MMS MISSION A SUCCESS

NASA Mission Sets Speed, Altitude Records for GPS Navigation

A NASA mission to monitor the Earth’s magnetosphere has set new records for the highest altitude and velocity for GPS navigation.

The Magnetospheric Multiscale (MMS) mission launched earlier this year sent four identically equipped spacecraft — each the size of a baseball stadium when its eight instrument booms are deployed — flying in formation in a highly elliptical orbit. Led by NASA’s Goddard Space Flight Center in Greenbelt, Maryland, the mission is studying a poorly understood phenomenon called magnetic reconnection, which occurs when magnetic fields from the sun connect and disconnect with magnetic fields of Earth. Magnetic reconnection underlies space weather

MMS MISSION continued on page 16

How Navigation Technology Is Helping Locate a Lost Airliner

How do you find an aircraft when its navigation and position reporting function are disabled?

That is the challenge facing investigators trying to determine the still-mysterious fate of Malaysian Airlines Flight 370 (MH370), which disappeared on March 7, 2014, with 239 passengers and crew en route from Kuala Lumpur to Beijing.

Their methods have included turning digital communications data into sophisticated positioning techniques, customized ocean current drift models using — among other resources — GPS-positioned self-locating datum marker buoys, and even tracing the habitat of barnacle species.

Discovery of a part of a Boeing 777’s wing — a relatively intact component known as a “flaperon” — on a remote Indian Ocean island on July 29, about 3,700 kilometers (2,300 miles) from the plane’s last calculated location has renewed interest in the tools and techniques used to try and find MH370. The flaperon found on a beach near Saint-An-dre, a town on the northeast side of the French overseas territory of La Réunion, has been determined to almost certainly have come from the Malaysian airliner, as

MH370 continued on page 10
I am pleased to report that the ION Executive Committee has accepted a recommendation made by the ION’s Government Fellows Committee, chaired by Dr. Clark Cohen, and has appointed Dr. Gerald L. Mader as the 2015-2016 ION Congressional Fellow. The ION Congressional Fellowship is sponsored through the American Association for the Advancement of Science (AAAS) Science and Engineering Fellowship Programs.

A Congressional Fellow serves as a Science and Technology staffer for a Member of Congress, or a Congressional Committee, making practical contributions to the more effective use of scientific and technical knowledge in government. The Congressional Fellow works to educate the navigation and engineering community regarding the public policy process, and to broaden the perspective of the science, engineering, and governmental communities regarding the value of such interaction.

Dr. Mader received his Ph.D. from the University of Maryland, and has worked at the National Geodetic Survey/NOAA, as the Chief of Geosciences Research Division for 34 years, with a primary focus on developing extremely accurate positioning techniques using GPS for a wide variety of geodetic, geophysical, and remote sensing applications.

He has been an ION member for 20 years and will be an excellent technical resource on the Hill. You can look forward to receiving updates from Dr. Mader on his appointment and activities in future issues of this newsletter. Congratulations Gerry!

Military Division Activities
My most sincere congratulations go to the ION’s Military Division, its leaders, and government liaisons on a successful Joint Navigation Conference (JNC) this past June. The JNC took place June 22–25, 2015, in Orlando, Florida, and more than 490 DOD personnel and related contractors attended the event. This represents over a 20% increase over last year’s attendance.

Award Nomination Reminder
As president, and a long-time ION member, I regularly witness how the Institute benefits from the talents and dedication of many ION members. Please take time this fall to acknowledge the contributions of your professional associates and nominate them for an ION award that recognizes individuals making significant contributions or demonstrating outstanding performance relating to the art and science of positioning, navigation, and timing.

Please submit your nominations for ION’s Fellows and Annual Awards at www.ion.org/awards by October 15.

Meeting News
The ION is now accepting abstracts for the ION’s co-located International Technical Meeting (ITM) and Precise Time and Timing Interval (PTTI) meetings, being held January 25–28, 2016, in Monterey, California. In order to increase the quality of technical program, manuscripts presented at the meeting, if received in proper form and on time, will be peer reviewed. See www.ion.org/itm and www.ion.org/ptti for a list of technical sessions and abstract submission instructions.

The ION’s Annual Awards will also be presented during this event, and the 2016 ION Fellows will be named.

Enjoy the rest of your summer, and see you all in September at ION GNSS+ 2015!

Mobile Access Upgrade
The ION National Office recently completed an upgrade to the ION website, making it mobile device responsive. Check it out at www.ion.org

I also invite you to follow us on Facebook and Twitter at @ionavigation.

FROM THE ION PRESIDENT, DR. DOROTA GREJNER-BRZEZINSKA

Congressional Fellowship

Gerry Mader has been an ION member for 20 years and will be an excellent technical resource on the Hill.
In late June, I had the honor and privilege of attending and participating in The Institute of Navigation’s Joint Navigation Conference (ION-JNC) in Orlando, Florida. This year attendance was up by 20 percent. The entire event was FOUO (For Official Use Only) with a classified (SECRET) day on Thursday held at — as improbable as it seems — a joint military and Walt Disney location known as Shades of Green. It gives Mickey Mouse and the military a whole new meaning!

The classified day included a remarkable War Fighter Panel, which, full disclosure, I have had the honor along with my colleague Jim Doherty at IDA (Institute For Defense Analyses) of co-chairing for the last several years. It is always heart-warming and invariably enlightening to hear our warfighters discuss capabilities that GPS enables for them in times of peace and war. You could even say this was the theme of the conference: “The capabilities that GPS technology enables.”

You might assume an FOUO- and SECRET-level conference would be slim pickings for a journalist. If that is all that transpired, then you would be correct; however, all the conversations outside the official sessions, especially around the displays and exhibitors’ booths, make it more than worthwhile. Not to mention all the tidbits you pick up at breakfast, lunch, dinner and evening socials. One of the most common phrases I heard all week was, “Now don’t quote me on this, but…” or the one I like to hear, “OK, this is on the record” or “You are recording this, right?” Everyone has a message!

ION-JNC in Dayton, Ohio
For the next two years (2016-17) ION-JNC will be held in beautiful downtown Dayton, Ohio, at the Dayton Convention Center. Dayton is home to the famous Wright Brothers Cycle Shop and the Wright Flyer.

Dayton also hosts the world-famous National Museum of the USAF (United States Air Force) located on Wright-Patterson Air Force Base (WPAFB). The classified day will be held at the prestigious USAF Institute of Technology (AFIT), also on WPAFB, where many an Air Force officer has earned a master’s and or Ph.D. The papers and sessions should be outstanding in view of the venue and the presence of the Air Force Research Laboratory (AFRL) at WPAFB, which is known as the Air Force’s only organization wholly dedicated to leading the discovery, development and integration of warfighting technologies for air, space and cyberspace forces.

Register early and send your clearance if you have one; it just gets better every year.

Launchers
I arrived in Orlando on Sunday, June 21 (yes, I traveled on Father’s Day) because events start bright and early Monday morning, to hear about the Falcon 9 launch failure, the first for that family of launchers. Even though it occurred 130+ seconds into the launch segment, if the rocket fails to deliver the payload or supplies to orbit or their destination, it is generally referred to as a launch failure.

ION-JNC 2015 continued on page 4
Technicians and subject-matter experts will be debating for some time exactly what caused the failure, but there can be no doubt this is a big blow to the Space Exploration Technology Corporation — better known as SpaceX.

