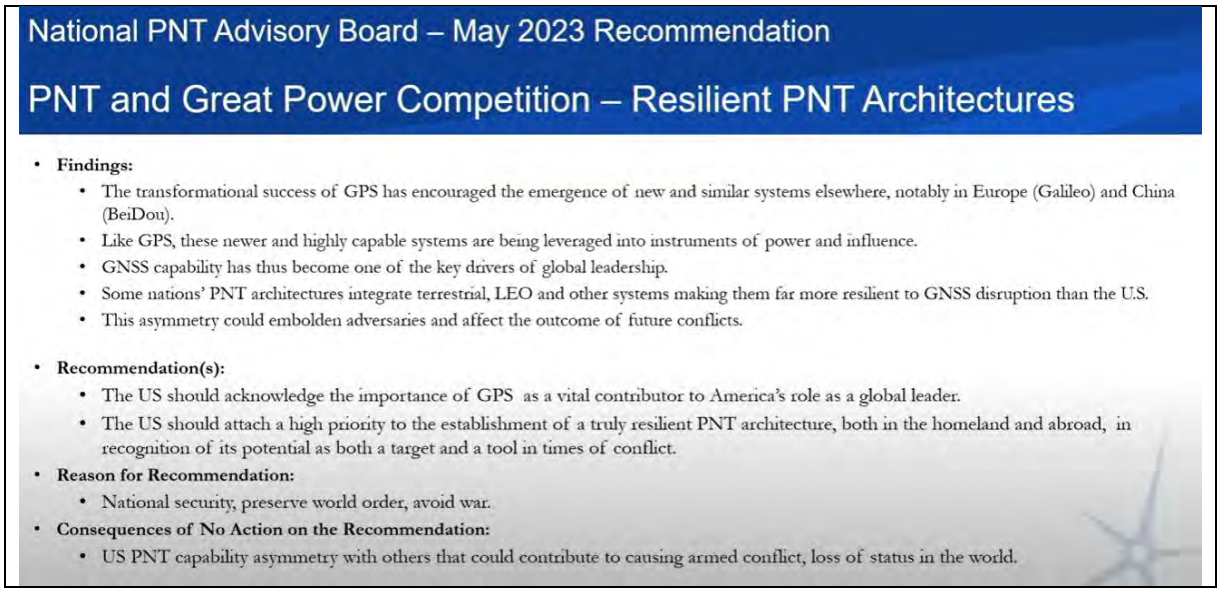
Slide 3

<Following presentation of the updated recommendation, Dr. Parkinson polled the board by asking if anyone disagreed with this proposed approach. There were none, so the updated recommendation was approved>

* * *

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

Mr. Shane (Chair, SPG Subcommittee) presented two recommendations. The first one is for a resilient PNT architecture (Slide 4).



Slide 4

Mr. Shane said this recommendation is really about an expression of soft power competition. The question is whether we are making a recommendation that is going to contribute any value and how will we know whether or not this recommendation has been accepted.

Mr. Shane asked Gen Hamel if we are making a recommendation that is actionable?

Gen Hamel noted that he's pushed on this recommendation because while this recommendation is important, it is difficult to get interest across the USG. We are going through a change of world order and are now confronting a lot of soft power competition across the world. Gen Hamel is not sure whether the U.S. really understands what is happening. We have people across the world bragging about jamming GPS, and adversaries such as China will use this to influence, break alliances, etc. The problem we're having is finding a department that will agree to own this problem. That's why we need to get an acknowledgement that this issue be part of the broad U.S. PNT interagency agenda.

Dr. Parkinson commented that at one point the board put in a recommendation that GPS be designated as critical infrastructure, but unfortunately that didn't happen.

Gen Hamel noted that's why we need to espouse some principles on how the issues should be treated in the national agenda.

Mr. Shields said his impression is that DHS has made PNT a supporting need of the broader critical infrastructure. Perhaps at the next board meeting we should have DHS back to specifically talk about recognizing the importance of PNT.

