Research is full of surprises. But for two key PNT projects the pathways are clear.

Dr. Elisa Felicitas Arias and Dr. Frank van Diggelen — speaking to the attendees at ION’s virtual ITM/PTTI conference in January — laid out the step-by-step processes now under way to improve, respectively, plans to update the International System of Units (SI) definition of a second and improve the accuracy of locations provided by cell phones in dense urban areas.

The SI second is one of seven units of measure based on natural constants. The current international definition relies on microwave atomic clocks using the cesium 133 atom. The uncertainty associated with this is on the order of 10^-16.

Advances in optical atomic clocks, however, now make it possible to reduce that uncertainty to a range of 10^-18. These new clocks use other elements including mercury, aluminum, strontium and ytterbium.

“These optical standards exist. They are reaching uncertainties at a level of 10^-18 that will for sure — and we know — contribute to go deeper in the knowl-

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PNT RESEARCH ON A GLOBAL SCALE

Making Clocks Less Uncertain and Cell Phones More Precise

The navigation team at NASA’s Jet Propulsion Laboratory (JPL) used quasars and the Deep Space Network to successfully navigate the spacecraft carrying the Perseverance rover to within 140 meters of its planned entry into the Martian atmosphere. Their accomplishment is all the more impressive given that the team was required to start the mission with a trajectory intentionally designed to miss the planet altogether.

The details of Perseverance’s journey emerged as Dr. Gerhard Kruizinga, JPL’s Navigation Team Chief, described how he and his colleagues planned and adjusted the path of the rover’s 471 million km trip from Cape Canaveral Air Force Station in Florida to Mars where it ultimate landed on the floor of Jezero Crater. Perseverance was the fourth Mars lander mission in which Kruizinga had participated, he told the attendees at ION’s March 23, 2021 webinar. Even so it is the first time he got to actually see the touchdown.

“(The rover) had quite a few cameras on board to actually show us where we were actually landing,” Kruizinga said, “and it was just quite spectacular to see.”

The job of the navigation team is to plot a trajectory for the spacecraft from Earth to a precise point above the Mars atmosphere — arriving at the right time and at the right angle to execute the entry descent and landing (EDL) plan. The}

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MARS WEBINAR

Using Quasars and the Deep Space Network to Navigate Precisely to Mars

Take-Off: The Perseverance rover was launched from Cape Canaveral Air Force Station, Florida on an Atlas V rocket on July 30, 2020.
Photo courtesy of NASA / Joel Kowsky
**Goals**

I am honored to take the gavel from our outgoing president, Dr. Jade Morton, and thank her for her many impressive achievements. I look forward to continuing to serve with Jade and all the members of the incoming Council for the next two years. Here are my strategic goals:

Get the ION’s programs back to normal as quickly as possible post COVID-19 vaccine. I, like many of you, have missed the sense of community and collaboration from our valuable, in-person interaction at ION events.

Welcome the 1,300 first-time attendees from ION GNSS+ 2020 VIRTUAL. We want these navigators to find their way back to our organization on a regular basis.

Make the ION Fellow nominations more industry friendly. I want to ensure that those who research, develop, and produce commercial technologies are fully acknowledged through the ION Fellows program.

Put the Navigation back into ION, by pursuing more practical navigation content. At the end of March, we had the pleasure of hearing from the team chief of the Mars 2020 Navigation Team (see the cover story). I want us to share more navigation stories, highlighting how our technologies are employed in creative and inspiring ways. If you know of an interesting speaker that would make a good webinar or story for the ION Newsletter, please share with the National Office staff.

Continue and accelerate our present efforts and positive trends to ensure diversity within our organization. This includes increasing the participation and influence of younger members.

In each of my following President’s Columns I’ll update you, and I look forward to your input and valuable help in pursuing and achieving these goals.

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**ION Council Convenes Virtually**

The ION Council met virtually on January 29, 2021. Outgoing president, Dr. Jade Morton, reported on several actions that had been taken by the ION Executive Committee in the preceding months. The most notable action being that ION’s Pacific PNT meeting, originally scheduled for spring 2021, would be delayed until spring 2022 at the same location (April 11-14, 2022 at Hilton Waikiki, Honolulu, Hawaii.) We will have the same technical program and program committee. This also means that the ION would be deferring a joint IEEE/ION PLANS technical program to the spring of 2023. Additionally, it was reported that the decision had been made to transition ITM/PTTI 2021 to a fully virtual program.

The Council also approved ION’s prior fiscal year’s audit report and next year’s National Office budget. Council members received an update on our financial status and how the COVID-19 pandemic was impacting National Office operations, the staff, and federal funds that had been secured to assist. ION’s Reserve Fund would enable ION to operate normally through the pandemic and recovery period, and ION members should not experience any changes to their benefits.

Additionally, the Council received an update on plans to begin electronic pub-
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Founded in 1945, The Institute of Navigation is the world’s premier non-profit professional society advancing the art and science of positioning, navigation and timing.

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“edge of the physical world,” Arias said during her plenary speech.

Arias previously served as director of the Time Department at the International Bureau of Weights and Measures (BIPM). She now contributes to time metrology and space reference frame programs at the Paris Observatory.

It Takes Time

Redefining the SI second is one of four priority areas for the BIPM, said Arias. Even so cesium will likely continue as a secondary representation of the SI second and Arias does not expect major changes for the commercial sector.

“They that run on cesium, will continue running on cesium until the moment when they will be able to commute to the new realization — or not. Running on cesium will remain possible, I suppose and I hope. So I don’t think that there is a negative perspective for industry fabricating cesium standards or laboratories developing cesium fountains. I don’t think so; the applications will still be there.”

Not that redefinition is imminent.

BIPM’s Consultative Committee for Time and Frequency (CCTF) has formed a 40-member task force to develop and propose a roadmap for updating the definition of the SI second. Their draft will be submitted to the general conference on weights and measures in 2022 but it will take time to approve any proposed change. Overall the inputs to the new definition will involve research at a number of National Metrology Institutes, the work of numerous experts and standards bodies and a process that will likely span 10 years.

“This process is not short,” said Arias.

Solving the Uber Problem

While few in the general public are likely to notice a change in the SI second, many, if not most, have already encountered location problems in the urban canyons of a large city.

“So I have myself experienced this often, and you may have, when you call for a Lyft or an Uber and it arrives on the wrong side of the street,” van Diggelen said during his plenary talk. “And depending on the street, that might mean it’s just impossible for them to get to you and the whole system just breaks down.”

