SPACE-BASED POSITIONING
NAVIGATION & TIMING

NATIONAL ADVISORY BOARD

NATIONAL SPACE-BASED POSITIONING, NAVIGATION, AND TIMING (PNT) ADVISORY BOARD

Tenth Meeting Minutes

August 14-15, 2012

Sheraton Pentagon City Hotel

900 South Orme Street
Arlington, VA 22204

James R. Schlesinger
Chair

James J. Miller
Executive Director

SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

Tenth Meeting Agenda
August 14-15, 2012

Sheraton Pentagon City
Blue/Yellow Metro Line to Pentagon City Metro Station
900 South Orme Street
Arlington, VA 22204

Tuesday, August 14, 2012

9:00 – 9:05	**BOARD CONVENES** *Call to Order*	Mr. James J. Miller, *PNT Advisory Board Executive Director, NASA Headquarters*
9:05 – 9:30	Introductions, Announcements, & Agenda: *Assessing the National Economic Benefits of GPS*	Dr. James Schlesinger, *Chair* Dr. Bradford Parkinson, *Vice-Chair*
9:30 – 9:45	PNT Executive Committee Developments *Emerging Policy Issues & Tasking Guidance*	Mr. Tony Russo, *Director, National Coordination Office for Space-Based PNT*
9:45 – 10:05	GPS Constellation Update & Modernization Plans *National Infrastructure Investments & Funding Challenges*	Brig Gen Martin Whelan, *Director of Requirements, Air Force Space Command*
10:05 – 10:15	Enhancing GPS III Performance & Value with Satellite Reflectors *Air Force/NASA Senior Advisory Group Update*	Dr. John LaBrecque, *Earth Surface & Interior Focus Area, Science Mission Directorate, NASA*
10:15 – 10:30	PNT Board Focus & Scope of GPS Economic Assessment Tasking *(1) Quantify Scope of Government & Industry Investments* *(2) Prioritize User Base Critical Sectors & Applications* *(3) Review Past Economic Analyses & Identify Gaps* *(4) Derive Values from Productivity Gains* *(5) Determine Ops & Cost Impacts of GPS Service Disruption*	Governor Jim Geringer, *PNT Board, Environmental Systems Research Institute (ESRI)* *"Stage-setter" for gov & industry presentations & data to be analyzed & structured into economic assessment by PNT Board members on August 15*
10:30 – 10:45	**BREAK**	
10:45 – 11:05	Department of Transportation Federal Investments in GPS *Assessing Economic Benefits & Productivity Gains*	Ms. Karen Van Dyke, *Director for PNT, DOT Research & Innovative Technology Administration*
11:05 – 11:25	Federal Aviation Administration Federal Investments in GPS *Assessing NextGen Economic Benefits & Productivity Gains*	Ms. Molly Smith, *Senior Economist, Aviation Policy and Plans, FAA*
11:25 – 11:45	National Geospatial Intelligence Agency's Relationship w/GPS S *Benefits & Productivity Derived from Fed Infrastructure*	Mr. Steve Malys, *Chief Scientist, National Geospatial Intelligence Agency (NGA)*
11:45 – 12:05	U.S. Geological Survey Fed Investments in GPS *Benefits & Productivity Derived from Fed Infrastructure*	Dr. David Applegate, *Associate Director, Natural Hazards, U.S. Geological Survey (USGS)*
12:05 – 1:00	**LUNCH**	
1:00 – 1:20	United States Naval Observatory Fed Investments in GPS *Benefits & Productivity Derived from Fed Infrastructure*	Mr. Edward Powers, *Division Chief, United States Naval Observatory (USNO)*

1:20 – 1:40	Case Study on GPS Network Timing Integrity & Financial Markets: *Impacts on Infrastructure When GPS Service is Disrupted*	Mr. Malcolm Airst, *Senior Principal Engineer, MITRE Corporation*
1:40 – 2:00	Case Study on Potential Impacts to Weather Forecasting and Environmental Monitoring if GPS Radio Occultation is Denied	Dr. Stephen Esterhuizen, *Instrument Research Laboratory, NASA JPL* and Dr. James Yoe, *National Weather Service [NWS], National Oceanic and Atmospheric Administration*
2:00 – 2:20	Case Study on Potential Impacts of High-Powered Transmissions to Common Radio Receivers in *Any* Adjacent Radio Band	Mr. Tom Powell, *Systems Director, The Aerospace Corporation*
2:20 – 2:40	GPS Benefits to Agriculture: *Case Study Derived from High-Precision Operations*	Mr. Benjamin Smith, *Account Manager, John Deere*
2:40 –3:00	GPS Policy Evolution: *Minimizing Disruption While Ensuring Spectrum Access & Stability for Economic Value & Growth*	Dr. Scott Pace, *Director, Space Policy Institute, The George Washington University*
3:00 – 3:15	**BREAK**	
3:15 – 4:00	Economic Values Derived from National GPS Applications *Past Study & Analysis on Emerging GPS Service Benefits*	Dr. Irv Leveson, *Founder, Leveson Consulting*
4:00 – 4:45	Economic Values Derived from National GPS Applications *Recent Study & Analysis on Current GPS Service Benefits*	Dr. Nam D. Pham, *Managing Partner, NDP Consulting Group*
4:45 – 5:00	Afternoon "Wrap-Up" Discussion *Preliminary Feedback & Discussion for Establishing Economic Assessment Work Plan on August 15*	All PNT Advisory Board Members
5:00	**ADJOURNMENT**	

Wednesday, August 15, 2012

9:00 – 9:05	**BOARD CONVENES** *Call to Order*	Mr. James J. Miller, *PNT Advisory Board Executive Director, NASA*
9:05 – 9:15	Announcements & Agenda *Some Thoughts and Guidance from August 14 Discussions*	Dr. James Schlesinger, *Chair* Dr. Bradford Parkinson, *Vice-Chair*
9:15 - 10:00	International Member Regional Updates & Perspectives ▪ Dr. Gerhard Beutler - *Making Use of Two Fully Deployed GNSS Constellations: The Science Perspective* ▪ Dr. Hiroshi Nishiguchi - *Implementation of QZSS Update* ▪ Dr. Rafaat Rashad ▪ Mr. Arve Dimmen	(*at member's discretion*) *Switzerland* *Japan* *Egypt* *Norway*
10:15 – 12:00	PNT Advisory Board Member "Round Table" Discussion *Establishing Expectations, Working Structure, Scope, Timeline, Assignments, and Deliverables for National GPS Economic Assessment – What top level questions need to be answered?* *(1) Quantify Scope of Gov & Industry Investments* *(2) Prioritize User Base Critical Sectors & Applications* *(3) Review Past Economic Analyses & Identify Gaps* *(4) Derive Values from Productivity Gains* *(5) Determine Ops & Cost Impacts of GPS Service Disruption*	All PNT Advisory Board Members
12:00 – 1:00	**WORKING LUNCH**	
1:00	**ADJOURNMENT**	

TABLE OF CONTENTS

Session of Tuesday, August 14, 2012

The session of Tuesday, August 14, 2012 was convened at 9 a.m.

Board Convenes: Call to Order by James Miller, Executive Director, PNT Board, NASA Headquarters.

Mr. James J. Miller welcomed everyone to the 10th meeting of the PNT Advisory Board. Over the past six years the Advisory Board has been providing advice and recommendations to the PNT ExCom on issues related to GPS. This past year the Advisory Board has tackled tough questions pertaining to the safe operation of the system. It is important to keep in mind the Advisory Board includes private citizens who volunteer their time and expertise. These individuals have the appreciation of the sponsoring organizations for their willingness to serve. This meeting focuses on the national and international financial implications of GPS. An analysis of this subject is needed to secure the system's future. He also noted Advisory Board is a public meeting under the Federal Advisory Committee Act [FACA] and that everything said is a matter of public record.

Dr. James Schlesinger, Chair
PNT Advisory Board

Dr. James Schlesinger, Chair, apologized for having missed the previous Advisory Board meeting due to last-minute illness. He congratulated NASA for the successful landing of "Curiosity" on the Mars. He also noted that Advisory Board member Ms. Ruth Neilan would not be attending due a scheduling conflict, and that Major General Martin Whelan would represent General William Shelton, Commander of U.S. Air Force Space Command (AFSPC).

Dr. Schlesinger invited comments on the NASA Inspector General (IG) report on *LightSquared*. None were forthcoming. He noted that the issues that had surrounded the challenge from *LightSquared* terrestrial broadcasts in the MSS frequency adjacent to GPS has been resolved and that the Advisory Board's position is well understood and that the PNT Board will continue to monitor issues that may interfere with Global Positioning System (GPS) signals.

Dr. Schlesinger commented that when looking at the IG's report, it had occurred to him that it appeared he had only reviewed the 8th PNT Advisory Board meeting in June 2011, which focused on issues related to losses from interference with the GPS system. The focus of the 8th meeting had been entirely commercial, without discussion of the economic benefits that were national or international in scope, including 'safety-of–life'. The great economic benefits of GPS were not mentioned at the June 2011 meeting *because* we have all been taking them for granted.

The Advisory Board has been tasked with a new assignment, which is to determine the worldwide economic contribution made by GPS, and this is reasonable since the U.S. Congress provides GPS funding. Dr. Schlesinger noted he would attend the next PNT Executive Committee (ExCom) meeting to make a presentation on the "intractable problem" of assessing the economic impact of GPS. It may not be possible to give a quantitative as opposed to a qualitative answer, but he hoped the answer would be sufficient for the ExCom to persuade Congress to continue to make funds available.

* * *

Emerging Policy Issues & Tasking Guidance

Mr. Tony Russo, Director
National Coordination Office for Space-Based PNT

Mr. Russo briefed that no significant policy changes have occurred since the previous Advisory Board meetings, and NSPD-39 remains in force. This document was created in 2004 and reaffirmed under the current Administration.

Mr. Russo presented a 'laundry list' of issues that have reached the Deputy Secretary level. In 2011, considerable effort had been directed toward the *LightSquared* issue, culminating with the January 13, 2012 ExCom memo to the National Telecommunications and Information Administration (NTIA). The conclusion on the *LightSquared* issue is that GPS at this time is not prepared to handle a strong signal in an adjacent or overlapping frequency band.

Other issues of importance to GPS include:

- On-going review of the Galileo Public Regulated Service (PRS), which is an encrypted signal.
- On-going preparations for the upcoming International Committee for GNSS (IGS) plenary meeting in Beijing, China.
- Implementation of the GPS modernized Operational Control Center (OCX)
- GPS interference and mitigation issues, including the proliferation of low-cost GPS jammers and determining the effect once all GPS, and GNSS, signals are in use.

- L1C patent filing in the United Kingdom (UK), where a local firm has issued a report stating it will require royalty payments for the use of this signal.
- GPS civilian funding
- Spectrum Task Force

In terms of the L1C patent filing issue, it has become clear that as the U.S. began working more with foreign systems, it could have been clearer regarding the "ground rules" for multilateral operations. The key is how to remain transparent regarding signal standards for signals interoperable with other systems, but without giving away intellectual property of consequence.

To-date GPS has been mainly funded by the Department of Defense (DoD), but issues remain on securing adequate funding for civilian-unique GPS capabilities such as L1C. A five-year agreement on this issue is nearing its expiration date.

Mr. Russo also noted that the ExCom memo to NTIA dated January 13, 2012 on the subject of spectrum interference, stated that proposals for future MSS services should be able to be "implemented without affecting existing and evolving uses of the space-based PNT services." The ExCom has created a technical task force led by NTIA with diverse interagency participation, to further study how issues can be made clearer to other parties.

> Gov. Geringer noted this issue is directly in front of the Advisory Board, and includes a wide range of activities such as economic impacts, public safety, scientific research, and national security. Both he and Mr. Russo are the points of contact for this issue, and yet it appears that the NTIA may be heading down another path on its own.
>
> Mr. Russo said the economic benefits examination is separate from the spectrum work that NTIA is undertaking. However, given the anticipated "funding challenges," it would be useful to have a report on the economic benefits accruing from GPS. Also, the technical task force is led by NTIA with participation of others at NTIA's discretion. At some point in the future, there will also be industry involvement. Currently he is not aware of whether or not the NTIA has requested help on this issue yet.
>
> Mr. Miller said there has been no such formal request. The NTIA has been invited to this PNT Advisory Board meeting, but responded it wasn't ready yet.
>
> Gov. Geringer commented that all meetings to date have been government-only participants.
>
> Dr. Hermann asked if other departments are included in the government-only task force.
>
> Mr. Russo said there are 17 or 18 participants on the technical task force, representing a cross section of government agencies. In addition, the meeting minutes were distributed to other agencies not directly involved.

The current tasking from the PNT ExCom is to assess the study on the economic impact of GPS. The Board is not being asked to produce an economic impact study, but rather, to provide advice on how such a study should be conducted; by whom, and what it should cover. This issue 'came to a head' last year when he was asked by Congress to address the question of economic benefits of GPS and he had not been satisfied with the rigor of his answer.

> Dr. Hermann asked if his response had included the study made by Dr. Leveson.
>
> Mr. Russo said that at the time that study was only halfway through.
>
> Dr. Hermann asked if Mr. Russo was aware of any parallel studies about highways, transportation or other economic sectors.
>
> Mr. Russo said considerable financial analysis has been done on justifying the commitment being made to the FAA NextGen. However, if large budget cuts should come, then a validated statement on the value of GPS would be very useful to have.

Mr. Faga raised a new matter – specifically, the President's order to seek 500 MHz of available bandwidth. This directive called for periodic reporting and funding from the Office of Management and Budget (OMB). What has happened with this?