(Editor’s note: SpaceX’s Falcon 9 was recently approved by the U.S. Air Force for bidding on launch contracts for defense satellites, including the next phase of the GPS III program. That would re-introduce competition into the heavy-lift military launch business, which currently relies on the United Launch Alliance joint venture of Lockheed Martin and The Boeing Company.)

I have known Elon Musk and experienced his outsize ego casually for more than 20 years, and I am constantly amazed at his accomplishments and would never bet against him. I do not mean the ego remark in a negative way, because history proves that if Elon says he will accomplish the seemingly impossible, then he will do just that. Can you say Tesla Motors? Setbacks just make him and his team more determined.

“It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow.” — Dr. Robert Goddard.

However, launch setbacks are played out on a national stage where lives may well be at stake. SpaceX President and COO (Chief Operating Officer) Gwynne Shotwell, the brains of the outfit, said following the launch failure, “I’m sure we will find the cause rapidly and resume normal launch operations within a year.”

Reportedly, SpaceX is already a bit tardy in scheduled launches with an enviable backlog totaling approximately $7 billion, many of which are government payloads. In the end, this merely highlights that the launch business is a tough nut to crack, and attention to detail is paramount. Every little detail must be scrutinized numerous times.

SpaceX vaulted from an upstart small...
company with a few employees to a certified government space launch contractor with more than $7 billion in contracts and 3,000+ personnel on the payroll in only 13 years. SpaceX previously successfully launched two cargo resupply missions to the space station. To date, it is the only predominantly commercial space company to accomplish that task.

Therefore, I am sanguine without a doubt (now I sound like Elon) that SpaceX will quickly discover the malfunction that caused the launch failure and correct it immediately. This is not to say that anyone at SpaceX has been intentionally careless, but the successful space launch business today is by necessity an OCD (obsessive compulsive disorder) culture of attention to detail where items are checked not once or twice but 20 times to make sure nothing has been overlooked or assumed.

However, for SpaceX the critical task, for the success of the company and future astronauts’ lives, depends on SpaceX’s assurance there will be no more failures for any reason. The U.S. military has proven for the last 16 years — 16 years without a single national security space launch failure — that it is an achievable goal.

Lest we forget, behind all the technological arguments and/or failures is the crux of the matter, which is nothing less than assured access to space and all that capability enables, which of course includes GPS. In 2006, General (USAF Retired) Thomas S. Moorman Jr., former AFSPC commander and VCSAF, wrote in the highly esteemed AFSPC publication High Frontier regarding a Senior Leader’s Perspective on Assured Access to Space. He stated clearly that “Assured access [to space] is a requirement for critical national security, homeland security and civil missions, and is defined as a sufficiently robust, responsive and resilient capability to allow continued space operations, consistent with risk management and affordability.”

Competition may well be viewed as a “good thing” in the space launch business. However, it is always trumped by assured access to space, which is a critical
national security requirement. Competition and national security needs must be balanced with the emphasis on what is gained by assured access to the high ground of space. Elon Musk, Gwynne Shotwell and the SpaceX team may well be capable of showing the rest of us “how it is done,” but first they must demonstrate unerring dependability, reliability and resiliency. I wish SpaceX the best of luck and every success.

People on the Move
In the past several months, several Air Force leaders considered key to the GPS program have retired, been promoted or left government service for personal reasons.

USAF General Ellen Pawlikowski is only the third female four-star general in USAF history, and she recently left SMC (Space and Missile Systems Center) for a job at the Pentagon, where she worked space and GPS acquisition and policy issues. From there she was promoted to four stars and now sits as just the ninth commander of Air Force Materiel Command. Gen. Pawlikowski was replaced at SMC by Lt. Gen. Samuel Greaves (USAF).

Brigadier General William Cooley (USAF) recently pinned on his first star while serving as the director of the GPS Directorate at SMC. He was recently selected for reassignment as program executive, Programs and Integration, Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, Missile Defense Agency (MDA), Redstone Arsenal, Alabama—an organization where Lt. Gen. Sam Greaves once served as the deputy commander. Can you say career broadening? Brig. Gen. “Wild Bill” Cooley is being replaced by USAF Colonel Steve Whitney, who has distinguished himself with yeoman service at the directorate as the GPS Military User Equipment (MUE) guru.

David W. Madden serves as a member of the Defense Intelligence Senior Executive Service and functions as the executive director, Space and Missile Systems Center, Air Force Space Command, Los Angeles Air Force Base, California. He is the senior civilian executive and the deputy program executive officer for Space. His responsibilities include managing the research, design, development, acquisition and sustainment of satellites and the associated ground command and control systems and user terminals.

In his military career, Dave served as the GPS Wing Commander at SMC. For personal and professional reasons, Dave has decided to leave government service soon, and my sources tell me he will take up a position in Denver, Colorado. Unfortunately, I am not currently at liberty to say where. I have been told the name of Dave’s replacement, but it was in an FOOU session and therefore not currently releasable. Suffice it to say, the individual is eminently qualified.

Each of the individuals mentioned has a very strong personality and a certain way of doing business. I have known them all for years and can honestly say their personalities and personal leadership styles dominated their successful careers to date. Frankly, I don’t see that changing. So, when you hear that military personnel are interchangeable and personalities don’t matter, as I unfortunately heard a very senior official say publicly recently. Please take that with a huge grain of salt and skepticism. People, personalities and leadership styles do matter, especially outside-the-box thinkers and leaders. Let’s wish everyone the best in their new endeavors.

Until next time, Happy Navigating, and remember: GPS is brought to you courtesy of the United States Air Force.

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A team of four climbers has recently returned from the highest point in North America with new GPS survey data to determine a more precise summit height of Mount McKinley. A new elevation finding was expected to be announced in late August.

The ability to establish a much more accurate height has grown with advances in surveying technologies since 1953 when the last official survey of Mount McKinley was recorded. The new elevation will eventually replace the formerly accepted elevation of 20,320 feet.

“Determining an updated elevation for the summit of Mount McKinley presents extraordinary challenges,” said Suzette Kimball, acting director of the U.S. Geological Survey (USGS) that undertook the expedition along with NOAA’s National Geodetic Survey (NGS), and the University of Alaska Fairbanks (UAF). “The USGS and its partners are using the best available modern GPS survey equipment and techniques to ensure the new elevation will be determined with a high level of accuracy and confidence.”

Unique circumstances and variables such as the depth of the snow pack and establishing the appropriate surface that coincides with mean sea level must be taken into account before the new Mount McKinley elevation can be determined.

In 2013, an elevation was calculated for Mount McKinley using a technology known as interferometric synthetic aperture radar (IfSAR). The 2013 elevation was slightly lower than the summit’s 20,320 foot height.

IfSAR is an extremely effective tool for collecting map data in challenging areas such as Alaska, but it does not provide precise spot or point elevations, according to the USGS. This new survey used GPS instruments that were placed directly on the summit to measure a specific point on the surface, thus giving a more defined spot elevation.

The USGS/NGS/UAF survey party included three GPS experts and mountainers from CompassData (a subcontractor for Dewberry), and a scientist/climber from UAF’s Geophysical Institute.

Now that the data collection expedition is completed, the three project partners and CompassData are in the process of analyzing the data.

The team began their ascent, with the needed scientific instruments in tow, on June 16. With diligent work and mostly favorable weather, the team safely returned to their starting point ahead of schedule.