The current president of ION, van Diggelen is a pioneer in Assisted GNSS and a principal engineer at Google, where he leads the Android Core-Location Team.

The phone makers and app developers on Google’s Customer Advisory Board told the company that their top location issue is inaccuracy in urban areas. Google’s own research shows there are over one billion fixes per day from smartphones that are at least on the wrong side of the street, or even on the wrong city block.

“So intellectually, of course, this is a very challenging and interesting problem,” van Diggelen said, “but commercially, is this an important problem? And the answer is: ‘Oh, yes, this is very important.’”

At the heart of the matter, he said, is that GNSS signals are blocked and scattered by tall buildings. Inertial navigation systems are not a solution, he said, nor are techniques like shadow matching — where satellite signal strength is used to improve location solutions. Shadow matching provides useful probabilistic information, but it’s not the whole answer to the problem, he said.

“Until recently, this was an unsolved problem and you could not do it with any amount of money,” van Diggelen told conference attendees.

But now Google has developed a solution that incorporates raw GPS measure-
ments (which are standard in Android phones) and a Google Bayesian approach to dealing with variations in the measurements. Those elements are part of a solution enabled by machine learning and Google’s vast database of 3-D maps and images.

The solution starts with the 3-D database and ray tracing — the secret of which Google has not revealed. The 3-D models help Google discern which signals are line-of-sight and which are not. With that start Google servers calculate the rays of the signals that are being bounced about by the city’s buildings and narrow down where the caller is located.

“So 3-D Model Assistance is a really key part of initializing this whole system,” van Diggelen said.

Having reduced the possibilities, Google Street View images for buildings around the location are then matched to the real-time view from the phone’s camera, thereby pinpointing the caller’s location.

“To make this work properly,” van Diggelen explained, “you have to have an idea of which street you’re on in the first place.”

Data Crunching

While the insights from the 3-D models are informative they are not enough to enable humans to program their servers to solve the location problem.

To get to a solution Google incorporated machine learning. That is it fed its cloud servers data including residuals, that is the measured range minus the expected range, signal to noise or C/N0 and other elements allowing for different signal types, different constellations and other factors. As they process the data the servers might give more weight to different elements.

Google also provides the servers the measured ground truth — then tasks its servers to take all these inputs and find the mathematical pathway whereby the data leads to the observed ground truth. After millions of such calculations the system has taught itself how to accurately determine the location of a cell phone user even when buildings are blocking satellite navigation signals.

Where does all that data come from? From testing. Lots and lots of testing.

“We have operators all over the world who do nothing but go out every day, five days a week and conduct tests against known ground truth,” said van Diggelen. “We do this in 20 cities, over four continents every day of the year — every weekday of the year, over a million data points.

Success and More

In one example of the solution, the 3-D maps and the computing power of Google’s servers enabled the company to cut the number of ‘wrong side’ location solutions in Berlin by 90 percent.

Google was able to take the effort a step further and in March 2020 introduced Version 1 (or V1) of their system — a pared-down application able run entirely on the phone.

“We’re actually doing processing on the phone, said van Diggelen, “and we’re providing corrections to the chip to give the GNSS chip information about the reflections so that it can improve its position. And then we also use the results in the fused location provider (FLP), which is the part of Android that gives you the combination of GNSS, sensor inputs, Wi-Fi and so on. And by doing this, this was on all Android phones version 10 and beyond, and this reduced wrong-side-of-street events by 50 percent.”

In December 2020 Google released V2 of the self-contained cell phone product for two Pixel phones. It should now be available on any phone with an operating system of Android 10 or higher.

“I can’t go into the details of what makes it better,” said van Diggelen, “but you can imagine with time we add in more and more into the phone. So this was released on Pixel 4A and Pixel 5 and gave 75 percent reduction in wrong-side-of-the-street.”

L5 Magic

However, the real solution, he said, will occur when Google can fully incorporate L5 signals.

“The key feature of all L5 signals,” said van Diggelen, “is that they have a 10

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Congratulations ION 2020 Annual Award Recipients

COL. THOMAS L. THURLOW AWARD
In recognition of outstanding contributions to the science of navigation.

Dr. Mingquan Lu
For significant and sustained contributions to the BDS-3 signal design and BDS-3/GNSS interoperable receivers development.

DISTINGUISHED SERVICE AWARD
For extraordinary service to The Institute of Navigation.

Dr. Y. Jade Morton
For extraordinary service to The Institute of Navigation.

SUPERIOR ACHIEVEMENT AWARD
For outstanding accomplishments as a practicing navigator.

Captain Andrew P. Zimmerman
For validating critical navigation processes and collaborating with Air Force tacticians to provide the highest standards of navigation and protection for the Air Force’s premier electronic attack asset.

DISTINGUISHED PTTI SERVICE AWARD
To recognize outstanding contributions related to the management of Precise Time and Time Interval systems.

Mr. Michael A. Lombardi
For system development and leadership in the successful delivery of the U.S. time and frequency standards signals to a variety of domestic and international PTTI users.

DR. SAMUEL M. BURKA AWARD
To recognize outstanding achievement in the preparation of a paper advancing the art and science of positioning, navigation and timing.

Jennifer E. Donaldson, Joel J. K. Parker, Dr. Michael C. Moreau, Dr. Dolan E. Highsmith and Dr. Philip D. Martzen

CAPTAIN P.V.H. WEEMS AWARD
For continuing contributions to the art and science of navigation.

Dr. Charles K. Toth
For significant contributions to the development and implementation of multi-sensor integrated navigation systems and for demonstrated excellence as an academic mentor and professional leader.

NORMAN P. HAYS AWARD
In recognition of outstanding encouragement, inspiration and support contributing to the advancement of navigation.

Ms. Karen L. Van Dyke
For her significant contributions to civil GPS applications, for her lead role directing the Adjacent Band Compatibility study, and for her commitment to international PNT coordination.
Dr. Robert Odolinski
For significant and sustained contributions to the BDS signal design, GNSS receiver development, promoting compatibility and interoperability between BDS and other GNSSs, and GNSS education.

Mr. Daniel A. Tazartes
For sustained technological contributions in the research, development and deployment of strapdown inertial navigation systems.

Dr. Demoz Gebre-Egziabher
For his contributions in the development and application of multi-sensor integration supporting UAVs and safety of life applications.