> Mr. Russo responded that a report had been unable to identify 500 MHz of contiguous bandwidth; the most recent figure he had seen was 130 MHz.
>
> Dr. Parkinson asked if that 130 MHz included the spectrum just below GPS.
>
> Mr. Russo said that was not part of the original specification. The overall goal was to get 500 MHz.
>
> Gov. Geringer noted that the Office of Science and Technology Policy (OSTP) had recommended finding 1000 MHz of shared spectrum. How do these two matters relate?

Mr. Russo said he did not know. The search for possible use is being made across the spectrum. The President's memo said that the 500 MHz was to be achieved without impacting any current critical capability.

Dr. Hermann noted there are technical restrictions on where in the spectrum the 500 MHz can go.

Mr. Russo acknowledged that not all areas in the radio spectrum are suitable.

In summary, Mr. Russo said the tasking to the board is to help draft an economic benefit study; review how complete and credible current studies are; determine who should conduct the study; and judge how the study may be evaluated for objectivity and completeness. Any 'outside group' conducting the study should not be so close to this issue as bring its credibility into question while, at the same time, not so distant as not being conversant on the issues.

Dr. Hermann asked if a submission date exists for the final study.

Mr. Russo said there was not, but suggested the report could take more than a year.

Dr. Schlesinger said it is important for the group not to overreach. There is a tendency for people who specialize in an area to 'overstate its glories and stupendous achievements.' One must remember that we are dealing with net benefits and, thus, there are costs that must be brought into account. Otherwise, there is a danger that the report will be viewed as a piece of advocacy rather than as evidence and conclusions.

* * *

National Infrastructure Investment and Funding Challenges

Major General Martin Whelan
Director of Requirements
Air Force Space Command

Gen. Whelan briefed that the Air Force has submitted its budget for review, which includes strong support for the GPS portfolio. Tough financial times may lie ahead, but GPS remains critical since it crosses all military domains, has an enormous economic impact, and plays a vital role in search and safety. The Air Force is also concerned about the risk of MSS terrestrial broadcasts in frequency bands adjacent to GPS and has funded a number of studies to determine its effects on military use of GPS.

In terms of GPS modernization, the L2C and L5 signals have been simultaneously broadcasted since August 2010. The L2C signal, for the time being, is a null signal without a navigation message. Work is continuing on trying to "get a better handle" on when the navigation message would be added to the default signal. Currently there is no 'set date' for this to happen, but Gen. Whelan's office is continuing to press the program office to determine when this will happen.

Dr. Parkinson raised his concerns about the particularly long gestation period for the L2C navigation message. This is probably due to the lack of an adequate signal monitoring capability but, in any case, it is important that the full navigational signal be turned on. Currently L2C users rely on codeless and semi-codeless tracking, but a full L2C signal should improve its robustness and encourage equipment manufacturers to take full advantage of this capability.

Gen. Whelan responded that he had seen information with a 12 to 18 month timeline for this to happen, however this statement has been made repeatedly over the past decade. He assured Dr. Parkinson that his message would be delivered back to Gen Shelton requesting a firmer date.

Gen. Whelan said the number of operational satellites was 31, with three in reserve. The signals broadcast are "somewhat mix and match."

Gov. Geringer asked how much of the satellite capability in orbit is not available to the civil community, and suggested that perhaps as many as 10-12 additional GPS satellites could be turned on.

Gen Whelan said the Air Force is currently limited by the ground infrastructure supporting the GPS constellation.

Dr. Parkinson said some GPS satellites are turned on but not broadcasting. There could be great advantages in turning on these signals to, among other things, enable better monitoring of the ionosphere.

Dr. Hermann asked Dr. Parkinson whether some Air Force doctrinal issue prevented them from taking the action Dr. Parkinson sought.

Dr. Parkinson said he thought not, but relayed the question to Mr. Kirk Lewis.

Mr. Lewis said this capability exists in AEP 5.5 of the Operational Control Center, and also on the satellites. Thus, no technical obstacles exist. However, he felt that some in the DoD community believed the civilian community should bear more of the costs involved. The civil community has committed $55 million; however, it is important to realize there are differences in meeting L2C and L5 requirements.

Dr. Hermann asked whether the message from the DoD is that "we could turn them on but we'd like to see your money first."

Mr. Lewis said that may be a part of it.

Gen. Whelan said he did not believe this consideration was in Gen. Shelton's thinking on this matter.

Dr. Schlesinger asked where the resistance was to turning on these signal. After all, U.S. taxpayers have paid for a capability that is not being made use of to its fullest extent.

Gen. Whelan said that, in his view, the resistance was within the program office and how much money is spent on the tools needed for the operations floor vs. how much goes to other modernization efforts. In any case there is no resistance from AFSPC and pressure from the Advisory Board is helping to hasten action.

Gen. Whelan continued describing recent developments in GPS, including the "expandable 24" GPS constellation and progress being made with on-going work between the Air Force and NASA on the implementation of Satellite Laser Ranging (SLR) on GPS III starting with SV-9. The GPS constellation is, overall, robust with 10 IIAs; 12 IIRs; 7 II2RMs; and 2 IIFs in service. In addition, there are two more IIFs "in the barn" should rapid response be necessary. The last IIF launch was on July 16, 2011, and the next launch is scheduled for October 2012. In addition, GPS III SVs 1-8 are moving along well in their development.

Capt. Burns asked if the recent outburst in solar activity have had impacts.

Gen. Whelan said there had been some effects, but not to GPS.

Dr. Parkinson said that from the standpoint of radiation, the GPS satellite is a "pretty tough" satellite.

Gen. Whelan said the GPS satellites are designed to work in a harsh regime.

Mr. Russo added that the main concern of the effect of solar flares on GPS is whether the ionosphere has been distorted.

Dr. Parkinson agreed, saying that the users most at risk are those relying on a codeless, or semi-codeless, tracking.

Gen. Whelan explained that Block one of OCX will become operational in 2016. On the civilian side, 24 GPS SVs will be broadcasting L2C by 2016 and L5 by 2018. Implementation of the operational Distress Alerting Satellite System (DASS) for Search and Rescue (SAR) on GPS III continues to move forward, and Gen. Shelton has directed to proceed with the integration and installation of SLR retro-reflectors (provided by NASA as government furnished equipment) while joint AF-NASA payload compatibility studies continue. In addition, the possibility of dual-launch of GPS satellites is under discussion.

Dr. Parkinson said he did not wish to seem ungrateful, but once dual launch is approved, he plans to push for triple launch. Some U.S. competitors are moving in this direction due to the limitations on launch facilities.

Dr. Schlesinger said he had always found it puzzling that the Air Force was so reluctant to save itself money by engaging in dual launch.

Gen. Whelan noted that there was some opposition to dual launch in Congress where some felt this would reduce the total number of launches, thereby limiting the market possibilities for firms in the launch business.

Dr. Schlesinger said the question was not to limit the overall cost of the missions, but the launch costs.

Gen. Whelan wrapped the discussion by reminding everyone that the current GPS constellation is the largest, best and most accurate ever. Modernization of both spacecraft and ground facilities continues, fresh payloads continued to be incorporated, and Gen. Shelton is committed to ensure everything moves forward as planned.

Dr. Schlesinger made reference to the list of the benefits of GPS and, for example, one could measure the supplies of oil that were saved in the Gulf Wars and Afghanistan through use of GPS and, also, reflect on the number of U.S. soldiers whose lives had been saved, along with reducing casualties among enemy combatants and the civilian populations. This is difficult to quantify in terms of financial 'cost,' but nevertheless essential.

Gen. McCarthy, referencing the list, added that it would be useful to match each advantage with the beneficiary involved.

Development of the GPS III Laser Retro-Reflector Array

Dr. John LaBrecque
Earth Surface and Interior Focus Area
Science Mission Directorate, NASA

Dr. John LaBrecque opened by thanking the Advisory Board for its continuous advocacy on the implementation of laser retro-reflectors on GPS III. Geodesy is an arcane science which is not understood by the world at large. However, it is enormously beneficial. Back in 1994, the International Association of Geodesy (IAG) first recommended that all GNSS satellites carry retro-reflectors. This has been supported by various U.S. agencies and, finally, a decision has been made to proceed with the integration of reflectors starting with GPS-SV9. Progress is being made on joint AF-NASA studies on payload compatibility. The GPS Mitigation Study is underway to review both Materiel and Non-Materiel mitigation options and recommendations will be made to a Senior Advisory Group in late September. The Senior Advisory Group would present its conclusion to the appropriate decision makers by November 2012 for inclusion in the GPS III Capabilities Development Document (CDD) and review through the Joint Capabilities Integration Development System (JCIDS) process.

> Dr. Hermann asked why the JCIDS is the final authority to determine whether this effort is implemented.
>
> Dr. LaBrecque said that the laser retro-reflector implementation is one of hundreds of capability improvements in the CDD. As a practical matter, once Gen Shelton (AFSPC Commander) had given its approval, the remaining issue is to finalize payload deconfliction, where a lot of progress has been made.
>
> Dr. Hermann said he had a profoundly different view on GPS governance as it relates to decisions on civil matters, and questioned whether JCIDS is properly equipped to handle civil matters as they come forward.
>
> Mr. Russo, while noting he is not directly involved in the question, offered an explanation. The issue concerns the potential for conflict between two hosted payloads on GPS.
>
> Dr. Parkinson said many people regard laser retro-reflectors as part of the primary mission to provide PNT services. Dr. Parkinson said, "with dismay," that back in 1975, someone came to his office to urge the inclusion of laser retro-reflectors on this satellite and within 20 minutes became convinced of this wisdoms. And yet retro-reflectors then disappeared as a requirement.
>
> Dr. Hermann said he did not object that AFSPC was to make the decision regarding this payload, but still had concerns on the vetting process for civilian requirements.

Dr. LaBrecque said that one must not only make a decision but also be ready to implement it. Among other things, NASA will build, flight-qualify and deliver 24 laser retro-reflectors to the AFSPC for placement on GPS Block III beginning with Space Vehicle #9 in 2015 and launch in 2019-2021. This includes the provision of the payload to the spacecraft contractor for integration, estimated at approximately $20M in cost, and then coordination of the ILRS tracking with the NGA and NASA SLR Data Operations Center at GSFC. The expectation is for an average of 2 new GPS III SVs to be launched per year after the launch of GPS SV-9, which means that the full geodetic requirements might not be reached until 2030. This is a long process. All GLONASS satellites are equipped with laser-retro-reflectors, and the other GNSS constellations (Galileo, COMPASS, etc) are moving forward with this capability. Once again, he thanked the Advisory Board for its support in advancing this effort.

* * *

PNT Board Focus and Scope of GPS Economic Assessment Tasking

Governor Jim Geringer
PNT Advisory Board Member
Environmental Systems Research Institute (ESRI)

Gov. Geringer noted that when he was in office, he would ask people who sought his intervention on an issue: "You are going to walk out of here with a decision. Are you prepared to live with it?" Therefore, the better he had been briefed, the likelier this would be a good answer. Gov. Geringer said he had just received an outline of the tasking but was confused as to why it had taken months to draw up. The task is to prepare a structure for use in an economic analysis of the value of GPS services in the U.S. and worldwide. This outline will be passed on to the ExCom, and the Board will seek assurances that it be as definitive, well-structured, and independent as possible. The ExCom recognizes that the Advisory Board is a voluntary body and does not itself have the time or resources to undertake a deeply targeted study.

There is a general lack of awareness of how broad-based the impact of GPS is. The first step is to identify the pertinent areas of GPS applications. These are:

1. General applications -- such as emergency services, tracking, marine, weather, rescue, recreational/automotive and location based services and others;
2. Hi-precision applications -- including aviation, robotics and machine control; commercial timing and agriculture;
3. Survey and mapping; and
4. Defense.

Each heading is, in turn, broken down into sub-headings. Within these sub-headings, each category has a 1 to 10 rating on the value the service provides to the nation; an estimate of the installed user base; and an estimate of the dollar value of the installed base.

Gov. Geringer added the following comments:

First, while there is increasing awareness among GPS funders of its importance, there is a far lower acknowledgement of consumer applications.

Second, it is very difficult to assign a value to any reduction in loss of life that may occur due to GPS-based search and rescue missions.

Third, it is intrinsically difficult to measure the cost of lost opportunities, because it is difficult to assign a probability to each.

Fourth, when economic benefits are considered, attention also needs be paid to the costs that would follow upon a disruption of GPS services.

Fifth, while the value and cost of existing operations can be assessed, it is a challenge to estimate what these will be in ten years, as other alternative approaches to specific tasks are developed.

Sixth, it is difficult to estimate the dollar value of laser retro-reflectors in improving overall GPS capabilities.

Seventh, a means to describe economic impact is needed. The most rapidly developing economic impact is that of precision GPS. Did other prospective benefits justify further use of the bandwidth?

Eighth, the greatest deterrent to hostile military action is a satisfied civil society, which includes economic prosperity. When some in the military take a position that advancing civil GPS capability could be getting in the way of military applications he would respond that in some instances encouraging advanced civil applications relying on GPS, and its resulting improvement in prosperity, mitigate the probability of hostile action against the U.S.

The Advisory Board should listen carefully to each of the day's presenters to consider what other applications may need to be included in the list. There is also a need to look beyond the immediate application. These applications are not "freestanding," but often have an impact into the aggregate benefits.

Dr. Schlesinger said any study should have an initial overview statement of what its purpose and limitations are – what is measurable? What is unknown? The main issue is that GPS has transformed the world's economy. This may be more important than identifying everything that could be attributed to GPS.

Gov. Geringer added that another, often little-acknowledged aspect of GPS service is was the timing function. While GPS is best-known for its use in automotive and as hand-held device for personal use, its timing aspect is not readily apparent. How could one assess such value? If other GNSS systems provide better timing services the U.S. system could, by default, become dependent on someone else's satellites. This would not be desired.