“We had nearly perfect weather on the mountain,” said Tom Heinrichs, director of the UAF Geographic Information Network of Alaska and part of the climbing team. “The logistics on the mountain all went well. The summit survey was successful and our preliminary look at the data indicates we will get a good solution for the summit elevation.”

Mount McKinley is part of Denali National Park, which hosts more than 530,000 visitors each year, including about 1,200 who attempt to climb Mount McKinley. In a typical year, about half of those who begin a McKinley climb reach the summit. The six million acre park will celebrate its 100th anniversary in 2017. The mountain was first summited in 1913.
The Erdapfel
This is the first of two articles on the history of the Terrestrial Globe.

The Nuremberg Germanic Museum houses one of the world’s most cherished and consequential navigation artifacts. It is called the Erdapfel. The Erdapfel (Earth apple), is the earliest known surviving terrestrial globe. Made just prior to the discovery of the Americas, it gives a fascinating insight into the geographic knowledge base of 15th century western civilization.

Although the Erdapfel is only 523 years old, the story of the Erdapfel might be said to begin 2,500 years ago in the 6th century B.C. The Greek philosopher/mathematician Pythagoras is the first person who taught that the Earth is a sphere in the center of the Kosmos (Universe), and that the planets, stars, and the universe were spherical because the sphere was the most perfect solid figure. Aristotle, who lived in Greece in the 4th century BC, was the first to offer evidence, albeit qualitative, that the Earth is spherical. His empirical observations to support his thesis that the Earth was spherical were:

1. Matter is drawn to the center of the Earth by gravity which would only be true for a sphere.
2. As one moves from north to south, new constellations are seen rising above the southern horizon.
3. During a lunar eclipse, the Earth’s shadow on the Moon is always round.

During the Middle Ages and pre-Renaissance, Aristotle was the standard scientific authority in the Christian and Muslim worlds. Literate individuals (who were, of course, the minority during those times) subscribed to the Aristotelian theory of a spherical earth, as well as to the erroneous posit of a geocentric cosmology. Not only did ancient and medieval intellectuals know the shape of the earth, there were relatively accurate estimates of the Earth’s size. Beginning with Erastophenes, the head librarian of the eminent Library of Alexandria, in the 2nd century BC, the circumference of the Earth was estimated to be 39,300 kilometers, or only two percent smaller than the actual value. The Greco-Egyptian Ptolemy, who lived from AD 90 to AD 168, was a writer, a patron of the Library of Alexandria, and a renowned mathematician, astronomer, geographer, and astrologer. One of Ptolemy’s main treatises is his Geography which includes a compilation of geographical coordinates, using a spherical coordinate system, similar to the modern latitude and longitude coordinate system. Ptolemy also devised and provided instructions on how to create maps both of the Roman empire and the known inhabited world spanning 180 degrees of longitude from the Canary Islands in the Atlantic Ocean to the middle of China and about 77 degrees of latitude from the Shetland Islands at about 60 degrees north latitude to anti-Meroe (the name Ptolemy gave to a yet undiscovered point at the same numerical south latitude (-16.5°) as the north latitude (+16.5°) of the ancient city of Meroe in present day Sudan). The destruction by fire of the Alexandria Library in the third century AD ushered in the Dark Ages and resulted in backwards steps in Western civilization’s knowledge of the shape of the earth and its relationship to the universe.

The rediscovery of Ptolemy’s maps at the beginning of the 14th century AD by Maximus Planudes, a Byzantine Greek monk scholar, might be cited as the event which triggered, from a geographical perspective, the end of the Dark Ages. By the early 1400s, new navigation tools and mapping advances ushered in the Age of Discovery. Alone among the European and Middle Eastern maritime powers, Portugal faced the Atlantic Ocean yet had no direct access to the strategic Mediterranean Sea. Thus, by necessity, if the Portuguese monarchy wanted to fulfill its goals of economic and religious expansion, it must turn towards the open waters of the Atlantic Ocean. S, the Portuguese sailed the great ocean, hundreds of miles from land and made many of the navigational advancements of the era. Led by Prince Henry the Navigator, Portugal was the hub of advanced navigational development which led to the discoveries of Canary and Cape Verde Islands as well as the colonization of much of the west coast of Africa. The exploration of the African coast was continued by private ventures after Prince Henry’s death in 1460 and in 1473 the Portuguese explorer Lopo Goncalves was the first European to cross the equator. In 1487 Bartholomew Dias achieved another first by sailing his ship around the southernmost point, the Cape of Good Hope, of the African continent. Finally, in 1497, another Portuguese expedition commanded by Vasco de Gama rounded the Cape of Good Hope and in 1498 consummated the Portuguese goal of a maritime passage to India and the Orient that circumvented the dangerous land routes through the Middle East.
Martin Behaim

Germany in 1459. Notwithstanding its dark history of anti-semitism in the 12th to 14th centuries, the cultural flowering of Nuremberg in the 15th and 16th centuries, made it the center of the German Renaissance. Behaim was born to a flourishing family of cloth merchants. The Behaim’s had cultivated a strong trading relationship with the Iberian peninsula and, in particular, with the expansionist maritime power of Portugal. While pursuing his family’s business, Behaim spent much of his time between the ages of 24 and 31 in Lisbon, Portugal, where he was thought to have acquired an interest in geography and exploration. Behaim displayed an extensive knowledge of mathematics and an intimate familiarity with celestial navigation. Because of his knowledge of mathematics and navigation Behaim received an appointment to the king’s council of mathematicians in 1483 and under that auspices assumed responsibility for a variety of research projects as assigned by the king. Among them Behaim was requested to develop improvements to existing navigational instruments. The exact innovations suggested by Behaim remain unclear. It is believed that he demonstrated the use of Levi ben Gerson’s cross-staff apparatus as a means of determining ship’s altitude. The cross-staff (also called a Jacob’s staff or ballestilla) resembles an Arabian kamal and works on the principle of coordinating the declination of the sun with the horizon. It is possible that Behaim suggested to the Portuguese to construct astrolabes of brass, to replace the older wooden models in Portugal. According to some scholars the Portuguese already were well versed in the use of solar declension tables and brass instruments by the 1480s when Behaim arrived in Portugal. Regardless, his innovations proved highly satisfactory, and in 1484 King John II dubbed Behaim with the honor of knighthood in the Portuguese Order of Christ. In 1485-86, according to most reports, Behaim was then invited to travel as cosmographer with Diego Cam on a southbound expedition to explore the West Coast of Africa. He married the daughter of the wealthy governor of cities in the Azores Island chain where he lived from about 1486 to 1490.

In 1490, Martin Behaim visited his native town of Nuremberg with the main objective of expanding his family’s clothing business. Nuremberg in the 15th century was a thriving German city known for its craftsmen and commercial trading enterprise. Based on his reputation in cosmography and connections with the business community, Behaim was awarded a commission by the city of Nuremberg to oversee the construction of the Nuremberg Terrestrial Globe. The production of the globe involved first the compilation of a map of world as a guide for the artist employed in painting the globe; secondly, the manufacture of the Globe, together with its accessories such as the iron stand; and thirdly, the transfer of the map to the Globe. The Globe was completed in 1492 before the discovery of the Americas. The Globe is slightly less than 21 inches in diameter. The surface of the Globe, painted by the renowned artist Georg Glockendon, is covered with over 1100 illustrations and inscriptions taken from sources including Ptolemy, Isidor of Seville, and Marco Polo. Perhaps the most attractive feature of the Globe consists of 111 miniature paintings showing items of geographical interest such as kings seated upon thrones, portraits of missionaries instructing natives, elephants, bears, camels, ostriches, parrots, serpents and mermaids.