Mr. Goward said that Mr. Roskind did mention something along the lines that GPS is one of 37 cross-cutting critical enablers. In response to Gen Hamel's point, the purpose of the board is to gather information to inform the government. That's a reason for us to reflect the concerns of the broader GPS user community in a recommendation like this one.

Dr. Parkinson said it seems we are dancing around the idea whether the term "Gold Standard" is meaningful. In fact, it's no longer about retaining the Gold Standard but rather that we are clearly falling behind. Is there something explicit about this in official documentation?

Ms. VanDyke said yes, it's in SPD-7.

Dr. Parkinson added that a recommendation could be that the EXCOM reaffirm that purpose because we are falling behind and would like to see a plan to reassure ourselves that we're not on the path to be relegated.

Mr. Shields added that the issue is not just whether BeiDou is exceeding us, but more importantly the resources China is now putting into PNT, which way outstrip what we are doing. China has built a supporting structure that is very capable (resources assigned to PNT, number of researchers, etc.) and, thus, the U.S. military should really work to keep up.

Mr. Shane noted that we need someone to take a deep dive to assess those capabilities and report back at the next board meeting.

Dr. Parkinson noted that he and Dr. Betz have gotten started on comparing the resources supporting PNT in the U.S. vs. China. The picture so far is bleak.

Dr. Betz noted that the comparison he's worked on with Dr. Parkinson was focused on the civil side of things. He's worried about the board's ability to address the military side.

Dr. Parkinson proposed focusing on the civil side.

Mr. Goward noted that in addition to the GNSS satellites, there are other parts of the architecture we also need to worry about. For example, China is also expanding a high-power terrestrial [PNT] system.

Gen Hamel said he agrees with Mr. Shields. Part of the reason he's advocating to put this in the context of great power competition is to show how others are accruing power across the world. PNT is probably the most exemplary area where this is happening. In the U.S., since each agency only has a slice of this there is no effective way to ventilate this across the whole of government.

Mr. Shane said we should probably move this recommendation into 'findings', and only recommend that the U.S. prioritize a resilient PNT architecture. That was his proposal.

Dr. Parkinson said that's a great idea, and that he and Dr. Betz revisit their attempt to show explicitly where GPS stands among the plethora of GNSS around the world.

Dr. Betz agreed, but also noted he is worried that the recommendation may not be actionable.

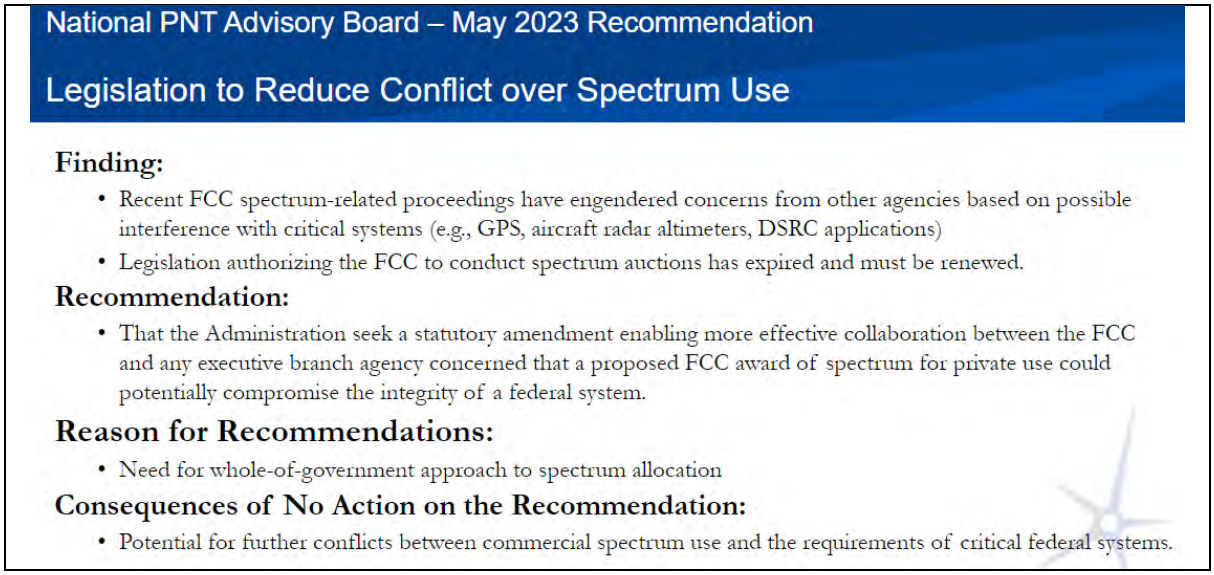
Dr. Parkinson said he believe we're on to something. First let's get the facts out there. Let's move the first bullet in the recommendation up to whether the findings are, and between now and the next meeting we can revisit this and develop the recommendation.