Dr. Schlesinger said that perhaps the International Representatives to the Advisory Board could assist with this.

Dr. Gerhard Beutler said migrating to other satellite systems is not an issue. The international community will use the combination of all GNSS systems.

Gov. Geringer said he believed the issue of people migrating is not as critical to this study. The point is that if the study is limited to the impact GPS had on the United States, and the world, then an opportunity is being missed.

* * *

Dr. James Schlesinger said the Advisory Board would hear a series of briefings pertinent to the value of GPS.

Department of Transportation: Federal Investment in GPS

Ms. Karen Van Dyke
Director for PNT
DOT Research & Innovative Technology Administration (RITA)

GPS is critical to a series of transportation programs, including: NextGen for aviation; Positive Train Control for rail; Intelligent Transportation Systems for land and other applications. GPS plays a role beyond just reducing costs and increasing efficiency.

For instance, traffic congestion – air, rail and highway – is a major impediment to the economy. There have been 32,788 vehicle fatalities this year, 4.2 billion hours of lost travel time; $80 billion in cost associated with urban congestion; and 2.9 billion gallons of fuel wasted. Such mobility losses affect the population and economy broadly. For example, wasted fuel alone results in costs of approximately $9 billion. On the other hand, issues such as reducing traffic fatalities cannot be gauged on cost factors alone.

Agencies within the Department of Transportation (DOT) have, to date, sent $128.7 million to the GPS Directorate. An additional $100 million has been committed to Wide Area Augmentation Systems. Additionally, research activities are being pursued across DOT.

> Dr. Hermann asked if there is an internal cost/benefit analysis that determines which proposals are approved.
>
> Ms. Van Dyke responded that each mode of transportation has its own criteria and develops its own list of projects to be funded. In the area of land transportation, DOT relies heavily on reporting from private entities.

When assessing economic benefits and productivity, it is largely done by examining the application level. One difficulty is that GPS is often embedded within a more complex system that makes it difficult to analyze the specific contribution from GPS. While the DOT has requirements for accuracy, availability and integrity, GPS is not the only PNT technology used to achieve such requirements. Another issue is historical. Namely, there is a weak information baseline available that pre-dates the introduction of GPS thus making comparison difficult.

GPS is a key component to DOT's programs for positive train control and to obtain the highest operational efficiency in rail. A degradation of GPS would lead to greater congestion and gridlock in rail, estimated by the Federal Railroad Administration (FRA) over the next 20 years to cost between $15 billion and $29 billion. In addition, the Automated Track Inspection Program had registered a 359% increase in track inspection over the past ten years, leading to improved safety.

In 2009, the DOT carried out a motor carrier efficiency study which revealed 2.7 billion miles of driving done by empty trucks; $900 million in time absorbed waiting in ports; and $9.67 billion in driver time lost to loading and unloading activities. GPS applications will play a central role in reducing such inefficiencies. For instance, the Smart Roadside Initiative and Roadside Inspection could save $461 million annually. Other programs include ITS Mobility Application (although no specific savings figures are available at this time).

> Dr. Hermann commented that many companies attempting to sell helpful things do so with a rationale as to why they worked. Is there any advantage in the Advisory Committee probing these rationales in more detail?
>
> Ms. Van Dyke said this would "absolutely" be of value.
>
> Gov. Geringer noted that ten years ago when Sears first implemented GPS tracking, they invested $100,000 and saw a first year return of $50,000,000.
>
> On the topic of maritime activities, Dr. Schlesinger noted that there are problems elsewhere than on the St. Lawrence Seaway. These include traffic jams on the Mississippi River and low water levels on the Erie Canal.
>
> Ms. Van Dyke noted that the example of the Seaway was used because, unlike other water systems, it falls entirely within the province of DOT. Use of the GPS-based Automatic Identification System began in 2002, and allows all ships to know the locations of other ships. This system improves fleet management by providing owners with more accurate arrival times, thus minimizing scheduling delays.

Ms. Van Dyke also reported recommendations from the DOT's chief economist. These include urging that attention be paid to the underlying assumptions and efforts made to tie GPS use to cost reduction across the board. It should be borne in mind that GPS also represents a cost for its users and, furthermore, is commonly tied to other technologies that helped supply the benefit. She urged incorporating these savings into a general equilibrium savings model.

> Dr. Parkinson speculated that it might be useful for the Advisory Board task leaders to spend some time with DOT's chief economist to make the study more credible.

Gov. Geringer expressed willingness to meet; though he suggested it might be more appropriate for the economist hired by the Advisory Board to have that meeting. A way was needed to aggregate the findings of the economists from different sectors.

Dr. Parkinson said he envisioned a 45-minute discussion of “the shape of the elephant” as seen by the DOT economist.

Gov. Geringer welcomed that comment, as it gives a sense of the scale of information to be sought.

Dr. Parkinson asked if Ms. Van Dyke could arrange such a meeting; she responded that she could.

Dr. Schlesinger asked if anyone has examined the impact of sequestration on air transportation.

Ms. Van Dyke said DOT has studied the matter.

Capt. Burns said that while the current FAA budget should not be impacted by sequestration, there are concerns about future budgets.

* * *

Assessing NextGen Economic Benefits & Productivity Gains

Ms. Molly Smith
Senior Economist
Aviation Policy and Plans, Federal Aviation Administration

This briefing covers three topics: First, current GPS usage by U.S. and international operators; second, NextGen benefits that depend on GPS; and, third, the safety and efficiency benefits of GPS.

GPS is an important tool for air operations. It improves safety and efficiency of over 35,000 instrument-based flights a day. Airline operators have invested $3-5 billion in GPS equipment, and U.S. taxpayers have invested $3 billion for the development of NextGen. Benefits currently provided by GPS include precise timing and better spacing between airplanes, both of which improve efficiency and overall transport capacity. NextGen is a pending transformation from current radar-based to a future satellite-based air traffic control system. The advantages of the new system include the safe accommodation of increased passenger traffic; a decline in flight delays and the time passengers spend on the runway; and greater ease in avoiding weather problems. NextGen also has a favorable environmental impact – aviation will be quieter, cleaner and more fuel efficient. Through 2018, the FAA and the civil air carriers will have invested $18 billion to implement NextGen, of which $11 billion is based on the use of GPS. The estimated benefits are $24 billion by 2020 and $106 billion by 2030, along with a reduction in carbon emissions of 44 million tons.

Dr. Hermann asked if these figures are credibly documented.

Ms. Smith said a NextGen planning document is published every year which includes this information.

Capt. Burns said his airline has undertaken an independent study and its conclusions are very close to those reported by Ms. Smith. This study was used to demonstrate the future benefits before receiving approval to spend the capital the new system would require.

Dr. Hermann noted that GPS is an essential enabler of NextGen. NextGen will improve aviation economy which, without GPS, would not occur. However, there is no easy way to assess the cost should GPS not be available.

Gov. Geringer said that estimating the financial impact of “no GPS” is difficult because the systems being described assume the continued availability of GPS.

Capt. Burns said this topic requires further discussion.

Ms. Smith identified some GPS safety benefits, including four categories of accident mitigation. The first three include: approach and landing; controlled flight into terrain (CFIT); and runway incursion. All three accident types have decreased markedly. Since 1999, carriers have had just two approach and landing accidents in U.S. airspace; only one involving an aircraft was GPS-equipped. The fourth category of accident mitigation is that of night flight accidents occurring among small aircraft. Such incidents have also decreased, particularly since the introduction of all-glass cockpits around 2003. During this time, the accident rate decreased by 44 percent, and in part due to the expanded use of GPS as small aircraft cockpits improved. The FAA’s assessment of lives saved due to GPS is estimated at 73 fewer deaths in general aviation. This estimate is conservative and does not include serious injuries or property loss.

The economic benefits of GPS are estimated at approximately $200 million each year. These stem from greater runway capability, reduced separation standards between aircraft, and more direct flight paths, thanks to GPS.

Dr. Schlesinger commented that where savings are concerned, he would prefer having a range of numbers.

Ms. Smith noted that her report credited no savings to faster freight delivery.

Capt. Burns said he believed the numbers are correct. His airline has built a business plan around the NextGen approach, but had been unable to take advantage of such things as decreased spacing because they had been unable to implement all these capabilities.

Dr. Hermann asked why full implementation had not occurred.

Capt. Burns said there are a great many process steps "between A and B."

Dr. Hermann suggested that, like fishing, airlines should direct their attention to the "good fishing holes." By this he meant they should focus on places like the San Francisco airport which were peculiarly subject to delays.

Capt. Burns said his airline has conducted a three-year study of the airspace. The process is on schedule, although the process itself is rather slow.

* * *

NGA's Relationship with GPS

Mr. Steve Malys
Chief Scientist
National Geospatial-Intelligence Agency

This briefing provides a summary on how the NGA both supports GPS and, in turn, is dependent on it. The NGA was both a DoD combat support agency and an intelligence agency, but it also works with other U.S. agencies in support of such things as humanitarian relief. Geospatial intelligence is a modern term to describe mapping and charting activities on the Earth.

Mr. Malys presented a brief summary of human efforts at mapping – ranging from the surveyor-based maps of the 18th century to the geospatial mapping of today. The objective is to answer the question of where one is located. GPS makes this more efficient. Data collected by the NGA includes geology, terrain elevation, gravitational field, magnetic field, terrain morphology, etc.

Gov. Geringer asked whether the "added value" of raw information gathered by GPS has been documented.

Mr. Malys said that the large variety, and quantity, of products derived with GPS support makes it difficult to assign a dollar value.

NGA, in turn, supports GPS by maintaining, and updating, the Terrestrial Geodetic Reference Frame, whose origin is located at the center-of-mass of Earth. In 1987 the knowledge of the precise location of this center accurate to within 1-2 meters, and as of February 2012 the accuracy had improved down to a 1 cm level. In addition, NGA contributes to GPS monitoring through the DoD Ground Station Network, which consists of 11 NGA monitoring stations, 6 Air Force monitoring stations, and two control centers.

There is a very important difference between defining a coordinate system and creating a coordinate system. In creating a coordinate system, NGA has greatly benefitted from the work of international systems such as the International GNSS Service (IGS), a global network of over 300 stations monitoring GPS, Galileo, and soon other GNSS systems such as Galileo and COMPASS.

In 2005 the NGA monitoring stations began feeding its data to GPS OCC in Colorado Springs. Due to "institutional inertia," 12 years has passed from the time this activity was first advocated to its implementation in 2005. However, once implemented, it quickly helped improve the service provided by GPS.

Dr. Parkinson asked if NGA would be tracking the new L1C GPS signal.

Mr. Malys said this subject is in continuing discussions with the Air Force. Development of NGA monitor stations took seven years from initial planning to deployment, due in part because the market for geodetic-quality GPS receivers was limited. In terms of tracking new navigation signals, NGA operates on an experimental basis and software-defined GPS receivers are used in several monitor stations. One drawback, however, is that these receivers collected so much data that one needed to make careful decisions about what it is one wants to track. The most important point is that all modern geospatial data is dependent on GPS and other GNSS constellations.

Gov. Geringer asked if someone did something to the data collected in order to generate value. This is a potential gap in how the Advisory Board should frame the GPS economic benefit study. The long timelines Mr. Malys had cited, adding that lengthy implementation periods are common to new technologies, have an impact on how the benefits of those technologies could be quantified.

Dr. Enge said he appreciated the point about the monitoring stations being essential, but he thought it might be useful to develop a separate thread driven by commercial multi-GNSS-constellation receivers. Has this been considered?

Mr. Malys said there are things a ground monitor station has to do that a commercial multi-GNSS receiver cannot do, for instance, continuing to track the signals through anomalies.

Ground stations also provide very high precision for measurements such as plate tectonics. For example, the ground station in South Korea measured a 10 centimeter displacement following the 2011 earthquake off Japan.

The Advisory Board took a lunch break at 12:20 p.m.

* * *

Benefits and Productivity Derived from Federal Infrastructure

Dr. David Applegate
Associate Director, Natural Hazards
U.S. Geological Survey

Key GPS applications of GPS in the US Geological Service (USGS) include: coastal and marine studies; geologic mapping and research; hydrologic mapping and research; watershed, water use and hydrologic applications; natural resources inventory and management; survey control; land use and land cover; and geologic hardware assessment and monitoring. These applications, in turn, have derived benefits in the areas such as economy, public safety, science, and national security.

Dr. Parkinson said Dr. Applegate had "flooded his in-basket" with applications. Did Dr. Applegate believe that this list of applications all relies on GPS?

Dr. Applegate said they did. In some cases, he said, the reliance depended on high-precision GPS; in other cases, it depended on the GPS timing capabilities.

GPS is critical in the area of Natural Hazards, which includes monitoring of tectonic plates, monitoring of areas prone to landslides, and USGS's support to the National Oceanic and Atmospheric Administration (NOAA) for weather prediction. For example, geomagnetic observatories that make storm forecasts rely on the GPS timing signal. The 9,000 stream gauges used for flood forecasting and water quality monitoring also rely on the GPS timing capability. USGS has spent approximately $15 million in upgrading this system.

The USGS also does a lot of mapping work that relies on GPS such as, for example, using Light Detection and Ranging (LiDAR) from an airplane for digital elevation modeling. This requires very precise knowledge of the position of the aircraft at the time of each measurement.

Dr. Parkinson asked if this could be done in the absence of GPS.

Dr. Applegate said USGS' ability to collect the high precision data would be compromised without GPS. LiDAR is particularly vital to predictions and changes made relative to the coastal zone, especially barrier island response to hurricanes. USGS investments in LiDAR are, approximately, $20 million on top of $40 million from Recovery-Act funding. Also, USGS has recently entered into an agreement with the Federal Emergency Management Agency (FEMA) to collect high precision elevation data.