It is possible that Behaim met Christopher Columbus during Columbus’ residence in Portugal circa 1485. This and other interesting theories about the Erdapfel and terrestrial globes will be discussed in the next Historian article.

Other ION Historian articles that may be of related interest include: “The Shape of the Earth Part I and II”, (Summer 2001, Fall 2001), “The Mercator Projection (Summer 2002)”, “Henry the Navigator (Winter 2009-2010, Spring 2010)”, “Around the World in 1081 Days” (Spring, Summer, Fall 2013).

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may other aircraft debris found later on the island.

Modern transport aircraft, such as the B777, employ a flight management system (FMS) with an integrated suite of navigation sensors, receivers, and computers, coupled with navigation and performance databases to provide performance and guidance information. Shortly after its departure from Kuala Lumpur, radar tracking indicated that the aircraft deviated from its planned route and headed south along the Malacca Strait before disappearing.

Although the aircraft’s position reporting appears to have been intentionally switched off at 17:22 UTC on the day of its disappearance, an Inmarsat satellite-based communications systems continued to elicit automated responses from the aircraft for nearly seven more hours. Inmarsat technical experts analyzed these data to determine the likely location of the aircraft.

An article written by a team of Inmarsat engineers and published earlier this year in the UK Royal Institute of Navigation’s *Journal of Navigation* probably provides the most definitive explanation of how that last location was determined. Their conclusions provided the point of departure and many of the parameters for the months-long search that followed the disappearance of MH370.

The subsequent — and thus far unsuccessful — sea and air search has covered 4.6 million square kilometers (1.8 million square miles) of ocean surface, and involved 29 aircraft carrying out 334 flights along with 14 ships. Réunion, located about 500 miles east of Madagascar (see accompanying map), lies outside the boundaries of the search area indicated by the Inmarsat analysis, but is well within the likely drift zone of debris from the presumed crash site.

### Turning Communications into Navigation

MH370 was equipped with a satellite communications terminal that used the Inmarsat Classic Aero system, which provides voice and data services through a network of seven geostationary satellites. Each satellite communicates with equipment on board the aircraft — called aircraft Earth stations (AESs) — through “global coverage” radio links to a ground Earth station (GES) that connects calls to their destination. If the onboard equipment does not send any data for an hour, the Classic Aero system checks that it is still connected by sending it a “log-on interrogation” (LOI) message or attempted “handshake” asking for a response. In the case of MH370, seven LOIs took place — the last at 0011 UTC.

Inmarsat used two key parameters associated with these messages in its MH370 analysis called the burst timing offset (BTO) and the burst frequency offset (BFO) to estimate the track of the aircraft. They used the BTO to calculate the distance of the aircraft from the GEO satellite and the BFO to estimate the speed and direction the aircraft was travelling relative to the satellite.

Although nominally stationary over the equator, the satellite actually has a slightly elliptical inclined orbit resulting in a north-south movement of 2,412 kilometers each day, a factor that needed to be incorporated into the analysis. Combining these data with aircraft performance constraints produced a range of candidate paths matching the BTO/BFO data.

Incidentally, the Inmarsat team deduced that the aircraft navigation system was operational during this time because the onboard terminal needs information on location and track to keep its antenna pointing towards the satellite.

The BTO component produced a set of subsatellite points in the form of a ring on the Earth’s surface with a constant distance to the satellite, assuming an aircraft cruising altitude of 10,000 meters. (See accompanying figure.) “The rings were then reduced to arcs by excluding...
locations that were too far away from the original location for the aircraft to reach at its highest speed,” according to the RIN journal article. The seventh and final satellite-aircraft interaction produced the arc along which search efforts have focused.

Unlike the timing-based BTO measurements that predicted the location of the aircraft relative to the satellite, the theory underlying the BFO called for the reverse: taking the aircraft location and velocity at a given time and calculating the BFO that this would generate. “This enables the likelihood of potential flight paths to be evaluated, depending on how well the calculated BFO values align with the measured values during the flight,” the Inmarsat authors wrote.

The BFO was calculated by combining the contributions of several factors as indicated in the following equation:

\[ BFO = \Delta F_{up} + \Delta F_{down} + \delta f_{comp} + \delta f_{sat} + \delta f_{AFC} + \delta f_{bias} \]

where \( \Delta F_{up} \) is the Doppler on the signal passing from the aircraft to the satellite, \( \Delta F_{down} \) is the Doppler on the signal passing from the satellite to the GES, \( \delta f_{comp} \) is the frequency compensation applied by the aircraft, \( \delta f_{sat} \) is the variation in satellite translation frequency, \( \delta f_{AFC} \) is the frequency compensation applied by the GES receive chain and \( \delta f_{bias} \) is a fixed offset due to errors in the aircraft and satellite oscillators. (See accompanying figure.)

The Inmarsat team validated its BFO methodology by applying it to measurements taken from other aircraft whose location and velocity were known and was found to work well.

According to the Australian Transport Safety Bureau (ATSB), the final handshake was a logon request from the aircraft. “This is consistent with the satellite communication equipment on the aircraft powering up following a power interruption,” says the ATSB. “The interruption in electrical supply is highly likely to have been caused by fuel exhaustion. In other words, we are confident the seventh handshake represents the area where the aircraft ran out of fuel before entering the ocean.”

The analyses concluded that MH370 had flown south towards Antarctica and ran out of fuel an estimated 2,000 kilometers (1,200 miles) west of Perth, Australia.

**Drift Analysis**

In concert with the Inmarsat and an international MH370 Joint Investigation Team that worked on trying to identify MH370’s flight path, an extensive air and sea search operation was developed in an effort to locate the aircraft.

Member states associated with the International Civil Aviation Authority (ICAO) and International Maritime Organization (IMO) have well-developed search and rescue (SAR) protocols for such operations. In the case of MH370 and at the request of the Malaysian government, this effort was led by the Australian Joint Rescue Coordination Center (JRCC Australia) based in Canberra into whose SAR region the most likely flight path fell.

To help define the most promising areas to search, especially as the weeks passed without finding signs of MH370, operation planners developed a drift model to identify the most likely movement of wreckage from a crash site. These models look at ocean currents, wind and other meteorological phenomena, physical features of the object being tracked, and so forth.

JRCC Australia uses a custom-designed drift-modeling program called Net Water Movement (NWM), with results validated and compared against another proprietary drift model as well as through the deployment of self-locating datum marker buoys (SLDMBs). The latter are floating devices fitted with a GPS receiver and Iridium satellite transmitter that provide water current...
and sea temperature information. The SLDMBs are deployable from aircraft or vessels, and 33 of these manufactured by Canada’s MetOcean Data Systems were deployed in the search for MH370. These transmitted their position and sea temperature regularly to JRCC Australia.

Before the underwater search for MH370 could begin, search organizers needed to accurately map the sea floor to ensure the safety and efficacy of search operations. Bathymetric survey vessels — the Fugro Equator and the Chinese Zhu Khezhen — spent months at sea, using multibeam sonar to scan the seafloor and gathering detailed, high-resolution data.