Dr. Mingquan Lu
For significant and sustained contributions to the BDS signal design, GNSS receiver development, promoting compatibility and interoperability between BDS and other GNSSs, and GNSS education.

Mr. Daniel A. Tazartes
For sustained technological contributions in the research, development and deployment of strapdown inertial navigation systems.

Dr. Y. Jade Morton
For her contributions to the advancement of navigation receiver technology including event-driven multi-GNSS data collection systems, robust tracking under scintillation, reduction of errors due to oscillator frequency offsets, multipath, and interference; and as an educator whose passion for teaching and mentoring has benefited students throughout the world.

ION used the January virtual award platform as an opportunity to also present the IEEE PLANS Kershner Award virtually. The PLANS organizers were unable to do this in the spring 2020 due to the COVID-19 pandemic that resulted in the cancellation of the IEEE/ION PLANS meeting (previously scheduled in April 2020).

IEEE PLANS KERSHNER AWARD
For outstanding achievement. The purpose was to recognize individuals who have made substantial contributions to the technology of navigation and position equipment, systems or practices.

Dr. Y. Jade Morton
For her contributions to the advancement of navigation receiver technology including event-driven multi-GNSS data collection systems, robust tracking under scintillation, reduction of errors due to oscillator frequency offsets, multipath, and interference; and as an educator whose passion for teaching and mentoring has benefited students throughout the world.

ION’s 2021 Fellows
The Fellows designation recognizes the distinguished contribution of ION members to the advancement of the technology, management, practice, and teaching of the art and science of navigation, and/or for lifetime contributions to the Institute.

Dr. Demoz Gebre-Egziabher
For his contributions in the development and application of multi-sensor integration supporting UAVs and safety of life applications.

Dr. Mingquan Lu
For significant and sustained contributions to the BDS signal design, GNSS receiver development, promoting compatibility and interoperability between BDS and other GNSSs, and GNSS education.

Mr. Daniel A. Tazartes
For sustained technological contributions in the research, development and deployment of strapdown inertial navigation systems.
times higher chipping rate than the corresponding L1 signals for that constellation. And so the correlation peak that I mentioned right in the beginning is ten times narrower than it would be for the L1 signal. And that is the single most important thing about L5.”

Whereas it’s only possible to model L1 in a statistical sense where the variance on the statistics is 50 meters, the L5 signal has distinguishable peaks. “Even if they overlap a little bit, the top of the peaks are distinguishable and therefore you can predict the delay with great certainty,” he said.

Later this year Google plans to release Version 3 of its self-contained software for Android phones and this version will tap into L5.

“L5 alone is not going to solve the non-line-of-sight problem,” said van Diggelen, “because there’s still a bias with an L5 measurement — it’s just more precise. But it’s this precision that gives us the magic because we can use it to model the reflection, even multiple reflections. And so 3-D Model Assistance plus L5 provides the solution that we really want for non-line-of-sight signals.”

Moreover, said van Diggelen, he recently added up the number of L5 capable satellites on orbit and it’s a lovely big number.

“There are 82 operational L5 satellites today,” he said. “Isn’t that fantastic? Thank you GPS, QZSS, Galileo, Beidou, and IRNSS — all these different operators have been putting up satellites with L5. And so we have a tremendous constellation of L5 satellites available today. And so by properly exploiting that, I think that’s how we reach the end game of the urban canyon problem.”
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Monopoly has been captivating players for more than a century and is now one of the world's most popular board games. Though focused on money and real estate, the board game is arguably a contest of navigation as well as chance. Navigation, after all, is the art of expeditiously and safely going from point A to point B. That is hardly different from going to Boardwalk from Atlantic Avenue, two iconic locations on a classic Monopoly board, while avoiding landing in Jail or on an adversary's properties.

We diminish the difficulty and importance of navigation when we consider only the science of maneuvering from place to place and fail to factor in the strategies and tools that help us choose whether to risk one route over another. Navigation applications such as Waze and Google Maps utilize algorithms to help users strategize how to avoid pitfalls. Monopoly played a very real role as a practical and strategic tool to help captured Allied airmen navigate back to safety during WWII.

Invented in 1904, Monopoly was first mass-marketed in 1935, according to the game's maker Hasbro. On the classic American game boards, players moved around a perimeter of squares named after properties in Atlantic City, New Jersey. The game was also licensed overseas during this period, and those boards featured the properties and cultures of major cities including London, Paris, New York, and Berlin.

The Berlin edition, however, earned the ire of Joseph Goebbels, Hitler's Minister for Public Enlightenment and Propaganda, allegedly due to the game's "Jewish speculative character" according to a translation on Wikipedia. It was also suggested that high-ranking Nazis (including Goebbels) lived on streets tagged on the squares of the game board as having the highest property values, "and they did not want to be associated with the game." The game last appeared in Germany in a pre-World War II Schmidt Spiele catalog in 1938.

The game reappeared in Germany, however, in the care packages sent to captured British airmen. M-19, the branch of British Intelligence devoted to methods of escape and evasion, was working on escape tools and maps to give to servicemen in case they were captured. Christopher Clayton Hutton was an M-19 innovator who developed a number of such items including compasses that could be hidden in cuff links or buttons and maps printed on silk. Silk is durable, quiet when you fold and unfold it, and can be scrunched into a tiny space like the heel of a shoe without damage, according to an article on Atlas Obscura.

At the time the only manufacturer in Great Britain able to print the silk maps was John Waddington, Ltd., a maker of game boards. Waddington also just happened to be the firm licensed to manufacture Monopoly boards for the United Kingdom.

Hutton worked with Waddington to devise a version of Monopoly that contained a compass — either hidden in a game piece or embedded beneath the surface of the board itself. There was also a two-part metal file, and genuine high-denomination German, Italian, and French currency concealed between Monopoly's famous play money.

"Under the strictest of secrecy, in a securely guarded and inaccessible old workshop on the grounds of Waddington’s, a group of sworn-to-secrecy employees began mass-producing escape maps, keyed to each region of Germany or Italy where Allied POW camps were being incarcerated. When processed, these maps could be folded into such tiny dots that they would actually fit inside a Monopoly playing piece," according to a widely circulated but unattributed ac-
count posted on the fact-checking website Snopes.com. Snopes looked into the story and determined it to be true.