Earthquakes are another national hazard, and this has led to research on creating prediction models. The National Seismic Hazard Assessment is being developed in partnership with FEMA, the National Institute of Standards and Technology (NIST), and the National Science Foundation (NSF). This effort is being undertaken as part of international work to reduce the consequences of earthquakes. GPS-based monitoring of Earth's crust enables the creation of model building codes that reflect an area's earthquake hazard. USGS has invested approximately $26 million in this effort; and NSF has invested $100 million in the Earth Scope initiative which also supports this effort. In these applications, GPS is essential not just for positioning but also for timing. Even a small change in the timing cycle can degrade the quality of the information recorded. Seismic stations are distributed all over the world, over 1,000 in Japan alone. During the major 2010 Japanese earthquake, both the offshore and onshore GPS stations had instantly noted the movement. The offshore displacement was as large as 25 meters.

Gov. Geringer noted that the briefing plots showed horizontal, but not vertical, displacements. Does GPS also have a role to play in measuring vertical displacements due to Earthquakes?

Dr. Applegate replied that, yes, GPS also measures vertical displacements. In fact, GPS is particularly adept at that since its coordinate system is independent from latitude/longitude/elevation measurements.

Gov. Geringer noted the frequent reference to the importance of the GPS timing function.

Dr. Schlesinger asked what one would do if a warning was issued, for instance, would it result in shutting down nuclear power plants?

Dr. Applegate explained that the idea for early warning is not to predict an earthquake but, rather report that an earthquake has occurred before the seismic wave reaches some distant point. In the case of Japan, for example, this enables slowing down the "bullet-trains" and warning fire departments to open their doors so their equipment was not trapped inside by electrical failure. In the case of Japan's nuclear reactor failure, it had been the first time that an earthquake exceeded the design standards of the reactor.

* * *

Benefits & Productivity Derived from Federal Infrastructure

Mr. Edward Powers
Division Chief
United States Naval Observatory (USNO)

The US Secretary of the Navy directs the USNO to develop and maintain standards for Precise Time and Time Intervals (PTTI) services, Earth orientation parameters, and the celestial reference for DoD components. USNO monitors the timing of the GPS to provide a reliable and stable coordinated time reference for the satellite navigation system. GPS time is given by its Composite Clock (CC); a "paper" clock consists of all Monitor Station and satellite operational frequency standards. The system time, in turn, is referenced to the Master Clock (MC) at the USNO and steered to UTC (USNO). Presently, GPS is the most competent system for time transfer, the distribution of PTTI. The system uses time of arrival (TOA) measurements for the determination of user position. Over the past 25 years, there has been a significant improvement in GPS monthly standard deviations.

Mr. Powers noted that in 1875, the United States and 16 other nations signed the "Convention of the Metre" in Paris, a treaty authorizing the Bureau International des Poids et Measures (BIPM) to coordinate how weights and measures would be used in commerce. This same agency acts today as the coordinator of UTC. The objective is to measure time to the sub-nanosecond level. The U.S. contributes its clock data to this effort. The agency collects data from various sources to determine time. Currently the U.S. was the source of about 27 percent of the data used.

Users of precise time include communications, banking, and the power grid. Back in the Block I days of GPS (in the 1990s), its users were the timing community once 10-11 GPS SVs became available. By the late 1990s, there were hundreds of timing GPS receivers worldwide; today, there are well over half a million timing receivers embedded in infrastructure worldwide.

Gov. Geringer asked how the alternate cell phone providers, who do not use Code Division Multiple Access (CDMA), operate?

Mr. Powers said CDMA technologies operate to the micro-second; if one traveled down a highway, the transition from one signal to another is seamless. Other systems use some sort of asynchronous technique. Different cell phone systems have different requirements for precision in timing. The "fourth generation" systems now in development are likely to "drift back to GPS."

Mr. Powers noted that the national power grid makes use of GPS precise time through various phase synchronizer mechanisms. The Traveling Wave Fault Locator, which relies on GPS precise time, plays an important role in finding broken lines. Also, today's banking and financial transactions are at such a speed that an investment company has an advantage if it can locate itself close to the trading floor. Currently time stamping on financial transactions is at the one second level. In a few years, it may be possible to reach a standard of milliseconds, or better, in timing accuracy. Science applications of PTTI at the nanosecond level include: Deep Space Network (DSN) and Very Long Baseline Interferometry (VLBI); calibration at laboratories (CERN, Fermilab, etc.,), and other future applications of timing such as geodesy, Earth Sciences, and astronomy.

On-going development efforts in timing include GPS Antenna Design Bandwidth and Response Design. High end GPS monitoring and differential correction services like those operated by JPL and the IGS are used to support high end scientific applications and require high quality GPS measurements to support centimeter navigation and picosecond level timing application. This technique enables group distortion to be controlled and, thus, enable more precise measurements.

Dr. Parkinson asked if such filters currently existed.

Mr. Powers responded that these were the most commonly used type. He noted that the narrower the antenna, the worse the group delay response characteristics became.

Dr. Parkinson asked how long it might take to recreate a system as shown.

Mr. Powers replied that it would take several years.

Gov. Geringer said he found it ironic that the 4^{th} generation networks Mr. Powers mentioned earlier would be dependent on GPS timing.

Mr. Powers said that apparently great faith is being put in designing an antenna filter so that they could both do what it was intended to do and not jam each other.

An Advisory Board member commented whether the further development of atomic clocks would lessen dependence on GPS.

Mr. Powers replied that an atomic clock does not give you the exact time but, rather, it exactly keeps the time that it has been given. Thus, it unlikely that chip-scale atomic clock technology will put GPS timing out of business.

Timing is crucial. For example, if someone in banking could manipulate time so that he could get his bids registered three seconds faster than anyone else, he could become very rich very fast.

Gov. Geringer noted that some trading floors are making considerable sums renting space to brokers who wish to be closer to the "action." Currently 75 percent of trades are now high speed trades.

* * *

Impacts on Infrastructure When GPS Service is Disrupted

Mr. Malcolm Airst
Senior Principal Engineer
MITRE Corporation

MITRE has been conducting work on GPS timing precise frequency signals for over four years, including a variety of studies and applications in industry, the academy, and government. While the world has become highly dependent on GPS timing, most people do not know that GPS is the source of their time.

The current trend is towards less expensive oscillators and boxes, and a higher reliance on GPS because it is so reliable. The "beauty" of GPS is its synchronicity; all users receive the same time. There are, however, a number of system vulnerabilities faced by GPS. These include:

- Unintentional interference, such as radio frequency interference or spectrum congestion;
- Intentional interference, such as jamming and spoofing; and
- Human factors, such as design errors or insufficient knowledge and training.

Jamming has gone from being a national security threat down to the far simpler and widespread act of someone purchasing a device either through the Internet or at a local electronics store. One of the most insidious devices is "delay and rebroadcast." This is particularly simple to accomplish when a less expensive oscillator is used. These devices can be used in what is called an "almanac attack," where a false time of the day is generated.

Dr. Hermann asked if such attacks are system-wide.

Mr. Airst responded they're transmitted locally.

The Civil GPS Spoofing Threat Continuum ranges from the simplistic (commercial signal simulator); to the intermediate (portable software radio); and the sophisticated (coordinated attack by multiple phase-locked spoofers). For example, the financial system is not well protected – among other things, Network Time Protocol (NTP) ports have unprotected firewalls and timing information is often carried by unsecured antennas located on the roof of the trading center roof. Also, the financial sector typically requires microsecond-level time accuracy and, yet, after discussions with users in the financial sector it became apparent that in many instances the method used to obtain time was inaccurate. For instance, some obtained time by hacking into a cell phone and then feeding that time into their stock trading system. Such practices are common to traders who, located on lower floors, lacked sky view access to signals. The implication is that an additional delay is built-in from having the time passed between the cellphone and the system. Most traders are unaware of this. The risk is that if one is able to manipulate the time of day then one could also manipulate his trading numbers. In addition, it is uncertain what these traders are using for their time indicators where a cheaper quartz oscillator is preferred over a higher accuracy, but more expensive, cesium clock. A cesium clock cost $50,000, compared to approximately $400 for a quartz clock, where one device is needed at each of the nodes. Finally, other potential augmentations to GPS-based timing include IEEE 1588.

Dr. Enge said very little had been presented on the subject of adaptive antennas, which he believed are quite robust. The Federal Aviation Administration (FAA) uses such antennas and, thus, has gained much greater protection against jamming.

Mr. Airst said MITRE found adaptive antennas were good and generally effective against low-powered jamming. However, the issue is with spoofers, where the "false signal is not much stronger than the authentic signal." In addition, it may be difficult to persuade financial users that adding such antennas was worth the investment.

The recommended mitigations include: migration to NTPv4; integrity checking via multiple atomic clocks; and employment of available Chip Scale Atomic Clocks. Much can be done to strengthen the current system but, alas, it is unlikely such steps will be taken until some expensive failure has occurred.

Dr. Parkinson suggested that Mr. Airst might want to urge people to get antennas that aim upwards.

Mr. Airst agreed.

*   *   *

Environmental Monitoring if GPS Radio Occultation is Denied

(Joint Briefing by Mr. Mr. Stephen Esterhuizen & Dr. James Yoe)

Mr. Stephen Esterhuizen
Instrument Research Engineer
NASA Jet Propulsion Laboratory

Radio Occultation (RO) measurements of GPS signals are critical to weather forecasting, climate change science and space weather. Users of this type of data include NOAA, US Air Force, NASA, NSF, Taiwanese National Space Organization, Korea Aerospace Research Institute, and the European Space Agency (ESA). Spectrum changes, such as terrestrial broadcasts in the MSS frequency band adjacent to GPS, cause severe disruption to RO. Research in RO has been on-going at Caltech JPL, and Stanford University, since the early 1970s. In 1995 the GPS/MET mission was launched with JPL-developed RO instrumentation.

GPS-based RO tracks over-the-limb signals of a GPS as it propagates through the atmosphere. As the signals cuts through the atmosphere, it is refracted; the level of bending is proportional to the density of the atmosphere. As the atmospheric density increases, so does the distance travelled by the 'curved' GPS signal. This causes a delay that is a function of the temperature of the atmosphere. RO is capable of determining temperature in lower atmospheres within 0.1 to 0.5 degrees Kelvin. GPS-RO has become the "gold standard" for determining vertical gradations in temperatures. In addition, by observing the refracted signals it is also possible to derive other parameters such as wind speed. However, there is a fundamental limitation to this technique due to the signal-to-noise ratio. The signal is extremely weak by the time it reaches the spacecraft on the other side of Earth, thus any radiometric interference can weaken the ability to make precise temperature measurements.

Following the success of the COSMIC-1 demonstration mission, JPL is now developing the TriG GNSS receivers for the COSMIC-2 mission. COSMIC-2 is a Taiwanese mission consisting of a constellation of 12 microsatellites that will collect GPS, GALILEO and GLONASS systems to produce a significantly higher spatial and temporal density of profiles over tracking GPS signals alone. The objective is to provide global GNSS-based RO measurements including: refractivity, temperature, moisture content, electron content, and density profiles for the troposphere, stratosphere and ionosphere. Half the constellation will be launched in 2015, and the other half in 2017. The wide bandwidth to track various GNSS system is preferred because once in space, it is no longer possible to make changes to the instrumentation. Implementing wider, and heavier, filters to mitigate radio interference would significantly increase the cost of the mission.

Dr. James Yoe
National Weather Service
National Oceanic and Atmospheric Administration

Dr. Yoe heads a group that seeks to improve the use of satellite data in weather, ocean and atmospheric models. Benefits in using GPS RO for environmental monitoring include its precision, stability, very low bias, accuracy of products, and system resilience. Dr. Yoe presented three charts depicting the observation impacts with various norms – kinetic energy; dry total energy; moist total energy. GPS RO is an important tool in developing this type of data. Until a few years ago some in the field had thought it unnecessary to include GPS data in the solution, but the opinion has changed. GPS RO also enables obtaining uniform, global, ionosphere measurements needed for space weather services.

Should GPS not be available, or be lost, the result would be an increase in random noise and refractory levels, resulting in the loss of the atmospheric water vapor content data. In summary, the National Weather Service and others rely heavily on GPS-RO; the use of adjacent bands degraded signal strength; and that such degradation would reduce the ability to protect lives, property and economic activity.

* * *

Dr. James Schlesinger reported that scheduled speaker Dr. Thomas Powell, Aerospace Corporation, was unable to attend.

* * *

Case Study Derived From High Precision Operations

Mr. Benjamin Smith
Account Manager
John Deere

Mr. Smith first asked how many present had at one time been engaged in agriculture (a fair number of hands went up). He then said that all hands should have gone up as everyone has connection with agriculture during meals. The anticipated world population by 2050 is approximately 9 billion. To feed this number, annual agricultural increases of 1.56 percent are required, compared to a historic growth rate of 1.4 percent. Precision agriculture increases yield and safety, and reduced costs. For example, precision agriculture enables a three percent gain in unutilized land by simply reducing the separation between rows of crops from one foot to one inch.

The use of precision agriculture enables farmers to have different seeding and propagation rates. Different fertilizers and pesticides can be applied in site-specific areas. Farmers also have the capability to turn off seeding or fertilizing a specific row. The level of automation in agriculture today has allowed a dramatic improvement in the level of control. Swath-control can prevent the overpopulation of plants, thereby reducing water use and weed problems. For instance, corn is considered to be a weed if in a soybean field.

> Gov. Geringer noted that wind-sensitive drift can be important.
>
> Mr. Smith agreed, but added that precision agriculture allows for operation in less than ideal wind conditions or fading light.