The positioning and navigation guidance for the SAR operation created something of a moving target. As refinements of both the Inmarsat flight path analysis and the drift model were made, the search area was revised, which in turn recalibrated the drift model. The accompanying figures show the current versions of both.

Australia’s national science agency, the Commonwealth Scientific and Industrial Research Organization (CSIRO), has undertaken further refinement to its drift modeling since discovery of the flaperon on La Réunion. That modeling takes into account the effect of waves (in addition to wind and current) and resulted in an extension of the scope of the area to include the western Indian Ocean.

The accompanying figure, based on CSIRO modeling and released by the ATSB, indicates the predicted drift as of July 30, 2015. It shows the final image from a computer simulation of the movement of potential debris resulting from the crash of MH370 somewhere along the 7th arc between latitude 39°S and 32°S. ATSB says the simulation was run from March 8, 2014 to July 30, 2015, to determine if the flaperon found on La Réunion could have drifted there from the MH370 search zone in the intervening time, incorporating the combined influence of ocean currents, winds and waves.

According to the ATSB, “Dr. David Griffin from the CSIRO concluded that if the flaperon drifted with an effective leeway factor of about 1.5 percent, then its arrival at La Réunion does not cast doubt on the validity of the present MH370 search area, taking the errors of the ocean, wind and wave models into account.”

However, Dr. Griffin also concluded that because of the turbulent nature of the ocean and the uncertainties of the modeling, it is impossible "reverse engineer" the data from La Réunion to refine or shift the MH370 search area itself.

Marine biology, however, may help narrow down the site of the aircraft’s final resting place employing methods reminiscent of those used by last year’s ION GNSS+ keynote speaker, natural navigator Tristan Gooley. An article in New Scientist magazine reports that the flaperon “is encrusted with barnacles and identifying the species could help work out where that encrustation took place — which may be where the wreck lies.”

If, for example, the barnacle species is Lepas australis, which generally inhabits cool waters south of 35 degrees south, “that could indicate a southern flight direction of MH370,” according to Hans-Georg Herbig at the University of Cologne in Germany. If instead the barnacles are a globally widespread species such as Lepas anatifera, that wouldn’t help, New Scientist quotes Herbig as saying — but a subspecies, L. antifera indica, might point back toward Perth, Australia.
Nominate a Colleague for ION Fellows and Annual Awards

Nominations for The Institute of Navigation’s (ION) Fellows and Annual Awards Program are now being accepted. The ION Annual Awards Program is sponsored by The Institute of Navigation and recognizes individuals making significant contributions or demonstrating outstanding performance relating to the art and science of navigation.

The Institute accepts nominations for the following annual awards:

**Early Achievement Award**
recognizing an individual early in his or her career who has made an outstanding achievement in the art and science of navigation.

**Superior Achievement Award**
recognizing individuals who are practicing navigators and have made outstanding contributions to the advancement of navigation.

**Distinguished PTTI Service Award**
recognizing outstanding contributions related to the management of PTTI systems.

**Captain P.V.H. Weems Award**
recognizing contributions to the art and science of navigation.

**Tycho Brahe Award**
recognizing outstanding contributions to the science of space navigation.

**Norman P. Hays Award**
recognizing outstanding encouragement, inspiration and support contributing to the advancement of navigation.

**Colonel Thomas L. Thurlow Award**
recognizing outstanding contributions to the science of navigation.

**Election to Fellow membership**
recognizes the distinguished contribution of ION members to the advancement of the technology, management, practice and teaching of the arts and sciences of navigation, and/or for lifetime contributions to the Institute.

Submit your nominations today for ION’s Fellows and Annual Awards at www.ion.org/awards. All nominations must conform to ION nomination guidelines. Details of the nomination process and forms are available at www.ion.org/awards. **Nominations must be received in proper form by October 15th to be considered.**
The horizon looks bleak for making significant progress on national civil positioning, navigation, and timing (PNT) initiatives. Why so bleak? With the end of the current fiscal year approaching, Congress is continuing to follow its established track record in falling short of passing next year’s federal budget. Simultaneously, each political party is posturing within the 2016 presidential election cycle.

Sure, we applaud the individual efforts of a few members of Congress to raise awareness of national PNT capabilities issues, but I fear that our government as a whole is aimlessly sailing into a period of inactivity, listlessness, and stagnation that can best be characterized as the federal doldrums. As any prudent mariner looks to telltale signs in the weather during the planning of a voyage, entering this period of federal doldrums could prove to be problematic for national-level civil PNT initiatives that have been in the spotlight for almost three years.

What is not clear is how long this period of listless wallowing will last. If it persists for the next 18 months, until the next administration takes office in January of 2017, then I believe we will have an opportunity lost. Any momentum that has been gained over the last few years to address the decade-old national policy vision for a national complement and backup to GPS will evaporate.

Before this happens, it is time to consider a different approach to achieve PNT resilience here in the United States — one similar to that being pursued in Europe for commercially owned and operated eLoran. For now I will let that suggestion stand. Due to limited space, I cannot elaborate further on this possibility now.

Returning to the point of government inactivity, I do believe that, for one, the Department of Defense (DoD) is attempting to promote a sense of leadership purpose for other responsible agencies on national PNT matters. It might turn out that assistance in moving the issue forward may come from the Congress in the form of supportive language added to the FY16 National Defense Authorization Act (NDAA).

This possibility was forecast at a July 22 DC Section meeting of the Institute of Navigation (ION) held at the U.S. Naval Observatory. At this meeting, which was titled “Keeping and Sharing Time, Policy and Demonstrations,” the keynote speaker was Congressman John Garamendi (D-California). Congressman Garamendi spoke on the criticality of the capabilities provided by GPS and, in particular, its time dissemination aspects. He commented that GPS’s unique capabilities have become so incorporated into virtually every aspect of the national infrastructure that our dependence upon these services is becoming critical.

As a response to this situation he described his bill, H.R. 1678, the National Positioning, Navigation, and Timing (PNT) Resilience and Security Act of 2015, legislation that he introduced on March 26, 2015. H.R. 1678 proposes that, “the Secretary of Defense, in consultation with the Commandant of the Coast Guard and the Secretary of Transportation, shall provide for the establishment, sustainment, and operation of a reliable land-based positioning, navigation, and timing system to provide a complement to and backup for GPS to ensure the availability of uncorrupted or non-degraded positioning, navigation, and timing signals for military and civilian users if GPS signals are corrupted, degraded, unreliable, or otherwise unavailable.”

At the July 22 ION event, Congressman Garamendi mentioned the possibility of attaching his legislation to the FY16 NDAA. Although language in an authorization bill could be helpful, there must also be a parallel appropriations provision identified within one of the department/agency budgets. Otherwise, any step to move forward with a backup will be considered an unfunded mandate requiring the department or agency to internally balance competing priorities in a very tough budget environment.

The outcome of situations is well known — more posturing, no decisions, and no actions to address the backup issue anytime soon. Once again a needed program risks foundering in the federal doldrums.

What remains to be seen is how the Office of Management and Budget (OMB) will view any suggestions by the interagency to reverse prior positions taken in 2010 when, founded on claims of government efficiency benefits, the administration decided to reverse directions and turn-off the U.S. Loran-C system, intended at the time to provide the foundation for an eLoran complement to GPS.
Congressman Garamendi’s awareness of potential OMB resistance was expressed in a July 28, 2015, hearing of the House Transportation and Infrastructure Committee which included a discussion on the backup for GPS. At this hearing, Representatives Duncan Hunter (R-CA) and Garamendi urged the executive branch to implement a national backup for GPS. Garamendi said “that there’s some folks at OMB that are a major problem in this. I know who they are, and I’m going to have a discussion with them.”