Mr. van Diggelen said we should first present the comparison table without judgement, and then say the board recognizes BeiDou has the following capabilities and let someone else make the judgement.

Dr. Parkinson said that's a good idea.

<Dr. Parkinson polled the board by asking if anyone disagreed with this proposed approach. There were none, so the updated recommendation was approved>

Mr. Shane then presented a reworded version of the spectrum recommendation (Slide 5).



Slide 5

<Dr. Parkinson polled the board by asking if anyone disagreed with this proposed approach. There were none, so the updated recommendation was approved>

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<The meeting was adjourned at 12:00 PM>

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Appendix A: National Space-Based PNT Advisory Board Membership as of the 28th 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

28TH PNT ADVISORY BOARD MEETING

CROWNE PLAZA, ANNAPOLIS, MD

General Session Wednesday – May 3, 2023

	NAME	ORGANIZATION	E-MAIL
1	BRAD PARKINSON	STANFORD	bradp@stanford.edu
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4	Stephen Mackey	DOT/Volpe	stephen.mackey@dot.gov
5	Andrew Hansen	DOT / Volpe	andrew.hansen@dot.gov
6	TIM MURPHY	BOEING / NASA	tim.murphy@boeing.com
7	VAHID MADADI	Gridtology	Vmadadi@gridtology.com
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28TH PNT ADVISORY BOARD MEETING

CROWNE PLAZA, ANNAPOLIS, MD

General Session Wednesday – May 3, 2023

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CROWNE PLAZA, ANNAPOLIS, MD

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28TH PNT ADVISORY BOARD MEETING

CROWNE PLAZA, ANNAPOLIS, MD

General Session Thursday – May 4, 2023

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28TH PNT ADVISORY BOARD MEETING

CROWNE PLAZA, ANNAPOLIS, MD

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Appendix C: Acronyms & Definitions

$	U.S. Dollar Currency
3D	Three Dimensional
4D	Four Dimensional
5G	5th Generation Mobile Communications Standard
A/J	Anti-Jamming
A-PNT	Assured PNT
ADS-B	Automatic Dependent Surveillance-Broadcast
AFRL	Air Force Research Laboratory
AFB	Air Force Base
AI	Artificial Intelligence
AIS	Automatic Identification System
AKM	Apogee Kick-Motor
ASAT	Anti-Satellite
ATM	Air Traffic Management
B	Billion
BeiDou	China's GNSS
C- Band	Range of electromagnetic frequencies used for various telecommunications purposes, including satellite communications
CCL	Dept. of Commerce Control List
CDMA	Code-Division Multiple Access
CER	Communications & External Relations (PNTAB Subcommittee)
CORS	Continuously Operating Reference Stations
CRPA	Controlled Reception Pattern Antennas
CTA	Consumer Technology Association
CSIS	Center for Strategic and International Studies
dB	decibel
DHS	Department of Homeland Security
DIU	Defense Innovation Unit
DLR	German Space Agency
DOA	Direction of Arrival
DOC	Department of Commerce
DoD	Department of Defense
DOMOPS	Domestic Operations
DOT	Department of Transportation
E1	Galileo Open Service Signal
E5	Galileo Aviation Signal
EAR	Export Administration Regulations
EC	European Commission
ECAS	Emerging Capabilities, Applications, & Sectors (PNTAB Subcommittee)
ECCN	Export Control Classification Number
EGNOS	European Geostationary Navigation Overlay Service
eLoran	Enhanced LORAN (Long-Range Aid to Navigation)
ESA	European Space Agency
ESG	Executive Steering Group
ESI	Education & Science Innovation (PNTAB Subcommittee)
EU	European Union
EUSPA	EU Agency for the Space Program