The issue of crop overlap is an important issue. Traditionally a 30 percent overlap of each row was required, but with precision agriculture the overlap is reduced to inches.

In 2013, John Deere will offer technology where multiple seeding/fertilizing machines will be able to exchange information and work in conjunction. This will result in significant savings in associated labor. Also, GPS precision farming also allows operations in the dark or under fog or low visibility conditions. Precision agriculture has allowed California farmers to greatly reduce the issues they had with applications near dusk. Precision yield-mapping is currently used by 80 percent of the grain producers in the U.S., and by 65 percent of large agricultural producers.

> Dr. Schlesinger asked to what extent precision agriculture is used outside the U.S.
>
> Mr. Smith replied that it is commonly used in places like Russia; however in many other areas, the customer base could not afford the technology.
>
> Gov. Geringer said the issue was also as much a matter of culture as economics. If precision agriculture displaces people who have no other immediate employment, then they have no incentive to use it.
>
> Dr. Schlesinger asked about large grain producers such as Argentina.
>
> Mr. Smith said the techniques were in considerable use in that country.

In terms of cost savings, $8.2 billion a year are saved by the reduced use of fertilizer, seed, fuel and labor. In environmental terms this results in 17.5 to 25.0 million acres saved from unneeded pesticide and fertilizer applications. Data shows that a ‘payback’ period of as little as six months may be possible.

> Dr. Parkinson noted that GPS allows farmers to take advantage of the best “window” of time when planting to produce the best yields.
>
> Mr. Smith commented that farmers sometimes work 24 hours a day at times to catch the window for planting, since a loss of just one day typically means a one percent loss in yield.

Last year, the Global Harvest Initiative reported a 1.7 percent increase in food production, well above the historic average of 1.4 percent.

Gov. Geringer pressed Mr. Smith for additional data on return on investment.

Mr. Smith said there were two separate cost categories – the hardware component, which is a one-time buy, and the signal component, which is an annual cost. A top-end Real Time Kinematic (RTK) network costs about $100,000, but it can be shared by multiple farmers.

* * *

Minimizing Disruption While Ensuring Spectrum Access & Stability for Economic Value & Growth

Dr. Scott Pace
Director, Space Policy Institute
The George Washington University

Dr. Scott Pace noted that those present constituted a "tough and knowledgeable" crowd.

The first GPS Presidential Directive was issued in March 1996 during the Clinton Administration; one key attribute was its dual-use vision, for both civil and military users. The policy stated that GPS is integral to global information infrastructure; it would be provided free of direct charges to users; Selective Availability (S/A) would be discontinued by 2006; international augmentation standards would be accepted; measures to prevent hostile use of GPS would be achieved; and foreign governments would be consulted on GPS guidelines. However, what was not on that list was the issue of spectrum protection.

The next Presidential GPS policy statement came in December 2004 under the George W. Bush Administration, and this time it included specific language about spectrum protection.

The current Presidential space policy issued in June 2010, under the Obama Administration, reaffirmed the 2004 GPS policy and added further emphasis on protection of radio navigation spectrum from disruption and interference. Specifically it includes the phrase: "sustain the radiofrequency environment in which critical U.S. space systems operate."

GPS bandwidth is probably the most important aspect of this issue. In 1996, the possibility of other GNSS providers was only anticipated in theory. However, by 2004 other nations had "climbed on the bandwagon" and, thus, this increased the requirements for adequate bandwidth for GNSS systems.

The goal of global compatibility and interoperability is to create an international system that is more than the sum of its parts. In addition, one must ensure there is a level playing field. GPS, and GNSS, applications have been driven by the marketplace, with narrow exceptions in public safety and national security applications. There are a number of ways in how GPS, and GNSS, could be harmed. This includes the forced sharing of limited bandwidth; out-of-band emissions that raise the noise floor; and spectrum segmentation – which breaks the band into smaller pieces and limits future development.

The challenge of spectrum protection is an outcome from the worldwide boom in wireless communications and ever increasing need for more bandwidth. The problem for GPS is the noise floor. Arrangements with industry arrangements can and have restrained unwanted emissions. However, these are no longer sufficient because they are typically limited to one country. In 1996, GPS jammers were associated with hostile military action, but today they have become a common consumer device. Other problem areas include continued pressure on L-Band use; international and unlicensed GPS re-radiators or repeaters; and licensed in-band pseudolites Industry-level negotiations, interagency agreements, and international regulatory agreements are needed to continue sustaining the Radio Navigation Satellite Service (RNSS) frequency bands.

However, progress has been made. Recommendations now exist in the International Telecommunication Union Radiocommunication Sector (ITU-R) on protection criteria. In the U.S., repeater/re-radiator use has been authorized but on a restricted basis, such as in laboratories. However, other countries are free to set their own standards. For example, in the United Kingdom, repeaters are licensed for civilian use, provided they *should* not have an impact beyond ten meters. This has created a proliferation risk of these devices, because it can lead to a "nonconforming use" that can spread into the rest of Europe. In turn, this could result in a sharing of the RNSS bands with interfering devices. The situation is one of the "camel's nose under the tent" where one also needs to pay attention to the standards as well as the regulations.

Navigation is different from communications and interference mitigations are different. In the communications world one 'listens' for zeroes and ones, which one then attempts to decode. In the navigation world, everyone knows what the ones and zeroes are but the trick becomes knowing *when* the transition from "ones" and "zeroes" occurs. If there is sufficient background noise, it is difficult to tell when these transitions occur. GPS is unique in that it complements other applications. Filters that work for communications don't necessarily work for navigation. GPS should be thought of as an information technology rather than as "an aerospace product." This is what happened early on when Europe thought of the Galileo GNSS as a specific aerospace product. They have gained a more sophisticated understanding of GPS applications in recent years, which has enabled better industry-level cooperation.

Dr. Scott Pace said that he is opposed to regulatory requirements for receiver standards, unless they're required for public safety or national security. Government mandates typically result in slower product innovation. Once a regulatory standard has been established, there is very little reason for anyone to try to do better. Innovation tends to be faster in areas where it is market–driven.

Gov. Geringer asked when the ExCom proposes receiver standards, what do they mean?

Dr. Pace said he did not know.

Mr. Russo said the ExCom has not proposed receiver standards; it has only urged that such standards be looked at.

Gov. Geringer said that the creation of any standard should not slow innovation and impose further costs.

Mr. Hatch noted that standards relating to protection of life are very important but, yes, they do slow down innovation.

Dr. Parkinson said that in a roomful of experts, there may be multiple interpretations of what something means. This created rooms for potential "mischief."

Dr. Pace said that U.S. policy is one in which the U.S. attempts to avoid engaging in "industrial policy" except for reasons of national security or public safety. However, the government has judged what a publicly compelling reason may be. His main point was that receiver design standards have a number of drawbacks, including that they are not supportive of innovation.

Dr. Pace said he thought there was doubt on whether such standards should indeed be imposed by the federal government. A spectrum management agency attempting to establish industry standards is, in his view, a particularly bad idea.

Dr. Hermann said the government should retain, for national security reasons, ways to influence outcomes that are different from what might be forthcoming from a voluntary group.

Dr. Pace noted that the government, as a purchaser, could establish whatever standards it wanted. However, market decisions are driven by trust; that is, people making an investment in anticipation of consistency in government rulemaking.

Dr. Hermann said in his experience, it is not possible to create standards under which all parties concerned anticipate being a winner.

Dr. Pace agreed, adding that the danger is when the standards process is distorted by a government mandate or by monopolistic intervention by one large entity.

Dr. Pace closed by presenting a chart on meeting GPS policy challenges. Such challenges include *Spectrum Protection* and *Regulatory Stability* at minimal cost. Spectrum protection includes the preservation of the RNSS noise floor and coordination with other GNSS providers. Regulatory Stability should emphasize continued reliable operation performance; transparent and stable interface specifications; and market-driven – not regulatory-driven – standards, with the exception of national security and safety-of -life.

* * *

Past Study and Analysis on Emerging GPS Benefits

Dr. Irv Leveson
Founder
Leveson Consulting

Studies to date about GPS benefits have been piecemeal; they have looked at specific applications. His 2010 *Interim Report* made a start on assessing benefits in a more comprehensive manner. The purpose is to inform policy making. It is important to keep in mind that if GPS had not been created, other technologies could have come into use in some areas. However, given that GPS does exist, then it is useful to examine the cost impacts should there be a temporary failure of the system.

Economists use an economic productivity approach that focuses on the benefits derived from productivity improvements and cost savings. In addition to direct benefits, there is an effort to measure such indirect effects as the impact on the demand for goods served and induced effects such as process innovation. Societal benefits of life, health and safety are also included. In general, these numbers are based on economic multipliers developed from mathematical modeling. In gauging the value of GPS, one has to consider the value of other GNSS systems. At present, because GPS has been in existence much longer, it is appropriate to think of other systems as a "value added" to GPS. Others, such as the Europeans, prefer assessing the value of Galileo as if GPS did not exist.

The objective of the study at The Aerospace Corporation is to provide a statement of overall benefits, both current and future. The result is a non-official internal study which has been provided to the Advisory Board. The study uses a bottom-up approach that looks at a variety of areas and then combines them, hoping that the laws of large numbers would help in summing the data. Some agency data was not available and, also, only data was used from economic sectors where good estimations were possible. Therefore, the aggregate figure is an underestimate.

Benefits in the tens of billions of dollars may be expected from precision applications in agriculture and surveying and mapping. In these two areas, the economic benefit for the 2008-2025 is "several hundred billion dollars," provided it discounts the benefits at 7% above inflation. This figure represents the aggregate for 17 years.

Dr. Hermann asked why the value added is being discounted.

Dr. Leveson said the basic reason is that this represents the cost of borrowing the necessary capital. Recent interest rates are considerably lower and, if this continues, then the net economic benefit would be greater.

Dr. Hermann expressed concern about the discount rate. If one were to use a 3% discount rate, then the benefit derived from the GPS applications would double.

Dr. Leveson said that the 7% rate is recommended by the Office of Management and Budget (OMB) and, in his view, it's a good number to associate with a risky project considering that in the long term, GPS may not be the only solution available.

Dr. Hermann said he had "a strong thirst" for some other unrelated infrastructure area to which GPS could be compared. If a similar study has been done on the Interstate Highway System, he doubts it would have been discounted by such a rate.

Dr. Leveson said this is true, but that the amplification went to the benefits figure where discount is a constant. More has to be considerably done on user costs. How these costs should be applied over time rests on a number of issues that have not been addressed yet.

Dr. Parkinson said if one deducts the cost of the GPS systems, does one also deduct the cost of whatever GPS enables?

Dr. Leveson said this was not the case as it is assumed no other means of achieving a given end would have been implemented in lieu of GPS.

The *Economic Benefits of Commercial GPS in the United States* and the *Costs of Potential Disruption* study estimated that the cost of signal interference is 100 percent of the cost of benefits. More information is required on aviation, high precision users, system investments, future benefits and other areas. Estimating direct benefits requires information on the market size, and this information is fragmented. Second, better understanding is needed of the share of productivity impacts that are attributable to GPS. If any given system uses GPS in concert with other technologies, what percentage of benefit should be attributed to GPS? Additional obstacles include: assessing how these variables change in the future; how reliable are existing productivity studies; and whether particular case studies are subject to biases or error. In general the study of the economic impact of GPS would be more authoritative if there is caution when using figures from the lower end of the range of answers. Assessing future benefits should be done under a variety of scenarios that reflect changing technologies, changing markets, market growth and penetration, and other factors. Such comprehensive approach would improve understanding of interacting variables and facilitate comparisons of benefits in alternate settings.

In conclusion, little effort has been made to synthesize all existing information. Studies to-date used a variety of methods and sources. Specific sector-to-sector information is required. Better understanding of the future as well as current benefits is needed. An overall picture of benefits is happening, but the differences in models and methods needs to be narrowed. An overall benefits study will try to come up with a comprehensive set of estimates; however, given the questions of spectrum impacts, there may be a need to look at very specific kinds of applications and at what their impact may be. Finally, the issue of short-term interruptions must be considered separately from long-term effects.

Gov. Geringer said Dr. Leveson had mentioned "baselines." Several speakers noted that in the absence of a baseline, it is difficult to quantify such issues. Dr. Leveson had mentioned scenarios which were based on the current number of civil signals. Could he clarify the distinction between baselines and scenarios?

Dr. Leveson said the "baseline" Ms. Van Dyke referred to was what the world would look like in the absence of GPS – for example, replacing GPS-based approaches with traditional surveying equipment. In some cases, you may want to see how something that exists now has been changed. However, people in aviation are more concerned with how they might benefit from prospective changes. Scenarios relate to the latter case.

Gov. Geringer asked how the information available could be usefully structured. He hoped to have a value-centered approach and not a results-centered approach.

Dr. Leveson commented that 10 years is a much easier timeline to work with than 20 years because one has a better grasp of what the available technologies are.

Dr. Hermann asked if Dr. Leveson knew of any useful studies of large domains – such as the highway system, Internet, etc.

Dr. Leveson said many studies have been done in the past. For, instance, there was the Eric Canal, also referred to as "the success that spawned 50 failures."

Dr. Parkinson said later canals failed because of the railroads. He added that he felt faced with "a counsel of despair" over the prospect of identifying the benefits of GPS with any rigor. The easier question seems to be what if you simply eliminate GPS?

Dr. Leveson said that risked confusing short- and long-term effects. For example, while we would not have cheap atomic clocks without GPS, presumably some alternative would have been created. However one cannot assess the efficiency of things that do not exist.

The circumstance, Dr. Parkinson said, seems to involve an enormous amount of conjecture.