His determination to see this through was further emphasized when he remarked, “I’m telling you now that, if you guys don’t get your act together, then we must pass legislation that designates a specific federal agency to get this done within a specific timeframe.” He closed by summarizing, “Listen carefully to what I’m saying. I don’t intend to back off.”

On one hand it is refreshing to see and hear this level of determination on the national backup issue by some in Congress. On the other hand, even with champions like Congressmen Hunter and Garamendi, it is concerning to recognize that the opportunity to get something done may be lost due to the national-level political business as usual of the next 18 months.

As the government wanders further into the federal doldrums, I suspect that those who are doubtless watching with the intent of ultimately exploiting this nation’s overreliance on GPS within our national critical infrastructure will not be so aimless in navigating their own strategic courses.

“If you guys don’t get your act together, then we must pass legislation that designates a specific federal agency to get this done within a specific timeframe.”
In addition to 25 onboard sensors, the MMS spacecraft contain a GPS Navigator developed by Goddard scientist that is crucial to the success of the mission. The MMS study design requires the four spacecraft to arrange themselves into a pyramid-shape formation that places the spinning spacecraft just 6.2 miles (10 kilometers) apart as their sensors gather data.

At the highest point of the MMS orbit more than 43,500 miles above the Earth’s surface — and well above the orbits of GPS satellites at about 12,550 miles altitude, Navigator set a record for the highest-ever reception of signals and onboard navigation solutions by an operational GPS receiver in space. At the lowest point of the orbit, Navigator set a record as the fastest operational GPS receiver in space, at velocities over 22,000 miles per hour, according to NASA.

The use of the onboard GPS receivers reduces mission costs by avoiding the use of more expensive ground-based tracking systems.

In addition to continuously tracking weak GPS signals, the Navigator also must operate as each MMS spacecraft spins at three revolutions per minute. To accomplish this, each satellite carries two Navigator receivers (primary and redundant), with four antennas placed around the perimeter of each to ensure uninterrupted reception of GPS signals.

“Spinning adds a whole new dimension to trying to figure out where you are,” said Ken McCaughey, MMS GPS Navigator product development lead at Goddard. “We have four GPS antennas on each spacecraft. As the spacecraft rotates we have an algorithm running that allows us to hand off from one antenna to the next without losing the signal.”

The mission launched on March 12 with the satellites stacked together inside a United Launch Alliance Atlas V 421 rocket, and already the GPS receivers are proving robust and effective.

“We’re tracking up to 12 GPS satellites at maximum altitude and track on average about nine,” says Goddard technologist Luke Winternitz. “We’re really excited about their performance so far.”

The pyramid formation configuration is needed to obtain three-dimensional observations of the magnetic reconnection. Because the MMS spacecraft must maintain a precise formation, the mission needed to not only accurately determine the current positions of the four observatories, but also predict where they would be in the future and how fast they would be traveling. Providing that predictive data is the Goddard Enhanced Onboard Navigation System (GEONS), created by Goddard technologist Russell Carpenter and his collaborator, Anne Long, a technologist with A.I. Solutions, a Lanham, Maryland-based contractor.

“Almost all activities associated with operating the mission depend on where the satellites will be positioned a few days hence,” Long says. That includes such operations as determining the best time to downlink telemetry and scientific data to calculating when ground controllers should command the firing of the satellites’ onboard thrusters to move the spacecraft and help maintain their orbital formation — an MMS activity that happens at least once every couple weeks. “You need to plan the formation in advance,” Long says.

In the first month after launch, the MMS team compared the Navigator position calculations with ground tracking systems and found the former to be even more accurate than expected. At 43,500 miles away from Earth, Navigator can determine the position of each spacecraft with an uncertainty of better than 50 feet.
During the mission’s first phase, which begins in September, the spacecraft will travel through reconnection zones on the sunward side of Earth, where the orbit extends out toward the sun to around 47,500 miles. About a year later, the satellites will move to Earth’s night-side or magnetotail where the magnetic fields also reconnect — an orbit that extends away from Earth to nearly 99,000 miles, almost halfway to the moon.

Even if an MMS satellite were to lose all GPS signals, GEONS can still compute its orbit by incorporating additional information including drag force, gravity, and solar radiation pressure. The navigation and positioning system will be even more important during the second phase of the MMS mission when the orbit will double in size.

“It’s going to be very interesting to see how far out MMS can still receive signals,” says Brent Robertson, the MMS deputy project manager. “But Navigator has already far exceeded expectations. I think there’s a good chance we’ll end up being able to use GPS and save us some of the expense of using ground observations.”

**Abstracts Due October 30, 2015**

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![The MMS spacecraft stack is seen in the Astrotech payload processing facility as engineers prepare to encapsulate the spacecraft into the payload fairing.](image)

![The MMS spacecraft stack is seen in the Astrotech payload processing facility as engineers prepare to encapsulate the spacecraft into the payload fairing.](image)

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![The MMS spacecraft stack is seen in the Astrotech payload processing facility as engineers prepare to encapsulate the spacecraft into the payload fairing.](image)
If you want to know where you are, you need a good clock. This surprising connection between time and place has been true for centuries and is explored in Time and Navigation: The Untold Story of Getting from Here to There, published by Smithsonian Books. The volume provides a companion book to the National Air and Space Museum exhibition of the same name.

Today we use smartphones and GPS to get around, but navigation technology has not always been so user-friendly and accessible. The oldest “clock” is Earth itself, because the oldest means of keeping time came from observing changes in the sky. Early mariners like the Vikings accomplished amazing feats of navigation without using clocks at all. Pioneering seafarers in the Age of Exploration used dead reckoning and celestial navigation; later innovations such as sextants and marine chronometers helped hone these techniques by measuring latitude and longitude.

When explorers turned their sights to the skies, they built on what had been learned at sea. For example, Charles Lindbergh used a bubble sextant on his record-breaking flights. Because celestial navigation was not well suited for all-weather military operations, World War II created an impetus for the development of new flight technologies, notably radio navigation.

These forms of navigation were extended and enhanced when explorers began guiding spacecraft into space and across the solar system. Astronauts combined celestial navigation technology with increasingly sophisticated radio transmissions.

The development of the atomic clock revolutionized space flight because it could measure billionths of a second, thereby allowing mission teams to navigate more accurately. Scientists and engineers applied these technologies to navigation on earth, eventually developing space-based time and navigation services such as the Global Positioning System that is used every day by people from all walks of life.

While the history of navigation is one of constant change and innovation, it is also one of remarkable continuity. By telling the whole story of navigation technology, Time and Navigation can help us understand where we have been and how we got there so that we can understand where we are going.