British and American airmen were told, before taking off on their first mission, how they could identify one of these unusual Monopoly sets. Each specially loaded board would have a tiny red dot, intentionally made to look like a printing glitch, located in the corner of the Free Parking square. A picture of one of the boards provided to ION by Hasbro shows there is also a version with a big “STOP” sign in the Free Parking box (see photo).

The boards were sent to prisoner-of-war camps under a provision of the Geneva Convention. Though some reports say they were distributed via the Red Cross a former archivist for Waddingtons told The Times of London in 2007 that the group specifically avoided that. The boards were always sent via private, often fictitious, organizations like the Licensed Victuallers Prisoner Relief Fund, they wrote, and not included in Red Cross packages so as not to create a reason to interfere with the delivery of Red Cross parcels.

The boards themselves may be quite rare. Those prisoners lucky enough to receive the games reportedly destroyed the boards after extracting their content to conceal what they were up to.

The story was declassified in 2007 though word of what went on did surface before that, according to Snopes. Once it was official the surviving craftsmen from Waddingtons’, as well as the firm itself, were honored in a public ceremony.

It is not known how many prisoners benefited from the boards and maps that Waddington produced. Civilization was not lucky enough to have Goebbels land on Jail, where his atrocities could be laid bare at the Nuremberg trials. Instead, after serving for one day as Hitler’s successor as Germany’s Chancellor, Goebbels committed suicide on 1 May 1945.

The game of Monopoly has its own legion of historians; the following sources were used in researching this article:
- *How Millions Of Secret Silk Maps Helped POWs Escape Their Captors in WWII*  
  By Cara Giaimo, Atlas Obscura, December 20, 2016
- *How Monopoly Games Helped Allied POWs Escape During World War II*,  
- *Custom Silk Maps*  
  https://burntpointlodge.com/products/silk-maps
- *Were Escape Kits Smuggled to WWII POWs in Monopoly Games?*  
- *Escape and evasion maps of World War II*  
  https://www.bl.uk/maps/articles/escape-and-evasion-maps-of-world-war-ii#

Marvin B. May is Professor Emeritus of Pennsylvania State University’s Navigation R&D Center and principle at Mayven Engineering. He may be reached at mbm16@psu.edu and mayven4@comcast.net.

All photos courtesy of Hasbro
Dr. Madeleine
Naudeau

This column features one of ION’s Technical Representatives each quarter to highlight the depth and breadth of their work, research, and interests. During their two-year terms, the ION’s Tech Representatives guide and advise the Institute of Navigation and the positioning, navigation, and timing (PNT) community. — Interview and write-up by Dr. Kyle Wesson

Dr. Madeleine Naudeau works as a Program Manager of the Space Communication & PNT Program at the Air Force Research Lab, Space Vehicles Directorate with which she has been affiliated since 2007. She currently oversees next-generation satellite navigation payload components and enjoys working at the systems and mission levels to help bring the technology developed in the labs to life in practical applications.

Last year, Madeleine led her team through the challenges that COVID-19 imposed on government workers and program managers. While they had a rough start, Madeleine says that AFRL handled the difficulties a lot better than other places, and she is very fortunate that she can go back into the office when needed.

Outside of the office, Madeleine is proud of her low-moisture garden. The secret, she tells me, is a really good drip system to supply water to carefully chosen plants. It was a hobby borne out of necessity; she realized how much of a challenge having a grass lawn was in Albuquerque, New Mexico which came with her then-newly-purchased house. So, Madeleine went instead with a drip system and plants. Her tulips were coming up the week we spoke.

Please read on to get to know Madeleine a bit better. I hope everyone continues to stay safe and healthy. – Kyle Wesson

1. How did you first get involved with ION?

I didn’t begin my career in PNT—I actually got my degree in atomic and semiconductor physics. One of the great things about my job at the Air Force Research Lab (AFRL) is the opportunity to work on a variety of very different technologies, which support many different applications. I landed in PNT in 2016 after becoming involved with the Navigation Technology Satellite-3 (NTS-3) flight experiment. Before that, I treated GPS as an invisible utility. Sure, I knew it was there, but I hadn’t stopped to think about the many different ways in which it touched my life. Despite this shocking lack of knowledge, I was asked by the program manager of the Advanced GPS Technologies program, Mr. Kevin Slimak, to lead the science aspects of his program. The first thing I did in my new role as Principal Investigator was to learn about the PNT community, which led me straight to ION.

2. What is your favorite aspect of being a member of ION?

The networking opportunities provided by ION were critical to my becoming familiar with the “who’s who” in PNT. Everyone in PNT goes to the ION conferences. I rapidly learned about the fascinating history of GPS from the key architects of the system. I even found out that someone I had known for years, who worked next door at Sandia National Lab, actually built Block I satellites!

3. What type of GNSS work do you do currently or have you done in the past?

At AFRL, Space Vehicles Directorate, we look at GPS from an architecture perspective, with heavy emphasis on the space segment. We develop technologies for the next generation of GPS satellites. One of our research efforts led to the development of Chimera, which was designed to be a modification to existing GPS signals, in particular the new L1C signal. With the Chimera modification providing authentication features in both the navigation message and the ranging code, users would have confidence they are tracking an actual GPS satellite. It would be extremely satisfying to see the team’s signal being broadcast from GPS, but that policy decision is way above our level.
4. What do you consider to be some of the most important current research, education, policy, or technical topics in GNSS for the next year?

Given the threat spoofing presents in safety of life situations, we are closely watching the growing national interest in incorporating a means of signal authentication on GPS.

5. What areas of ION have you been involved in, and what areas do you hope to see grow in the future?

The webinars have become a fixture in our team meetings. Whenever a new webinar comes out, someone is assigned to watch and report back a “5-min update” on what they learned. It gives the team the opportunity to broaden their knowledge of PNT beyond their current research area. Sometimes we get too focused on GPS, and it’s good to be reminded of alternatives and complementary technologies.

6. If you were not in your current field, what would you want to do for a living?

I grew up in Texas and went to graduate school in what I considered to be the cold north, in Ann Arbor, Michigan. After several years of snow filled winters, I was very keen to move south, so when the opportunity came up to move to Albuquerque, I jumped. The desert brownness took some getting used to, but nothing beats the open vistas and sun-filled days. I quickly gave up on a grass lawn and began to research low-moisture gardening. My garden is where I spend my free hours.

Galileo Satellite Maneuvered out of Harm’s Way

The European GNSS Agency (GSA) was able to prevent an on-orbit collision between Galileo satellite GSAT0219 and an old upper stage from an Ariane 4 rocket by moving the satellite temporarily to a safer orbit.