* * *

Recent Study & Analysis on Current GPS Service Benefits

Dr. Nam D. Pham
Managing Partner
NDP Consulting Group

Dr. Nam D. Pham said his organization specializes in assessing the economic impacts of public policy. His briefing includes a paper on the U.S. benefits of commercial GPS, covering the development of GPS and its economic benefits to the U.S. economy. It described how the "very rough" estimates of GPS benefits were determined and, further, estimate the economic costs of GPS disruption. It also addresses the limitations in work to-date and made suggestions for future work.

GPS equipment sales rose 55 percent to $40 billion between 2005 and 2010. The market can be broken into three segments: commercial (25%), non-commercial (59%) and military (16%). GPS equipment sales doubled that period. These figures, however, do not include sales to aviation users. The study focuses on the commercial market where GPS equipment sales rose 75 percent between 2005 and 2010 up to 122 million units. During this period the price of GPS devices decreased by 11 percent.

Dr. Parkinson asked if these figures were U.S. only.

Dr. Pham said they include both U.S. and Canada.

The methodology to estimate the economic impact is a bottom-up approach that includes estimated productivity benefits and cost savings – from labor, capital and other investments.

Dr. Schlesinger asked if these are net or gross savings.

Dr. Pham was they are gross.

The study also looks at the rate of GPS adoption within a given industry. Three industries are included in this study: agriculture; engineering construction; and commercial land acquisition. They account for 60% of the sale of GPS equipment. The fact that other segments were not included was a limitation on the study.

Dr. Parkinson asked if credit is given to GPS-making companies for the fact that they and their employees pay taxes.

Dr. Pham said the difficulty with such estimation is that effects could be either quantifiable or non-quantifiable impacts; in addition, there are either direct or indirect impacts on taxes paid. The study focuses only on the end-user market segment, such as farmers. Data on indirect effects has not been captured.

Gov. Geringer said the Advisory Board could choose to say: if we cannot capture the full universe of data, we can look at the three areas identified by Dr. Pham and see what the gains are. Such a report could be a preliminary report, to be followed by something more fully documented.

Dr. Pham said that would be appropriate.

One finding on the impact of GPS on industry shows a wide range of results. For example, in precision agriculture, the range is 23% to 90% depending on the geographic region and crop. For the purposes of this study, the range was averaged. In agriculture, there's a $10.1 billion benefit in increased production with the current 60% adoption level of GPS technology, and a $16.9 billion gain once 100% is reached. GPS technology has also resulted in an additional $9.8 billion in savings in labor, capital and inputs. Approximately $500 million was spent in 2010 on GPS equipment, including 38,000 units at a price of about $13,000 per unit.

Dr. Parkinson noted that sales could be either the initial equipment buy or after market purchases. Does the figure presented by Dr. Pham include the total cost to the farmer?

Dr. Pham said that based on conversations with manufacturers, he believed it did.

Dr. Parkinson said he thought it is important to report costs fully, that is, not just the cost of the equipment.

Gov. Geringer said the Advisory Board also wanted to know the rate of return, which is not the same as the annual profit.

Mr. Hatch reported that a study, which he believed Duke University had conducted, shows a 12 to 18 month payback. Getting firm numbers is difficult because some farmers are buying 5- to 10-year old equipment at reduced cost. One individual reported his payback period had been 2.1 years.

An annual benefit of $9 billion is estimated for engineering construction, based on a 40% utilization rate. Savings include $7.6 billion in wages; $1.3 billion in capital; and $0.3 billion in input affected.

An annual benefit of $10 billion is estimated for land transportation, based on a 67.9% adoption rate. The principal benefit is $6.4 billion in labor savings. More is spent in this sector on GPS equipment ($3.2 billion) compared to the other areas.

Gov. Geringer noted that the "land transportation" sector really only includes truck transportation; it does not include rail.

Dr. Pham acknowledged that was the case.

In summary, estimated expenditures on GPS equipment has been $8.3 billion annually, resulting in estimated benefits between $67.6 and 122.4 billion. A number of direct and indirect impacts are not included in this figure; such as, for example, how the number of needed employees changes when GPS is used down the supply chain. In addition, this study does not address the reduction in carbon emissions.

Future work could include a more detailed look at the industries in question, as results varied widely within a given industry. Furthermore, working directly with manufacturers and their sales force would help to gain a better understanding of the benefits GPS purchasers sought. In addition, future work should cover industries that were not included in this effort, such as aviation where the expenditure on GPS equipment is relatively lower, but the benefit is much higher.

An Advisory Board member commented that he believed the benefits of future GPS technologies would likely be surprisingly large: was there any way to accommodate this?

Dr. Pham said his study has not looked into technologies currently under development.

Gov. Geringer said one thing the Advisory Board must grapple with is the very rapid development of the field.

Dr. Enge said he was not sure whether the historical, and "prudent" view, was realistic. The problems facing GPS will be overcome in ways that provide solutions to other problems, therefore adding to overall value.

Dr. Parkinson said the situation struck him similar to an "1858 gold miner," that asked, "How much gold is required to become rich?" By analogy, how much benefit does GPS have to show to make its value unquestionable?

Mr. Russo said he felt the group could be on shaky ground if it assigned too much value to new developments. It is difficult to show that other technologies could not be developed that would lessen the reliance on GPS.

Dr. Parkinson said the question the Advisory Board has is to address was how much benefit is enough.

Gov. Geringer suggested it would be wise to under-promise and over-deliver. Starting with the three segments described earlier, and introduced a "wow" factor, would help people to speculate on what gains may be down the road.

Dr. Parkinson cautioned against extrapolating numbers from one industry to another, as this could prove intellectually easy to attack.

Dr. Schlesinger said the group's basic problem is that the GPS system is grossly underestimated by both the public and government. The Advisory Board's task is not so much to present specific figures as to convey the importance of this topic. If it proves possible to convey the value of GPS to members of Congress, then the effort will have succeeded. Members of Congress, for example, take considerable interest in issues such as aviation safety and, thus, the role GPS plays in this area must be emphasized.

The PNT Advisory Board adjourned its Tuesday, August 14 session at 5:40 p.m.

Session of Wednesday, August 15, 2012

The PNT Advisory Board convened its Wednesday, August 15 session at 9 a.m.

Board Convenes
Call to Order by James J. Miller, Executive Director, PNT Board, NASA Headquarters.

Announcements and Agenda
Dr. James Schlesinger, *Chair*

Dr. James Schlesinger said he believed it was fate that had caused him to read in the *Washington Times* the statement, "economics is rightly called the dismal science and economists have been known to put their would-be brides to sleep in the midst of their marriage proposals." He noted that a former chairman of the Council of Economic Advisors had presented a talk some years ago, saying in part: "An economist is someone who is pretty good with numbers, but lacks the personality to become an actuary."

*   *   *

International Member Regional Updates & Perspectives

Making Use of Two Fully Deployed GNSS: The Science Perspective

Dr. Gerhard Beutler
Switzerland

Today there are two fully-deployed GNSS systems – GPS and GLONASS. Both systems are important contributors to the IGS and applications in the area of geodesy. An important advantage of GPS for geodesy is that it has six orbital planes and the orbital period is exactly one-half sidereal day. This means that each satellite traverses the same region twice every day. For GLONASS, a complete ground track takes eight days, having an evolution period of 8/17ths of a sidereal day. Since 2011, GLONASS has had 24 space vehicles in operation. Galileo is still far from operational, but once in service, the space vehicles will move slower and, thus, will take ten sidereal days to completely close its ground track.

Dr. Beutler posed the question: why do we need a multi-GNSS for geodesy? The most important point is the increased number of simultaneously-visible satellites over any given area. This was particularly important both in the upper latitudes and under limited satellite visibility such as in canyons. Single systems will, invariably, have "problematic" areas where coverage is not as ideal. Multi-GNSS enables "normal users" to obtain mean Position Dilution of Precision (PDOP), and it improves by 36 percent by adding GLONASS to GPS, and 42 percent when adding Galileo to GPS and GLONASS. Scientific users will also have additional signals and frequencies.

The IGS pilot service began in 2001, and the first operational service followed in 2003. IGS has been tracking GLONASS since 1997. In 2011, IGS launched the *Call for Participation* in the Multi-GNSS Experiment (MGEX), which goes even beyond the GPS & GLONASS combination. Dr. Beutler stressed that IGS' most important function is to generate the best overall combined GNSS signal. To assist with this, currently there are over 400 active tracking sites distributed worldwide.

IGS key activities also include:

- Real-Time Pilot Project
- IGS contributions to the Global Geodetic Observing System (GGOS)
- The United Nations International Committee on GNSS (ICG), in particular co-leading Working Group D on reference frame timing and application.
- Co-chairing the new ICG task on international GNSS monitoring and assessment.
- Developments from MGEX and a future open IGS real-time service.

The receiver manufacturing industry has made excellent use of the GNSS signals available. A case study of combined GPS and GLONASS data was presented to the Advisory Board. This case study has produced both combined and separate solutions (including GLONASS-only solutions), something that is being done for the first time. Ninety-two GPS/GLONASS stations were included. Results for one station, with the batch length of one day, showed GLONASS providing "roughly" the accuracy that GPS was providing in 1994, which is remarkable.

Dr. Parkinson asked if by "roughly" he meant the User Range Error (URE) was equivalent.

Dr. Beutler said yes, he did.

A puzzling problem is that if one solves for the center of mass of the Earth with GPS, the solution moves within +/- 2 centimeters, whereas with GLONASS, the solution moves 15-30 centimeters. This difference is not one of data quality, but appears to be systematic to the GLONASS system itself and reflects the fact that GLONASS operates in only three orbital planes (vs. six in GPS). There is a striking correlation of the estimated Z-coordinate with the elevation of the Sun above the orbital plane and the Sun standing more or less perpendicularly above the orbital plane. This suggests the differing GLONASS results reflect solar radiation pressure, and can be corrected with a parallel shift of the orbital plane to explain 95-100% percent of the difference.

Dr. Hermann asked if what one was seeing was an actual change in the bodies involved or in the mathematical derivation.

Dr. Beutler said it appeared to be modeling problem.

Mr. Hatch asked whether knowing the radiation pressure exactly would make the observed effect disappear.

Dr. Beutler responded that it would not because the solutions would include a wrong set of parameters.

Dr. Hermann said he had assumed there is a model for this effect. Was Dr. Beutler saying that the parameter used for solar radiation pressure was wrong? Dr. Beutler said this appeared to be the case.

In summary, being able to generate both independent, and combined, IGS-like solutions is improving our ability to develop better models. Combined GPS and GLONASS signals are definitely clearer than tracking these separately. The implementation of laser retro-reflectors on GNSS satellites will enable independent validation of systematic errors. Also, the implementation of accelerometers on GNSS spacecraft would allow direct measurements of non-gravitational forces as opposed to the current modeling approach.

Dr. Parkinson said this could be difficult to implement.

Dr. Beutler agreed, noting that very delicate instruments were involved.

Mr. Murphy said he doubted the aviation community would be given any choice when it came to relying on non-US systems. There are already on-going struggles with a mandate requiring aircraft flying in Russian airspace to carry GLONASS-capable equipment by January 1, 2017. This could lead other nations following a similar approach regarding use of their own GNSS systems.

Dr. Parkinson offered a metaphor: “The international timing standard, carried in the atomic clock in Paris, is the amalgamation of timing standards from everywhere. Any country with an atomic clock can be part of this. But it is handled as a weighted solution and, thus, not all individual time reports are treated equally.” Similarly, not all GNSS signals need be treated equally. Solutions using multiple systems should weigh them to obtain an optimum solution. Therefore, he hopes the Russians would not prevent the use of GPS in their air space.

Mr. Murphy said he hoped no country would ban the use of a particular GNSS system, but this could still happen. Wide area augmentation systems have become part of the problem because they have footprints that extend beyond their coverage area. For example, as a pilot he may be able to use Pakistan information from the Indian regional navigation system; however he doubted Pakistan would allow him to make use of it due to on-going mistrust between the two nations.

Dr. Parkinson said Mr. Murphy had identified a very difficult problem. One would hope that nations would realize there’s a payoff in having better accessibility.

Dr. Beutler said it would be an “absolute shame” for any country to forbid the use of any particular system.

* * *

Implementation of QZSS Update

Mr. Hiroshi Nishiguchi
Japan

Since the previous Advisory Board meeting, the Japanese Cabinet has made two important decisions as a result of a better understanding of the critical role GPS plays. The first decision reflects basic thoughts on the promotion of full-fledged Quasi-Zenith Satellite System (QZSS) operations and, the second reflects the implementation of strategic architecture for space exploration and utilization. Three things that are spurring the Japanese government to materialize its QZSS architecture: (1) studies on the specifications to make QZSS more practical; (2) studies on the Operations and Management (O&M) structures for QZSS; and (3) revision of the Cabinet Law Office to undertake responsibility for O&M. An additional step is setting up the

Office of National Space Policy and a Space Policy Committee within Japan's Cabinet Office. This last step was accomplished July 12, 2012.

The mission of the Office of National State Policy includes: interagency coordination; operation and management of QZSS; and outreach activities. This body includes membership from the appropriate government agencies and is headed by a newly-appointed Space Policy minister. On the other hand, the Space Policy Committee is a newly-created body that reports to Japan's Prime Minister. This is a seven-member body authorized to assess policies relating to space exploration and budget allocation.

The people of Japan have shown increasing interest in the practical applications of GNSS. The results of a survey of 234 companies and institutes resulted in a better understanding of the current private sector GPS use in Japan: 22 percent in land surveying; 19 percent in basic research; 17 percent in personal navigation; 16 percent in vehicle navigation; and lesser amounts in other areas. Additional possibilities are now opening up in the area of personal navigation and, also, automated operations in mobile mapping, precision farming, and construction.