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ION Newsletter 18 Summer 2015

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BOOK REVIEW

Time and Navigation: The Untold Story of Getting from Here to There
By Andrew K. Johnston, Roger C. Connor, Carlene E. Stephens, and Paul E. Ceruzzi

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Corporate Profile

Technology Advancement Group
www.tag.com

Technology Advancement Group®, Inc. (TAG®) is a 30 year old company that manufactures highly specialized rugged computer systems designed to survive harsh military environments. TAG’s headquarters, located on our 8-acre campus in Dulles, Virginia, includes 35,000 sq. ft. of research and development, systems manufacturing, and Highly Accelerated Life Testing (HALT/HASS) capabilities. Specializing in Positioning, Navigation, and Timing (PNT) technologies, TAG’s Precise Positioning Service, Global Positioning System-Survey (PPS GPS-S) is the Army Program of Record for geodetic, construction, and airfield survey. TAG’s strength is meeting unique military program requirements, as evidenced by approximately 20,000 TAG systems deployed across the DoD today.

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

Mr. Robert Henry Kern, 85, died June 4, 2015 in Danvers, Massachusetts. Bob was a superb engineer and creative entrepreneur founding FTS and Kernco. Bob was best known to the ION community for his pioneering work for Naval Research Laboratory developing space-borne cesium frequency standards, the first prototype GPS cesium units flown on the NTS-2 Satellite, the production units for GPS Block I satellites, and quartz oscillators flown on many of the latter Block IIR satellites. His later work explored alternative technologies for future satellite frequency standards. He is survived by his wife, Evelyn, son Andrew, and daughter Joanne McDermott.

Section News
Washington DC Section

A meeting of the revitalized DC Section of The Institute of Navigation was held at the U.S. Naval Observatory (USNO) on the evening of July 22, 2015. In attendance were 80+ current and past ION members and their guests.

Congressman John Garamendi was the keynote speaker and spoke on the criticality of the capabilities provided by GPS and, in particular, its time-dissemination aspects. Congressman Garamendi has introduced H.R. 1678, the National Positioning, Navigation, and Timing (PNT) Resilience and Security Act of 2015.

The proposed legislation directs that “the Secretary of Defense, in consultation with the Commandant of the Coast Guard and the Secretary of Transportation, shall provide for the establishment, sustainment, and operation of a reliable land-based positioning, navigation, and timing system to provide a complement to and backup for GPS to ensure the availability of uncorrupted or non-degraded positioning, navigation, and timing signals for military and civilian users if GPS signals are corrupted, degraded, unreliable, or otherwise unavailable.”

The evening’s event also included a program entitled “Keeping and Sharing Time, Policy and Demonstrations” and a tour of the USNO facility including the Master Clock Building, the facility’s 26-inch and 12-inch telescopes (through which Saturn was observable), and the USNO Library. A social hour preceded the program.

Minutes of the meeting and future meeting announcements of the DC Section can be found at <https://www.ion.org/membership/section-dc.cfm>.
It’s All Hackable

Move on from standalone systems and look what happens — today’s connected computers on wheels are subject to the same mischief as your smartphone, desktop, pad, or GPS.

In July, WIRED magazine’s Andy Greenberg broke the now-(in)famous story of a remote hack of a Jeep Cherokee. It made the international news, caused a lawsuit and a recall, and flurries of concern from Congress and federal agencies.

Cybersecurity experts Charlie Miller and Chris Valasek had been trying to figure out how to interfere with an automobile from a distance for quite awhile. They succeeded with the help of an SUV driven by Greenberg on I-64 near St. Louis and a vehicle vulnerability study grant from the Defense Advanced Research Projects Agency (DARPA).

Miller and Valasek used a laptop and a burner cell phone to wirelessly break into the Cherokee’s entertainment system, UConnect. Once in, they were able to find their way into the Linux operating system used by the multimedia computer and thus on to the windshield wipers, window controls, accelerator, brakes, engine. . . They stopped the car dead in its tracks.

And that’s not all. Alex Drozhzhin, a writer for international software security group Kaspersky Lab, said in his blog, “Another possibility researchers found is to track the car with its GPS navigational system. To exploit this possibility you even don’t need to change the head unit’s software, it’s a built-in option...[Also] with help of a femtocell (compact cellular base station) which they bought on eBay, they were able to get into Sprint internal network and manage a mass scan of IP addresses listening to the certain calls they already knew about after hacking through Wi-Fi.”

Fiat Chrysler Automobiles (FCA) recalled over 1.4 million cars after the hack was publicized; UConnect is used by a number of their vehicles and all of these are vulnerable.

In Congress, Senators Ed Markey (D-Massachusetts) and Richard Blumenthal (D-Connecticut) plan to introduce a bill that would require cars sold in the United States to meet specific standards of protection against cybercrime and invasion of privacy.

FCA and one supplier, Harman International were sued for alleged fraud, negligence, unjust enrichment, and break of warranty after the hack became known, and the plaintiffs called for everyone with a UConnect system in their cars to join the litigation.

In a Bloomberg Business news interview, automotive technology expert Thilo Koslowski said, “The Jeep case was a great example of how it’s not about the vehicle itself, but the network. Once these systems are connected to the outside and start talking to each other, that’s when the problems start.”

Face to Face with a Renaissance Ship

In 1546, an English war ship that looks to our eyes just like Captain Hook’s, sunk into the airless silt of Portsmouth harbor in England with a full fighting crew and all of the tools, weapons, and paraphernalia of Henry VIII’s England.

In 1982, archaeologists brought it back up in one piece, one of the great feats of maritime archaeology. Remarkably preserved, it now sits in its own museum, along with hundreds of artifacts and even facial reconstructions of a few of the crew members.

A number of navigation tools were found in the wreck – the best the Tudor navy had to offer. They include three magnetic compasses, brass calipers to mark distances on the navigator’s chart, the lead weight from a sounding line, four sand glasses, a pocket sundial, and a log reel.
Key Lawmakers Move to Make DoD Responsible for eLoran, GPS Backup

By Dee Ann Divis, Inside GNSS

A quintet of well-placed lawmakers, tired of federal dawdling, are prepared to make the Pentagon responsible for building and maintaining eLoran as a backup system for GPS. The move could come by the end of the year, possibly through language attached to a must-pass bill.

Leading the bi-partisan charge are Duncan Hunter, R-California, chairman of the House Transportation and Infrastructure Committee, and the subcommittee’s ranking member John Garamendi, D-California.

The two sent a joint letter last July to the Departments of Defense, Transportation, and Homeland Security — the three agencies responsible for publishing the Federal Radionavigation Plan — asking why there had been no progress on a then-10-year-old presidential directive to establish a backup for GPS.

“America’s Global Positioning System (GPS) is an essential element of nearly every infrastructure upon which our economy and security depend,” the two wrote. “While GPS is superbly maintained and operated, its signals are necessarily faint and can be easily disrupted. This has become a well-recognized and unacceptable risk for our nation.”

Since then officials from a number of agencies have been meeting to discuss establishing a GPS backup. They are weighing the advantages of old proposals like an Enhanced Loran (eLoran) system, said Karen Van Dyke, director of positioning, navigation and timing (PNT) and spectrum management at the Department of Transportation (DoT).

They are also looking at new approaches, such as linking up local commercial radio frequency ranging (RF) networks into a national system.

One of the issues is understanding what system users would be willing to adopt, Van Dyke told Hunter during a July 28 hearing before the House Subcommittee on Coast Guard and Maritime Transportation.

“I hear your testimony and I’m going: ‘Here we go again,’” Garamendi said to Van Dyke during the hearing. “Yeah, there are undoubtedly alternative systems, but all of them are localized — and then coordinating all those together is going to require some sort of overarching system. You know that. I think everybody that is interested in this has known this for at least 15 years.”