EXCOM	National Space-Based PNT Executive Committee
FAA	Federal Aviation Administration
FACA	Federal Advisory Committee Act
FCC	Federal Communications Commission
Galileo	European GNSS
GBAS	Ground Based Augmentation System
GDGPS	Global Differential GPS System
GEO	Geosynchronous Orbit
GHz	Gigahertz
GNSS	Global Navigation Satellite System
GOAT	GPS Operational Awareness Tool
GPS	Global Positioning System
HARS	High Accuracy & Robustness Service
HAS	High Accuracy Service
HRTR	High-Rate Tracking Receiver
HUD	Head Up Display
Hz	Hertz
IATA	International Air Transport Association
ICD	Interface Control Document
ICG	International Committee on GNSS
IDM	Interference, Detection and Mitigation
IE	International Engagement (PNTAB Subcommittee)
IEEE	Institute of Electrical and Electronics Engineers
IGNSS	International Global Navigation Satellite Systems Conference
ION	U.S. Institute of Navigation
ISR	Intelligence, Surveillance and Reconnaissance
ITAR	International Traffic in Arms Regulations
ITS	Intelligence Transportation Systems
JPL	Jet Propulsion Laboratory
JPO	Joint Program Office
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
lbs	pounds
M	Million
m	meter
MEO	Medium Earth Orbit
MHz	Megahertz
NASA	National Aeronautics and Space Administration
NAV	Navigation
NCO	National Coordination Office for Space-Based PNT (hosted at Dept. of Commerce, Washington, D.C.)
NGA	National Geospatial-Intelligence Agency
NOI	Notice of Inquiry
NSC	National Security Council
NIST	National Institute of Standards and Technology

NITRO	Nationwide Integration of Time Resiliency for Operations
NOAA	National Oceanic and Atmospheric Administration
NRL	Naval Research Laboratory
NTIA	National Telecommunications and Information Administration
OSCE	Organization for Security and Cooperation in Europe
OSNMA	Galileo Open Service Navigation Authentication
PIRT	Purposeful Interference Research Team
PNT	Positioning, Navigation, and Timing
PNTaaS	PNT as a Service
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
PTC	Positive Train Control
QZSS	Japan's Quasi Zenith Satellite System
R&D	Research and Development
RF	Radio Frequency
RIN	Royal Institute of Navigation (United Kingdom)
RMS	Root Mean Squared
RNT	Resilient Navigation and Timing Foundation
RPO	Rendezvous and Proximity Operations
RTK	Real-Time Kinematic
S/A	Selective Availability
SATCOM	Satellite Communications
SBAS	Space-Based Augmentation System
SBIR	Small Business Innovation Research U.S. Government Contracts
SDA	U.S. DoD Space Development Agency
SDR	Software-Defined Radio
SIF	Spatial Information Fusion
SME	Subject Matter Expert
SOAP	SooP Open Architecture
SoOP	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)
SSP	Space Safety Program
SSV	Space Service Volume
STEM	Science, Technology, Engineering, and Math
TV	Television
UAS	Unmanned Aerial Systems
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
U.S.	United States of America
URE	User Range error
USAF	U.S. Air Force
USG	U.S. Government
USML	U.S. Munitions List

USNO	U.S. Naval Observatory
USSF	U.S. Space Force
W	Watt
WAAS	Wide Area Augmentation System