Japan has also been active to develop GNSS use. Three important activities in this area include: (1) participation in the multi-GNSS monitoring network throughout Asia and Australia, with whom it shares pertinent data; (2) participation in application demonstrations – these include, in particular, disaster mitigation and precise positioning; and (3) participation in a series of regional workshops held in Bangkok/Thailand, Melbourne/Australia, and Jeju/South Korea.

> An Advisory Board member noted that Japan had monitor stations as far south as Australia. Do they exist solely to monitor QZSS?
>
> Mr. Nishiguchi responded that, no, these would monitor both QZSS and GPS.
>
> Gov. Geringer commented that Japan has conducted a fairly detailed analysis of critical infrastructure, supported by an analysis of how QZSS would be integrated into other GNSS systems. Could this analysis be made available to the Advisory Board?
>
> Mr. Nishiguchi said this report could, of course, be made available. The Japanese government has come to realize the importance of GZSS to world systems, in particular with national security and safety-of-life aspects. This realization was hastened by the major earthquake of 2011, including the rapid measurement of the tectonic movement thanks to GPS.
>
> Mr. Marquez said his understanding was that the final size of the QZSS constellation was still to be determined. Has a final decision been made?
>
> Mr. Nishiguchi said the likely options combining QZSS and GEO satellites are either "five and two" and "four and three." These are still being evaluated.
>
> Mr. Lewis asked whether an array of this size would meet Japan's sovereign needs without a 'GNSS-like' system.
>
> Mr. Nishiguchi said that is still being discussed.

In summary, U.S.-Japan cooperation in the multi-GNSS era is based on bilateral government consultations and multi-lateral conferences within the ICG. The Japanese government has decided to undertake primary responsibilities on GNSS issues and, of course, he believes the role of the Japan GPS Council has been successfully achieved with the generous contributions from other nations.

* * *

Update by the Advisory Board Member from Egypt

Dr. Rafaat Rashad
Egypt

In the 17^{th} century – 250 years ago – the British Navy sought an invention of a machine to supply accurate time so that ships at sea would be able to determine their longitude. They offered the sum of 20,000 British Pounds to the inventor. Two years later, James Harrison presented a very complicated clock that was accurate to within two to three seconds a day. The prize being offered was, in current terms, equivalent to US $3 million. Today, GPS offers a far more accurate time. Time is part of applications in everyday life – science, industry, communication and elsewhere. It is now unthinkable for GPS not to be available.

Also, it is important to call attention to the international efforts in reaching the current levels of accuracy. For example, soon after Galileo announced it would not have Selective Availability (S/A), the U.S. announced that GPS S/A would be set to zero and phased out of future GPS space vehicle designs. This and other acts of intellectual cooperation have brought about many other advances around the world – for example, in Japan QZSS, in India, the Indian Regional Navigation Satellite System (IRNSS), and many others use augmentation systems around the world today.

Finally, the Advisory Board and other bodies have encouraged providers to cooperate on developing more accurate equipment and, also, protecting their own interests by protecting GNSS signals from future hazards and threats. In terms of the proposed economic study of GPS, and potentially also GNSS, it is better to focus more positively on the benefits offered by these systems rather than looking at the costs following a system disruption. Much of what has been presented on the topic to date rests more on assumptions than verifiable figures. What is needed are qualitative studies supported by verifiable data. Also, there are many important factors that cannot be measure in terms of cost, including safety, quality of life, and others. It is important that nations move forward on the development of GNSS systems not just to meet their own needs but, also, those of the international community. This is an excellent exercise of soft power where the cost paid for innovation becomes the price paid for global leadership.

* * *

Update by the Advisory Board Member from Norway

Mr. Arve Dimmen
Norway

Mr. Arve Dimmen began by referencing the 8th meeting of the Advisory Board where, he had presented plans for a regional mapping authority and the development of a station at 79 degrees North to support this task. This works does not just support Norway but, also, the international community. Funds have been secured for the entire project and by 2018, the new observatory will be in operation. This is very good news for everyone concerned about mapping sea level change and factors related to climate change.

Mr. Arve Dimmen noted that the maritime had not been discussed in cost discussions. GNSS is embedded in all phases of marine navigation, from port operations to the open seas. GNSS is vital to many offshore operations and, in many instances, is the only provider for high precision. GPS positioning and timing data is essential to provide increased location accuracy to ship crews for navigation, to the port authorities for traffic management, and for improved charting systems. Estimating the economic value of these is difficult, and one needs to be in contact with all those who use it daily and can attest to the consequences had GPS not been available. How ambitious should we be in trying to accomplish this? How much fact and figure is needed to convey the obvious? A November 2011 press release said that 6 to 7 percent of Europe's GNP – about 800 billion Euros – relies on satellite navigation. Perhaps the methodology that developed this figure should be looked at more closely to see if the number is sufficiently accurate. The current global market for GNSS equipment and services is estimated at 124 billion Euros, with the expectation of reaching 220 billion Euros by 2020. This is just the market for improvements. The question is, what work is needed to complete the economic case?

> Dr. Parkinson said a "triage" approach may be the best. First, attention should be paid to those things that appeared amenable to quantification.
>
> Mr. Hatch said he had been amazed at the extent to which the transfer of goods from ship to shore has been facilitated by GPS.
>
> Dr. Parkinson asked if Norway is pursuing eLoran.
>
> Mr. Dimmen said the status of eLoran is to keep it in operation, for the time being,. No date had been set to decide its future.
>
> Dr. Parkinson said he knew the British had modernized all their transmitters as of a few years and now use solid state systems.

* * *

PNT Advisory Board Round Table Discussion

Dr. James Schlesinger, Chair, opened the roundtable by commenting that in economic studies it is essential to study not only the "trees" but the "forest" as a whole. Otherwise the audience will be lost. The audience for this study is the political process in Washington and the general public, both of whom greatly underestimate the importance of GPS.

Dr. Bradford Parkinson said that Gov. Geringer had been asked to lead the discussion.

Gov. Geringer said he would preface his remarks by recalling national space policy, which states that the U.S. must maintain its leadership in space-based positioning, navigation, and timing. He noted that Dr. Nishiguchi was very clear on how Japan had adopted a policy on what they wanted GNSS to accomplish, and their stated goal has more specificity than current U.S. Presidential policy. In the U.S., there is a clear military goal for GPS but a rather undefined set of goals elsewhere in the society. There is evolving set of goals on the civil side but, to-date, these are not being adequately considered. Dr. Beutler had offered a good comment: there is a difference between modeling and measuring an effect. In statistics and economics, Gov. Geringer said one can measure only so accurately; thereafter, modeling is required. He noted that the group has a tendency to delve down rather than delve broadly. It needs to do the latter, given the audience for this effort. The study must be credible and independent. It must survey the existing literature and past studies to see they are complete; whether gaps exist; and whether peer review is necessary. We can build on what the two economists had reported to the group: (1) there are sectors where the definition is easy and one can show clear economic benefit; and (2) everyone is interested in navigation. Thus, adding the topic of maritime transfer to the current set of economic areas would result in a reasonably compact report that could be given to the ExCom to identify key areas and benefits. Gov. Geringer called attention to a list of major GPS applications that had been drawn up by Dr. Parkinson, and suggested a "triage approach" emphasizing those areas in which great benefit could be most readily shown. For example, if ground transportation is not complete then the task becomes determining what is required to make it ready. We also need to look at the GNSS capabilities as an integrated system. Without a clear policy, it is difficult for the U.S. to form clear goals and, in terms of the absence of goals, it cannot know it is achieving.

General McCarthy said his understanding was the Advisory Board had been asked to provide the ExCom with a structure of how a study would be undertaken by some other entity. The amount of funding needed is relatively small. The report is bounded by four categories: (1) Emphasize economic data that is correct and credible; for example, precision agriculture. It is important to catalog the GPS industry and how much it contributed in terms of revenue; (2) Identify the indirect GPS economic benefits, which are difficult to quantify and, perhaps, the experts undertaking the study could come up with a discount factor to calculate how GPS allows indirect costs to be reduced; (3) Identify non-monetary but quantifiable benefits, such as lives saved and faster response times in a disaster; and (4) Identify intangible benefits such as the ability to keep the world fed and avoiding warfare. These four points provide a basis of a study that could be done fairly quickly and at a reasonable cost.

Dr. Schlesinger reiterated that the ultimate purpose is not to persuade economists, but to persuade the U.S. Congress and the wider U.S. public. There are important aspects of GPS which are underappreciated. The public does not understand how important timing signals are to cell phones, ATMs, financial instruments and transactions, or even to routine visits to one's bank. There is a virtual void of public knowledge. The public, however, does understand that if you are hiking the Appalachian Trail, GPS will tell you where you are.

Mr. Murphy offered several thoughts. It is important to make clear the interconnected nature of the value network. Another aspect that needs to be reported is the compatibility with other international systems. On a different note, the report would provide a snapshot in time, and quite possibly be obsolete by the time it is released. Perhaps there could be some benefit in developing a web-based tool to encourage people to tell their stories about the value they got from GPS. People could be amenable to tell their success stories.

Dr. Schlesinger recalled that eight years ago there had been a cave-in in Pennsylvania and rescue crews were able to drill to the right spot because of information from the GPS system. Those miners could be interested in telling their story.

Mr. Murphy said other stories might be forthcoming from fire fighters, first responders, and others.

Dr. Hermann said he agreed with Gen. McCarthy that to go beyond "two or three significant figures" would undercut the credibility of the report.

Mr. Nishiguchi said that studies require data, and that in the absence of data it is very difficult to get results. The examples presented to the Advisory Board should be capitalized upon, and further focus would improve the data. Thereafter one can, to an extent, generalize from the results and present an overall picture.

Dr. Parkinson said there is a further dimension to consider, namely, what is the consequence if a large powerful signal from a non-particular source occupies the lowest 10-15 megahertz of the adjacent frequency band? It would be very reasonable for the Advisory Board to pursue the matter, including the following four options to the GPS user base: (1) obvious and severely affected; (2) affected; (3) somewhat affected; and (4) not affected. It is important for the economists involved in the study to know what those affects might be.

Gov. Geringer asked for comments from the economists who had presented the previous day.

Dr. Leveson said he liked what he had heard very much and was thinking how to best integrate the different perspectives. The work on interference to GPS may be separable. The suggestion for stories was good. Something would be found as work on quantification proceeded and there was no need to prejudge even in the case of interference to GPS. In essence, the entire approach seems doable, but needs to focus on specific time frames.

Dr. Pham said his initial reaction was that this is a very good start on executing the plan. The material could be broken into four cells: quantifying and non-quantifying; direct and indirect. The intended audience includes public policy makers, media, and the general public. When his firm does this type of work, numbers are always presented in ways that are easy to understand. Information on breakdown by states and by congressional district can be just as important as breakdown by crops and regions. If more details are sought, then it is possible to do breakdowns by industry components. His team wishes to work with manufacturers to get more reliable data on what their customers have to say about the equipment.

Dr. Leveson said one way to make the topic sensible to the public is to translate statements about productivity into statements about incomes and jobs.

Dr. Hermann said that he was not persuaded that the spectrum intrusion issue belongs in a report on economic impacts. Spectrum intrusions are hardly the only thing to which GPS was at risk. For instance, cyber warfare may also be a risk to GPS applications.

Dr. Parkinson said the DOT has suggested the report describe what threats exist and whether mitigation schemes exist. The NTIA approach, on the other hand, is more along the lines of "let us assume what we are going to do." The question should be "how are we going to do it?" The Advisory Board is in a position to highlight which areas are sensitive.

Ms. Van Dyke said that, to clarify the DOT approach, the agency is looking at the entire band adjacent to GPS and attempting to define what is the maximum power the band can carry and still be compatible with GPS.

Mr. Lewis said that, regardless of economic impact, one needs to be prepared with a mitigation strategy. This does not appear to be tied to the assessment of the economic value.

Dr. Hermann said he expected the assessment to show that GPS has substantial financial and societal impact to the U.S. and the world. The issue of mitigation strategies for a GPS outage should be independent of the particulars of the economic analysis.

Gov. Geringer said that in Wyoming a discovery had been made that black tail bears were not extinct, and this prompted efforts to increase their numbers. Soon after, the discovery was made that a particular type of prairie dog was not extinct, prompting similar efforts. Then it was learned that black tail bears ate prairie dogs. The point is that we need to place these issues in proper context and, thus, we should find a way to combine them.

Dr. Hermann said he had not heard the White House justification for identifying 500 megahertz of available bandwidth. It may well be a worthy goal, but he did not think it was supported by an economic rationale.

Mr. Brenner said that as one who advocated more broadband space, and was aware of the "spectrum crunch," he wished to stress that there is an overwhelming economic case for the application of more broadband. This has been stated in a document prepared under the Economic Stimulus Bill. He is not aware of a similar document on the GPS side. A similar document is needed for GPS.

Dr. Parkinson suggested the following response: "GPS represents infrastructure already in place; whereas for broadband expansion the infrastructure is not in place." How critical is bandwidth near GPS to the overall plan for 500 megahertz? Can the 500 megahertz requirement be moved to another part of the spectrum?

Mr. Brenner said the issue is more than a matter of additional spectrum. At Qualcomm, the goal is to increase capacity by 1,000 times over current levels. Private investment was needed to do this. No one knows whether, say, 450 megahertz rather than 500 megahertz could be sufficient. Congress has authorized various approaches in the tax cut bill, for example, bandwidth could be returned from television bandwidth as aerial transmissions have ceased.

Dr. Parkinson said it appears that some of the higher bands looked easy to use if the devices existed. Was this true?

Mr. Brenner said it was true that certain spectrum bands are better than others; further, not all spectrums are licensed. For example, Wi-Fi is unlicensed. Devices are currently being introduced and rolled out at the 50 and 60 gigahertz bands. Generally it is not difficult to add a new band; the problem is that a device can only support so many bands.