EU Space Surveillance and Tracking (EUSST) warned the Galileo Service Operator (GSOp) on February 25 that there was a risk of the upper stage hitting the satellite. Refined predictions confirmed the risk of collision was high so, in a first for the Galileo system, the GSA decided to maneuver the satellite out of the way.

“The satellite was taken out of service on 5 March, and users were informed via NAGU #2021009,” GSA said in a story on its website, and the satellite was shifted to a temporary orbit. It was expected to be back in service a few weeks later.

There are more than 500,000 pieces of debris being tracked as they orbit the Earth, NASA said in a 2013 posting. Though many are far smaller than an upper stage they are all traveling at speeds up to 17,500 mph, which is “fast enough for a relatively small piece of orbital debris to damage a satellite or a spacecraft.” Collision between larger objects poses the additional risk of creating even more bits of high velocity “space junk.”

RESCHEDULED TO APRIL 11-14, 2022

PACIFIC PNT

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Defence Matters

A Salute to the DoD PNT Policy Lead

Raymond (Ray) J. Swider Jr. Retires

On March 31, 2021, Raymond (Ray) J. Swider Jr., the lead for Positioning, Navigation and Timing (PNT) policy in the office of the Department of Defense’s Chief Information Officer, retired following decades of federal government service, of which the last 21 years were in the Office of the Secretary of Defense (OSD) advancing the Global Positioning System (GPS) for the DoD as well as the military’s diverse, overall PNT Enterprise.

Under the heading of Defense Matters, I find it altogether fitting and proper to dedicate this article to Ray in recognition of his decades of unparalleled contributions to the PNT needs of the warfighter.

Beginning with his entry into the U.S. Air Force Academy in June of 1969, Ray gave nearly 52 years of unbroken federal service to our nation. He began his career as an Air Force pilot, became a program lead for the Local Area Augmentation System (LAAS) program within the Federal Aviation Administration and joined the OSD in February of 2000.

Ray’s initial assignment in OSD was as the principal staff assistant for PNT Policy, working for the Assistant Secretary of Defense (ASD) for Command, Control, Communications & Intelligence (ASD(C3I)). It was during this period that decisions were being finalized for the ending of GPS Selective Availability, a highly politicized feature of the system, which required coordination between the Pentagon and the Executive Office of the President.

Following a Pentagon reorganization in 2003, the portfolio of the ASD(C3I) was reconstituted under the ASD for Networks & Information Integration (ASD(NII)). Subsequent reshuffling of duties had PNT policy transferred to the DoD Chief Information Officer (DoD CIO), after the position of ASD(NII) was eliminated by Secretary of Defense Robert Gates.

Throughout these high-level office moves, synchronizing PNT policy with oversight of the acquisition the PNT capabilities provided to the warfighter was a fundamental aspect of Ray’s ever-growing list of responsibilities. He ensured the transitions were managed seamlessly.

Ray’s portfolio of policy issues also included high-profile initiatives to protect GPS spectrum, from the ultra-wideband incursion issues in the early 2000s to the ongoing Lightsquared/Ligado issue.

Spectrum issues were a significant consideration in GPS modernization decisions being made at this time. They were also an important factor as other space-based PNT services (Global Navigation Satellite Systems or GNSS) emerged to compete with GPS. The primary interest of DoD then and now was in preserving viability of GPS military capabilities.

Ray was recognized by the State Department as the principal representative from OSD for the U.S. delegation, leading the GPS-Galileo negotiating team that successfully concluded the 2004 Executive Agreement between the U.S. and the European Union (EU). That agreement was then signed by Secretary of State Colin Powell.

It was a complex undertaking to balance the dual-use nature of the GPS service against the introduction of Galileo with its multiple services. Galileo was being pursued as a non-military PNT source, seeking to utilize spectrum identified for the then
future GPS M-code. As the principal OSD member, who was engaged for the entire period, Ray brought to the U.S. side of the table his undaunting commitment to protecting military grade GPS for the warfighter.

The 2004 Agreement, much to Ray’s credit, established the precedent for compatibility criteria between GPS and other GNSS which has stood the test of time as many new GNSS have come online since.

Ray’s direct contributions to the military utility of GPS for the warfighter are also found in his early role as a member of the U.S. delegation to NATO’s Subcommittee 8.

In 2004 Ray was elected by the NATO subcommittee members to serve as its chair. He remained chair when the subcommittee was succeeded by NATO Capability Panel 2 (Navigation and Combat Identification) and served until his final meeting in March 2021.

As chair he oversaw the development of the NATO Standardization Agreement (STANAG) addressing Navigation Warfare, the establishment of the NATO Navigation Warfare Working Group and ongoing work addressing the Galileo Public Regulated Service (PRS).

Ray was also designated as the Federal Officer for the Defense Science Board Task Force on the Future of GPS, chaired by the Honorable James Schlesinger. Ray oversaw production of a watershed report by the Task Force which not only charted the future for the modernization of GPS but also for the evolution of the PNT Enterprise for which GPS was and is the cornerstone.

As a direct result of this report, the DoD engaged with the Department of Transportation to conduct a National PNT Architecture effort from 2005 to 2011, involving over 30 military and civilian agencies and organizations.

Ray served as the DoD co-chair of the interagency effort, which produced both an Architecture and an Implementation Plan that has carried forward until today as an integral part of the biannual Federal Radionavigation Plan.

Ray was also designated as the project manager for what were called the Atlas and Herakles studies, addressing GPS
management reform. Both studies were commissioned by Deputy Secretary of Defense Paul Wolfowitz. These two studies reaffirmed the precedents for the dual-use value of GPS for both military and civilian applications alike. They also provided the framework through which the leaders of DoD and civilian agencies could consider management and financing alternatives to sustain and improve the operation of GPS.

With respect to his oversight responsibilities for GPS policy and delivery of GPS capabilities to the warfighters, Ray was instrumental in focusing leadership attention on the development of a family of formal compliance documents under DoD Directive 4650.05 that defined the overarching policy and organizational responsibilities for the DoD PNT Enterprise, NAVWAR, PNT security, and the operational procedures of the Congressionally mandated PNT Oversight Council. They provide the policy framework for ensuring that the DoD PNT Enterprise meets warfighters’ needs and keeps pace with the ever-increasing threat to maintaining a PNT advantage over U.S. adversaries.