“This goes to the Coast Guard also,” Garamendi said to Gary Rasicot, director of the Coast Guard’s marine transportation systems. “You’ve had the original responsibility, and frankly I think you have failed in that responsibility. You’ve gone round and round.”

Playing Money Tag

The main stumbling block is not a technical one. The primary question is which agency will be put in charge of a backup system and gets tagged to pay the bill — some $40 million to set up a four-transmitter network that would provide timing data across the country. Although a $40 million program is small by federal standards; given the already painfully tight budget environment — and the general expectation that it will get considerably worse — no agency has been willing to take responsibility.

Finding the funding is a key element of a bill (H.R. 1678) proposed earlier this year by Garamendi and co-sponsored by Hunter. The measure would hand the responsibility for a GPS backup to the Pentagon and give it three years to have the network “fully operational.”

But why tap the Pentagon and not the Department of Homeland Security or Transportation?

“First of all you go to where the money is,” Garamendi told those attending the July 22 meeting of the D.C. Chapter of The Institute of Navigation. “I love the Department of Transportation. The Coast Guard — perfect organization. Flat out no money. However, I love the Department of Defense — over $600 billion — not a nickel for a backup system. Something is wrong with that equation.”

The GPS backup legislation, however, has yet to make it out of committee. What is out of committee and in the hands of conferees in the National Defense Authorization Act or NDAA.

Garamendi suggested that it might be possible to address getting a GPS backup through the Senate/House conferencing process for that bill. “We have time, under that congressional time clock, and that’ll be into the fall, when the NDAA actually goes forward.”

But what are the chances? Better than usual, it appears. Among the conferees working on the NDAA are Garamendi and all three of his Republican co-sponsors: Hunter, Shuster, and LoBiondo.

In fact, a provision already resides in the authorization act that would force the DoD to take a role in a backup system.

“There’s language in NDAA that causes the Department of Defense to act,” Garamendi told the ION gathering. “God help me, but it actually says ‘study,’ but it forces the [Secretary of Defense] to have a specific plan in place by January 1 of this coming year. That’s pretty fast time actually. And with that in place, it can move forward.”

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GNSS Program Updates
News from Systems Around the World

GPS
The U.S. Air Force successfully launched the 10th Boeing-built GPS IIF satellite aboard a United Launch Alliance Atlas V from Cape Canaveral Air Force Stations on July 15. The spacecraft is destined for plane C/slot 3 of the GPS constellation.

The launch almost coincided with the 20th anniversary of the declaration of full operational capability (FOC) for the GPS constellation, which occurred on July 17, 1995. The final two IIF satellites are scheduled for launch on September 15 and next February.

The U.S. Senate appropriations committee has approved language matching a House decision to cut $17 million from the $27 million requested for the civil contribution to the GPS program. The money is supposed to pay for the additional monitoring that the Federal Aviation Administration (FAA) needs incorporated into the new GPS ground control system to support its programs. The FAA is depending on GPS for its Wide Area Augmentation System (WAAS) and NextGen programs.

The new cuts put DoT some $100 million behind in providing the funding it was obligated to send to the Defense Department, a shortfall that has affected the ability of military managers to complete the Next Generation Operational Control System (OCX).

GLONASS
The last of the modernized GLONASS satellites (GLONASS-M) has passed all acceptance tests, according to an internal newspaper published by Information Satellite Systems–Reshetnev Company (ISS-Reshetnev), the satellites’ manufacturer.

That makes nine GLONASS-M satellites in storage on the ground awaiting launch between now and 2017, according to ISS-Reshetnev, which is based in Zheleznogorsk, Krasnoyarsk region, Russia. According to the company, after the remaining GLONASS-M satellites have been launched, nine more GLONASS-K satellites will be launched through 2020.

BeiDou
China launched two more of its new-generation BeiDou navigation satellites, which have begun operating and established inter-satellite links.

The two satellites were launched on July 25 by a Long March III-B rocket from the Xichang Satellite Launch Center in Sichuan Province, southwest China. The middle Earth-orbiting (MEO) satellites are the second and third new-generation BeiDou spacecraft placed in orbit by China, following a successful single-satellite launch on March 30 of an inclined geosynchronous orbit (IGSO) spacecraft. The newly designed Phase III satellites, which provide higher accuracy positioning, contain new rubidium clocks designed and built in China, according to BeiDou officials.

In the current and final phase of system development now under way, China will migrate its B1 open civil signal from 1561.098 MHz to a frequency centered at 1572.42, which has become a common band for current and future GNSS signals, including the GPS L1 and L1C and Galileo’s E1. The signal modulation will also change from a quadrature phase shift keying (QPSK) modulation to a multiplexed binary offset carrier (MBOC), similar to L1 and E1 but with some unique characteristics.

China has successfully tested the inter-satellite link that provides communications and distance measurement between satellites. The BeiDou constellation currently has 17 healthy satellites (out of 19) on orbit and transmitting a variety of navigation signals.

Galileo
Europe’s 9th and 10th Galileo satellites have arrived in French Guiana in preparation for their joint launch the Guiana Space Center this September.

September’s launch on a Soyuz rocket will place in orbit Flight Models 5 and 6 of the full operational capability (FOC) version of Galileo spacecraft.

Two more FOC satellites are still at the European Space Agency (ESA) ESTEC technical center in Noordwijk, the Netherlands, midway through being tested. Fourteen more are being built by OHB-System in Bremen, Germany.

Four of the Galileo spacecraft are in-orbit validation (IOV) models, and two of the four FOC satellites are operating from incorrect orbits due to a malfunction of the Soyuz Fregat launch vehicle. The satellites were left in elliptical orbits, which were also incorrectly inclined with respect to the equator.

ESA flight operations specialists and experts from several European national space agencies and industry managed to move the spacecraft into somewhat improved orbits that may make them suitable for navigation. The satellites’ positions now mirror each other, meaning they overfly the same location on the ground every 20 days. This compares with a standard Galileo repeat pattern of 10 days, which will help ESA synchronize their ground tracks with the rest of the constellation.

According to ESA, the main hurdle in using the two spacecraft operationally is that their orbits fall outside of the almanacs of Galileo satellites’ orbital locations broadcast within the navigation messages. However, at the improved altitude, the satellites’ signal can still be received in open sky search.
Topics of the World Congress 2015

1. Satellite Navigation Systems (GPS, GLONASS, GALILEO, BEIDOU/COMPASS, QZSS, etc.)
2. Augmentation Systems (SBAS, GBAS, etc.)
3. GNSS Modernization
5. GNSS Receivers and Antenna Technologies
6. Interference and Spectrum Management, Jamming and Spoofing
7. Autonomous Navigation
8. MEMS, Atomic Clock and Micro PNT
9. Space and Atmospheric Weather Effects on GNSS
10. Aviation Applications
11. Marine Applications
12. Terrestrial Applications
13. Precision Agriculture and Machine Control Applications
14. Healthcare Applications
15. Urban and Indoors Applications
16. Automobile Navigation
17. Space Applications and Remote Sensing
18. Precise Positioning, RTK
19. Radar and Alternative Sensors
20. GNSS Environmental Monitoring
21. Ionosphere Monitoring with GNSS
22. Algorithms and Methods
23. Collaborative Methods
25. Backups to GNSS
26. Time and Frequency Distribution
27. Other PNT Topics

Congress venue
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