Gov. Geringer asked if it is, at a minimum, possible to "define a few bricks" on which to build an approach.

Dr. Schlesinger said there is an issue on how to distinguish between real mitigations, mitigations as reassurance, and window dressing. Users must do more than simply demand they be protected "from the ravenous beasts."

Mr. Miller said he worked years ago with Mr. Brenner on how GPS had to be protected from Ultra Wide Band (UWB), and was curious to know why Mr. Brenner's views have changed with broadband.

Mr. Brenner said this was an excellent question. This is in part due to UWB being an untested technology ahead of its time, whereas broadband is in existence today. Also, UWB didn't have a constituency whereas broadband has one.

Dr. Hermann asked whether that's a good process model.

Mr. Brenner said he believed it was. The broadband document had involved 35 requests for comment. In addition, the stimulus report had cited such things as the educational smart grid, public safety, and other benefits in broadband.

Dr. Hermann said he hadn't seen quantification of the dollars of benefit involved.

Mr. Brenner said the plan had detailed figures. Some had come from private entities in requests for comment; others from within government.

Dr. Hermann asked if Mr. Brenner had a number in mind.

Mr. Brenner responded that he believed every one percent penetration of broadband meant a one percent increase in Gross Domestic Product.

Mr. Nishiguchi suggested the group return to Dr. Schlesinger's statement about the GPS timing signal. The use of the timing signal is increasing even though this is not yet visible to people in general. Given the invisible nature of GPS timing, broadband had taken over as a topic of conversation that represents the state of the art. In order to get correct timing one needs the technical capability to receive the timing signal; and for this, even the lower 10 megahertz cannot be given up. Was it not possible to come up with an argument and put logic into the argument?

Dr. Parkinson said the Advisory Board could try to do this. However, some things obvious to the Advisory Board were not obvious to other people.

Mr. Hatch said that with 10 to 15 years of lead time, precision agriculture could have been made to work in a different bandwidth. It might be that the MSS band which was depended upon for GPS differential corrections would need to be moved. Would anyone undertake this?

Dr. Leveson said that on the economic analysis, the main subject before the Advisory Board, "we have laid out an awful lot." He believes the best way to deal with the task is to produce a 25- to 30-page report that presents the arguments as clearly as possible, and citing some numbers. He urged that an appendix or spreadsheet be added for anyone who wanted to source the estimates. A broader report could then follow to fill in the numbers for other economic sections.

Dr. Schlesinger said he did not understand why GPS – which he regards as transformative as the steam engine or the internal combustion engine – was not taught in school.

Dr. Parkinson expressed agreement. The problem is that GPS has benefited so many people in so many ways, and had been integrated into so many things, that it had a "helluva" marketing problem. The GPS market is for everyone, but people don't realize it. The economic study is a step in that direction, but "we are not going to win the battle in one blow."

Mr. Lewis noted that one thing to consider is that language has changed over time. For computers, the term is "information access." GPS lacks a similar tagline. When the topic of global timing services is discussed there is no straightforward clarity about what it has accomplished. Those working with GPS continue to use "engineers' terminology" – which the average high school student does not understand.

Gov. Geringer said this emphasizes the need to find stories to tell.

Mr. Miller said that on that matter, he would continue to work with Ms. Karen Van Dyke at DOT to develop simple ways to understand the infrastructure. He would also speak with Mr. Russo and Col. "Stormy" Martin to ensure that the issue continues to be brought forward.

* * *

The August 15, 2012 session of the PNT Advisory Board adjourned for a working lunch at noon.

Appendix A: Space-Based PNT Membership

Special Government Employees

- **James R. Schlesinger** (Chair), MITRE and Barclays Capital
- **Bradford Parkinson** (Vice Chair), Stanford University
- **Dean Brenner**, Qualcomm
- **Joseph D. Burns**, United Airlines
- **Richard DalBello**, Intelsat General
- **Per K. Enge**, Stanford University
- **Martin C. Faga**, Former President & CEO, MITRE
- **James E. Geringer**, ESRI
- **Keith R. Hall**, Booz-Allen Hamilton
- **Ronald R. Hatch**, NavCom Technology, John Deere
- **Robert J. Hermann**, Global Technology Partners, LLC
- **Rajiv Khosla**, Colorado State University
- **Lance Lord**, Former Commander, Air Force Space Command
- **Peter Marquez**, Orbital
- **James P. McCarthy**, U.S. Air Force Academy
- **Terence J. McGurn**, private consultant (retired CIA)
- **Timothy A. Murphy**, The Boeing Company
- **Ruth Neilan**, Jet Propulsion Laboratory
- **Charles R. Trimble**, Chairman, U.S. GPS Industry Council

Representatives

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

- **Gerhard Beutler**, International Association of Geodesy (Switzerland)
- **Ann Ciganer**, U.S. GPS Industry Council
- **Arve Dimmen**, Norwegian Coastal Administration (Norway)
- **Hiroshi Nishiguchi**, Japan GPS Council (Japan)
- **Rafaat M. Rashad**, Arab Institute of Navigation (Egypt)

Appendix B: Presentations

Space-Based PNT Executive Committee Emerging Policy Issues – Anthony Russo

Development of the GPS III Laser Retro reflector Array [LRA] – John Labrecque

Department of Transportation: Assessing Economic Benefits and Productivity Gains from GPS – Karen Van Dyke

Federal Aviation Administration: Estimated Benefits of GPS for U.S. Civil Aviation – Molly Smith

NGA [National Geospatial-Intelligence Agency] Relationship with GPS – Stephen Malys

US Geological Survey Investments in GPS – David Applegate

Applications of GPS Provided Time and Frequency and Future – Edward Powers

GPS Network Timing Integrity – Malcolm J. Airst

Case Study on Potential Impact to Weather Forecasting and Environmental Monitoring if GPS Radio Occultation is Denied – Stephen Esterhuizen

Weather and Space Weather Impacts for Users of GPS Radio Occultation – James G. Yoe

Economic Benefits of Precision Agriculture – Ben Smith

GPS Policy Evolution: Spectrum Access, Stability, and Growth – Scott Pace

GPS Benefits Data: Availability and Study Needs for Present and Emerging Benefits – Irv Leveson

The Economic Benefits of Commercial GPS Use in the United States – Nam D. Pham

Making Use of Two Fully-Deployed GNSS: The Science Perspective – Gerhard Beutler

Implementation of QZSS Update – Hiroshi Nishiguchi

* * *

Presentations are posted at www.GPS.gov

Appendix C: Attendees

PNT Advisory Board, Wednesday, August 14 attendees

PNT Advisory Board Members:

James Schlesinger, Chair	
Gerhard Beutler	AIUB
Joe Buns	United Airlines
Arve Dimmen	Norwegian Coastal Authority
Per Enge	Stanford University
Jim Geringer	Environmental Systems Research Institute
Robert Hermann	PNT Advisory Board
Jim McCarthy	U.S. Air Force Academy
Bradford Parkinson	Stanford University
Hiroshi Nishiguchi	Japan GPS Council
Rafaat Rashad	IAIN

Other NASA Personnel:

Juan Ceva	NASA Jet Propulsion Laboratory
Steven Esterhuizen	NASA Jet Propulsion Laboratory
Dale Force	NASA
Munther Hindi	NASA/ASRC
John LaBrecque	NASA
A. J. Oria	NASA/Overlook
Calvin Ramos	NASA
Tom VonDeak	NASA
Stephanie Wan	NASA/ASRC

Other Attendees:

Malcolm Airst	MITRE Corporation
Ken Alexander	DOT/FAA
Daniel Applegate	USGS
Jim Burton	National Coordination Office
Ray Clore	U.S. Department of State
Robert Crane	National Coordination Office
Charlie Daniels	Overlook Systems
Michael David	OSTI
Dee Ann Davis	*Inside GNSS*
Sebastian DeLiso	DOD
Steve Edson	JS J6
Gene Fisher	NOAA
Rick Foote	DOC/NOAA
Steve Grupenhagen	SAF/AQS
Michael Ha	FCC
Ron Hatch	John Deere
Joseph Healy	USCG
Robert Hessin	Overlook Systems
Thomas Johnson	NGA
Dan Jordan	Lockheed Martin
Jason Kim	Department of Commerce
Titus Ledbetter III	*Space News*
Irv Leveson	Leveson Consulting
Mark N. Llewellyn	John Deere
Steve Malys	NGA
Col. Harold Martin	USAF-NCO
Jules McNeff	Overlook Systems
Mitch Narks	FAA
David Olson	FAA
Scott Pace	George Washington University
J. J. Palermo	CIO/BAH

Nam Pham	NDP Consulting
Tom Powell	Aerospace
ED Powers	USNO
Robert Rosenberg	GPS/IRT
Tony Russo	National Coordination Office
Joseph Sapp	AF/A350
Leslie Schroeppel	SAIC/FAA
Hank Skalski	POT/AFSPC
Ben Smith	John Deere
Molly Smith	FAA
Lisa Snow	JS J5
Joseph Thomas	AF/ASRS
Michael Tucker	
Karen Van Dyke	Department of Transportation
Rick Vosburgh	Physical Devices
Neil Weston	NOAA
Martin Whelan	Air Force Space Command
Frank Williams	AFS/ASRS
Barbara Wiley	NGA
Jim Yoe	NOAA/NWS

PNT Advisory Board, Thursday, August 15 attendees

PNT Advisory Board Members:

James Schlesinger, Chair	
Gerhard Beutler	AIUB
Dean Brenner	Qualcomm
Joe Buns	United Airlines
Arve Dimmen	Norwegian Coastal Authority
Per Enge	Stanford University
Jim Geringer	Environmental Systems Research Institute
Robert Hermann	PNT Advisory Board
Jim McCarthy	U.S. Air Force Academy
Bradford Parkinson	Stanford University
Hiroshi Nishiguchi	Japanese GPS Council
Rafaat Rashad	IAIN

Other NASA:

Juan Ceva	NASA/JPL
Dale Force	NASA/GRC
Munther Hindi	NASA/ASRC
Calvin Ramos	NASA
Tom Van Deak	NASA
Stephanie Wan	NASA/ARSC

Other Attendees:

Regina Cates	CSG
Dee Ann Davis	*Inside GNSS*
Steve Grupenhagen	SAF/AQSL
Michael Ha	Federal Communications Commission
Irv Leveson	Leveson Consulting
Jules McNeff	Overlook Systems
Hamid Park	Harvard University
Nam Pham	NDP
Robert Rosenberg	GPS/IRT Chair
Leslie Schroeppel	SAIC/FAA
Hank Skalski	Department of Transportation
Scott Pace	George Washington University
Karen Van Dyke	Department of Transportation
Neil Weston	National Oceanic and Atmospheric Administration

Appendix D: Acronyms

AF	Air Force
AFSPC	Air Force Space Command
BIPM	Bureau International des Poids et Measures
CC	Composite Clock
CDD	Capabilities Development Document
CDMA	Code Division Multiple Access
CFIT	Controlled Flight into Terrain
COMPASS	Chinese GNSS Constellation
DASS	Distress Alerting Satellite System
DoD	U.S. Department of Defense
DOT	U.S. Department of Transportation
DSN	Deep Space Network
eLoran	Enhanced Loran
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
ExCom	PNT Executive Committee
FAA	Federal Aviation Administration
FACA	Federal Advisory Committee Act
FEMA	Federal Emergency Management Agency
FRA	Federal Railroad Administration
GALILEO	European GNSS Constellation
GEO	Geosynchronous Equatorial Orbit
GGOS	Global Geodetic Observing System
GLONASS	Russian GNSS Constellation
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPS IIA	GPS Block IIA
GPS IIF	GPS Block IIF
GPS III	GPS Block III
GPS IIR	GPS Block IIR
GPS IIRM	GPS Block IIR(M)
IAG	International Association of Geodesy
ICG	International Committee for GNSS
IEEE	Institute of Electrical and Electronics Engineers
ICG	International Committee for GNSS
IGS	International GNSS Service
IG	Inspector General
IRNSS	Indian Regional Navigation Satellite System
ITU-R	International Telecommunication Union – Radiocommunication Sector
JCIDS	Joint Capabilities Integration Development System
JPL	NASA Jet Propulsion Laboratory
L1C	GPS 4^{th} Civilian Signal (interoperable with the Galileo Open Service)
L2C	GPS 2^{nd} Civilian Signal (for science applications)
L5	GPS 3^{rd} Civilian Signal (for safety-of-life, such as aviation)
LiDAR	Light Detection and Ranging
MC	Master Clock
MGEX	Multi GNSS Experiment
MHz	Megahertz
MSS	Mobile Satellite Service
NASA	National Aeronautics and Space Administration
NCO	National Coordination Office
NextGen	Next Generation air traffic control
NGA	National Geospatial-Intelligence Agency
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NTP	Network Time Protocol
NTIA	National Telecommunications and Information Administration
O&M	Operations and Management
OCC	GPS Operational Control Center
OCX	GPS modernized Operational Control Center
OMB	Office of Management and Budget

OSTP	Office of Science and Technology Policy
PDOP	Position Dilution of Precision
QZSS	Quasi Zenith Satellite System
R&D	Research and Development
RNSS	Radio Navigation Satellite Service
RO	Radio Occultation
S/A	Selective Availability
SAR	Search and Rescue
SLR	Satellite Laser Ranging
PNT	Positioning, Navigation, and Timing
PRS	Public Regulated Service (on the Galileo GNSS)
PTTI	Precise Time and Time Intervals
RTK	Real Time Kinematic
URE	User Range Error
USGS	US Geological Service
USNO	US Naval Observatory
UTC	Universal Coordinated time
UWB	Ultra Wide Band
VLBI	Very Long Baseline Interferometry