Ray was also the driving force behind the development of a formal strategy for the DoD PNT Enterprise, signed by the DoD CIO in November 2018, and published as a public-release document in September 2019. This important document presents the strategy for the DoD to provide and assure a PNT Enterprise to the U.S. military and its allies (the Joint Force) and enable the execution of NAVWAR operations to maintain a PNT military advantage in support of national security and strategic military objectives.

A principal feature of the new strategy is its emphasis on use of groundbreaking integration techniques for open-system applications of PNT capability options which will dramatically increase the agility and flexibility of future resilient PNT applications in defeating evolving threats. This strategy shows great promise in savings of future defense expenditures and years of delay previously anticipated for integration of new PNT options into DoD weapon systems across all warfighting domains.

Ray never forgot his aviation roots and was a consistent champion in advocating for DoD’s National Air Space (NAS) needs through the Policy Board on Federal Aviation (PBFA). His relentless pressure in holding the Federal Aviation Administration accountable to their federal responsibilities strongly influenced PBFA leadership to establish a stronger stance in asserting DoD’s “Mission First” culture in dealing with the topic of GPS equipage and self-certification of military GPS user equipment for operations in the NAS.

To Ray on behalf of all the warfighters who have benefited from your commitment to duty: Thank you for your leadership and dedication to GPS and the PNT Enterprise. You will be missed.

Contributing to this “Salute to Ray” was Jules McNeff, Vice President of Programs and Strategy, Overlook Systems Technologies, Inc.
ION Partners with the Engineering Research Visioning Alliance (ERVA)

Established via a cooperative agreement with the National Science Foundation, ION has become a member of the Engineering Research Visioning Alliance (ERVA). ERVA was officially launched on April 7, 2021. The first engineering research visioning alliance of its kind, ERVA is a diverse, inclusive and engaged partnership that enables an array of voices to impact national research priorities. ERVA will help the U.S. remain an international leader by identifying and developing new, high-impact engineering research directions to help the engineering community solve major challenges and improve daily life. To learn more about ERVA and get involved, visit www.ERVACommunity.org and follow @ERVACommunity on Twitter, LinkedIn and Facebook.

James D. (Jim) Litton, a pioneer of GPS, passed away the end of January, 2021, at 89. Jim helped develop the earliest GPS receivers at Magnavox. Under Litton’s tutelage, when the first GPS satellites were launched, his division developed early and pioneering GPS navigators and survey sets which were standards for the industry and incorporated many of the early rapid advances in GPS signal processing technology. He co-founded NavCom (now part of John Deere) in 1995. Under his direction as NavCom’s CEO, NavCom became a technical leader and rapidly growing commercial enterprise in GPS and wireless communications technologies. Most recently, Jim was CEO of the Litton Consulting Group, Inc. (LCG), consulting in the general areas of precise positioning systems, machine control and sensor system development. He was awarded the ION’s Hays Award (2006) in recognition of his pioneering leadership contributing to significant advances in design and performance of satellite navigation and surveying instruments.

Navigation 2021
European Navigation Conference & International Navigation Conference

15-18 November 2021

Register your interest at rin.org.uk/Navigation2021
EDL is the famous “seven minutes of terror” that starts when the spacecraft enters the atmosphere and hurtles toward the surface behind its protective heat shield until the parachute opens. EDL continues as the spacecraft descends more slowly, its cameras and automatic navigation system working quickly to find — and maneuver it to — a safe landing place. There it touches down with the assistance of the retro rockets on the sky crane.

The EDL team gives the EDL plan to the navigators, who work backwards from the atmospheric entry point to the launch pad on Earth.

“We look in the back of the book at the answer,” said Kruizinga, then figure out how to make it work.

**Challenges**

The task, he said, is to navigate the spacecraft over 470 million kilometers to where it can slip into the open end of an imaginary garden hose that’s 10 km wide and 700 km long and runs from the edge of the Martian atmosphere to the surface.

“What the EDL folks want us to do,” Kruizinga said, “is actually fly into that tube, if you want, without actually hitting the walls.” It’s the equivalent, he said, of hitting a golf ball from New York to Perth, Australia and scoring a hole in one in a 10 cm cup.

To achieve this, he said, they had to determine the position and the velocity to an accuracy of 2.8 kilometers and 2.0 meters per second. Moreover, in the case of Mars, there’s no rolling across the green to the cup. The angle at which the spacecraft arrives matters as much as its on-target accuracy.

“If you come in too steep,” said Kruizinga, “you burn up. If you come in too shallow, you actually bounce off. So there’s a -15.5 degree angle requirement.” But, he added, we have to hit that with the uncertainty of 0.2 degrees (3σ) — then crosstrack basically in a direction perpendicular to the entry velocity. We have to be within 5 km (3σ).

As if that was not challenging enough the timing has to be right because there is only one opportunity to land every sol — that is every Martian day. Another thing: mission navigators are not allowed to aim the spacecraft for Mars at the start of the mission. They must set a course to miss the Red Planet entirely and then correct it when the spacecraft gets closer. There is a concern about hitting the planet with the upper stage of the rocket or the Perseverance spacecraft itself, should it suffer a technical failure.

“You would think, well, you go straight to Mars; we’re not allowed to,” Kruizinga said. “And the reason is the upper stage of the launch vehicle; once it actually stops the engine, it will just fly basically with the rover to Mars as well. And we don’t want that to impact because it hasn’t been cleaned for planetary protection reasons.” So the requirement is that the probability of hitting Mars with the upper stage be less than a hundredth of a percent for at least 50 years.

Fortunately the team had six opportunities to make those course adjustments. There was, however, yet another limitation, said Kruizinga. “You can only bring so much gas.” They had just 45 kilograms
of propellant available, he said, to make the maneuvers necessary to get to the opening of the imaginary EDL tube “or basically our delivery target.”

Communications and More

To deliver the corrective flight instructions JPL used the Deep Space Network (DSN), an array of three complexes, each approximately 120 degrees in longitude from each other, with 34-meter and 70-meter radio antennas. The antennas are located at Goldstone, near Barstow, California; near Madrid, Spain; and near Canberra, Australia. The strategic placement of the sites permits constant communication with spacecraft as Earth rotates, NASA said. “Before a distant spacecraft sinks below the horizon at one DSN site, another site can pick up the signal and carry on communicating.”

The DSN also provided the team with the ranging and Doppler data it needed to both model and adjust the spacecraft’s trajectory. “These measurements only observe the line-of-sight components of the spacecraft position and velocity,” Kruizinga told the ION Newsletter.

NASA uses Doppler (frequency) data from a station to the spacecraft instead of phase like GPS. The diurnal signature of the Earth provides additional state information when in the proximity of the Earth. Calibrations are needed, he said for the Earth’s troposphere and ionosphere and modeling is needed of the Earth orientation parameters and ephemerides. The team also takes into account the Earth’s rotation around the Sun and other factors like forces on the spacecraft.

“To give you an idea of our accuracy,” he said, “We’re using actually 0.1 millimeters/second (1σ) data weights for our Doppler data. For ranges the data weight is 3.0 m(1σ).”

While measuring the range and the Doppler gives you very accurate information and the direction to Earth it leaves an area of uncertainty about the spacecraft’s position that is very small in the direction of the line of sight to Earth, but quite large perpendicular to that. It is basically in the declination and the right ascension direction of that position.

To solve this problem, he said, the navigators used a form of Very Long Baseline Interferometry.

“What it basically tells us,” Kruizinga said, is the angular distance in the direction of the baseline — where it is in the sky and how much you are off. “This measurement tells us where we are in the declination and the right ascension.”

The Mars 2020 ΔDOR data weight = 60 psec or ~2.4 nrad (1σ), Kruizinga said in his charts. At Mars distance the ΔDOR data weight translates to about 500 m.

“This actually turns out to be the enabling measurement that allows us to

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do this landing that accurately,” Kruizinga said. Without ΔDOR “you could not decide early enough if you were on the right track or not. Eventually you will, but by that time, it’s too late.”

The technique uses quasars, he said, because quasars are so far from Earth — billions of light years — that to all intents and purposes, they’re fixed points in the sky. Quasars are “basically the foundation of our coordinate frame,” he said.

The mission did run into a problem when the DSN station at Madrid had snow and was unable to move its antenna for five days. To try to correct the problem they switched from using one quasar to another.

**Mars Storms**

One of the things that Mars mission planners are interested in avoiding is the Red Planet’s storm season, said Dr. Gerhard Kruizinga, the Chief of the Navigation Team at NASA’s Jet Propulsion Laboratory. “There are periods when there’re big storms and we’d rather not land in big storms because there’s much more density variation and that makes entry guidance a lot more challenging.”

**Finding Mars**

One of the challenges with any Mars mission, said Kruizinga, is that no one knows precisely where the Red Planet is. “For an observer on Earth, you know exactly where Mars is all the time. But at tens of meters, you don’t know exactly where it is, he said.

There is enough mass in the asteroids between Mars and Jupiter that it can perturb the Martian orbit, Kruizinga explained. “And the problem with the asteroid mass is it’s not evenly distributed. It changes all the time as (to) where they are. So you get kind of like a body with mass varying properties. And those are not very well known. And it depends how many you take into account and how much you don’t. And that’s why there’s still some uncertainty left in the Mars ephemeris, which is at the level of 100 meters or so.”

Because there is nothing directly sensing the Red Planet, navigation to Mars relies on looking back at the Earth. “We’re basically navigating through the rearview mirror continuously,” Kruizinga said.

“We kind of sense Mars at the very end,” he told the audience. “About 20 hours before we land, the Mars gravity well just starts curving the trajectory. But by that time, if you need to do something about it in terms of you’re not on the right course; it’s most probably too late. A GPS-like system for Mars would help for future missions, he said in response to a question.

“Once you get below the altitude of the GPS satellites right — or I guess MPS satellites — then you would actually get relative position to the planet. That’s basically what we’re lacking for most of our flight,” he said. “It’s that we have no idea...”

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**Corporate Profile**

Braxton Science and Technology Group  
www.parsons.com/capabilities/space/

Braxton Science and Technology Group (BSTG) joined Parsons Corporation (NYSE: PSN) in 2020, providing end-to-end customized mission solutions to meet customer needs in the rapidly evolving space domain. The company has proven expertise in Position, Navigation and Timing (PNT) capabilities, assisting essential programs with software defined GNSS signals research, demonstrating agile PNT experimental operations and supporting GPS satellites since 2007. Parsons Corporation is a leading disruptive technology provider for the future of global defense, intelligence and critical infrastructure with capabilities across cybersecurity, missile defense, space, connected infrastructure and smart cities. To learn more about Parsons’ leading space capabilities, please visit: https://www.parsons.com/capabilities/space/

For more information on corporate membership in the Institute of Navigation, please contact Kenneth P. Esthus at 703-366-2723 extension 1004

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**Calendar of Upcoming Events**

**AUGUST 2021**

**24-27:** ION Joint Navigation Conference (JNC) 2021, Northern Kentucky Convention Center, Greater Cincinnati, Ohio and AFIIT, WPAFB, Dayton, Ohio  
Contact: ION  
Web: ion.org

**SEPTEMBER 2021**

**20-24:** ION GNSS+ 2021, St. Louis Union Station Hotel, St. Louis, Missouri  
Contact: ION  
Web: ion.org

**NOVEMBER 2021**

**15-18:** NAVIGATION 2021, International Navigation Conference (INC) and the European Navigation Conference (ENC), Edinburgh, Scotland  
Contact: RIN  
Web: www.rin.org.uk

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really where Mars is until the very end. So it would definitely improve things a lot.”

**Results**

Though there were difficulties — including the snow in Madrid and a period without two-way Doppler because a cooling pump that thought it had a problem triggered several hours of safe-mode operations — the most challenging part of the mission, Kruizinga said, was conveying confidence in the navigation solutions.

It’s understandable if officials are nervous, Kruizinga said, keep in mind that each maneuver is a $2.5 billion decision. “If you don’t do it right, it goes wrong, so people are really worried.”

And then there is the track record. Out of all the missions sent to Mars by all the Earth’s space agencies, only about 40 percent were successful, according to NASA.

“I would talk to the lab director sometimes and make sure that he’s not worried that something is wrong, you know — and convey to him that we are confident (in) what we did. That definitely was a challenge,” Kruizinga said.

The navigation team would have long sessions with a “gray beard” group — a panel of other expert navigators who were not involved in the mission.

“They review our work,” said Kruizinga, “and you get really critical questions.”

Getting through that process, he said, “and kind of convincing them that, ’No. Things are all right.’ That’s a challenge — to really make people feel good.”

The navigation results during the Perseverance mission should help build their confidence.

Though the mission planners allowed for six Trajectory Correction Maneuvers (TCMs) to redirect the spacecraft toward the planet and then fine tune its approach the navigation team only needed three. Perseverance was so tightly on target that the final TCMs were waived.

“If you have a 2.8 kilometers (requirement),” said Kruizinga, “and we’re only 140 meters off. That’s pretty darn good.”

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**JANUARY 2022**

**24-27:** ION International Technical Meeting (ITM) & ION Precise Time and Time Interval (PTTI) Meeting 2022, Hyatt Regency Long Beach, Long Beach, California  
Contact: ION  
Web: ion.org

**APRIL 2022**

**11-14:** ION Pacific PNT 2022, Hilton Waikiki Beach Hotel, Honolulu, Hawaii  
Contact: ION  
Web: ion.org

**JUNE 2022**

**6-9:** ION Joint Navigation Conference (JNC) 2022, Town and Country Hotel, San Diego, California  
Contact: ION  
Web: ion.org

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Innovation for Time’s Sake

The United Kingdom’s National Timing Centre (NTC) is working with Innovate UK to help develop new technologies and approaches supporting the dissemination and application of resilient time, frequency and synchronization.

The NTC, which has a total of £6.7 million to support the effort, is particularly interested in projects that include one or more industry sectors or involve cross-sector technologies such as those contributing to telecommunication technologies or timing over digital networks. NTC hopes to engage, but is not limited to, working with sectors like telecommunications, energy, autonomy, finance, smart factories, sensors, the Internet of Things (IoT), broadcast, health, space, and transport including rail, road, aviation, and maritime.

The first stage of the program involves funding feasibility studies lasting from four to six months with per-study costs of between £50,000 and £250,000. The total budget for this phase is £2 million.

NTC then has up to £4.7 million to spend on the second stage where participants may get the opportunity to demonstrate their technology.

The competition is open to UK organizations, working either alone or cooperatively, and applications are due no later than June 9.

Beidou Under China’s Five-Year Plan

China, which has been heavily promoting the use of its Beidou Satellite Navigation System, announced it would continue that effort under the country’s newly approved five-year plan.

The nation will also “push the high-quality development of related industries,” the Xinhua news network said, citing a draft outline of what is the 14th in China’s long running series of five-year plans.

China.org.cn said in a press release that, under the new plan, China would also seek to “accelerate the establishment of a new development pattern of “dual circulation,” where domestic and foreign markets can boost each other, with the domestic market as the mainstay.”

China’s five-year plans “serve as manifestos that guide the direction of investment and indicate research ambitions,” Nature said in a March 11 article on their website. Among the key themes of the new plan, which covers the period 2021-2025, is a shift toward self-sufficiency fueled in part by strained relations with the U.S.

“The US–China conflict was a wake-up call for China,” Mu-Ming Poo, a neuroscientist and scientific director of the Chinese Academy of Sciences’ Institute of Neuroscience in Shanghai told Nature.

For example, American concerns over the potential to use advanced microchips for military applications led to a decision last year to restrict the export to China of chips used in smartphones.

This “revealed a major bottleneck in the application of home-grown advances in basic research to fulfill China’s technological needs,” said Poo.

Your Map On Your Sleeve

Nature also recently reported on a stunning development by Chinese scientists that could literally let you wear your map on your sleeve or use your jacket to check your phone.

Chinese researchers have developed a cotton fabric laced with conductive and luminescent fibers that has the potential, the researchers said, “to change the way in which we interact with electronic devices.”

An abstract of the Nature article described a 6-meter-long, 25-centimeter-wide display textile containing 5×105 electroluminescent units spaced approximately 800 micrometers apart.

“The fabric is flexible and breathable and withstands repeated machine-washing,” they said and the electroluminescent remains stable even when the textile is bent, stretched or pressed.

“The researchers,” innovationintextiles.com reported, “incorporated a touch-sensitive 16-button fabric keyboard, solar-energy-harvesting threads and battery fibers into their textile to add interactivity and power supply. They added electronics to wirelessly link it to a smartphone via a Bluetooth connection so users could send and receive messages on their sleeves, as well as see real-time locations on a map.”

EU Seeking Asia-Facing Entrepreneurs

It will be interesting to see how China’s objectives mesh with efforts underway in the European Union to develop new opportunities for EU GNSS products in Asia.

European GNSS Agency (GSA) just closed the application period for GNSS.asia, a Horizon-2020 project designed to support EU start-up firms with satellite navigation products they hope to market in China, India, Taiwan, South Korea, Japan and Australasia.

Participating companies will get workshops and training designed to give them insights into these markets, help them build up their networks and understand the way business is done in the region.
Tensions Rise Over the Impact of Military GPS Anti-Jamming Tests on Aviation

American pilots are increasingly concerned about the GPS interference they are encountering due to research-focused jamming by “friendly forces.” That is the U.S. military is creating problems for aircraft by intentionally jamming its own GPS signals in spots across the United States to test out technologies developed to thwart jamming.

One passenger aircraft in Idaho suffered just such interference while flying through dangerous, smoky skies.

“It was saved from crashing into a mountain only by the last-minute intervention of an air traffic controller,” the IEEE Spectrum reported.

New data shows, IEEE wrote that “in all likelihood, there are many hundreds, possibly thousands, of such incidents each year nationwide, each one a potential accident.”

In one case, an airliner — flying without GPS positioning because of disruptions out of the U.S. Army’s White Sands Missile Range — missed its initial landing approach due to high winds. It had to make another attempt to land relying only on visual aids in predawn darkness in an area surrounded by rising terrain.

The National Business Aviation Association (NBAA) and the Aircraft Owners and Pilots Association (AOPA), expressed alarm about the dangers of intentional GPS disruption in a February letter to the Federal Aviation Administration (FAA) and Department of Defense (DoD).

They noted in the letter that “both the frequency and impacts of these events have continued to grow significantly over the past decade and will continue to proliferate over time according to both the FAA and DoD.”

They also noted that neither the FAA nor the DoD had responded to a list of proposed mitigations.

“It is vital that pilots have continuity and access to optimal navigational and safety tools, of which GPS is vital,” said Jim Coon, AOPA senior vice president of government affairs and advocacy in a March 5 press release. “We strongly support our warfighters, but we believe DoD and FAA should review their GPS testing processes so that our nation’s airspace continues to be as safe as possible.”