50TH ANNIVERSARY OF THE SPACE AGE

GPS AND SPUTNIK

On October 4, 1957, the first human-made object ever to leave the atmosphere was launched 560 miles into Space. Sputnik was a 180-pound basketball-sized metal sphere that circled the earth every hour and a half.

And it belonged to the Russians.

(Many contemporary Western news reports referred to Sputnik as a Russian term for moon or natural satellite. It actually meant a traveling companion.)

For the United States, this uncomfortable news led to a number of remarkable achievements — including the NAVSTAR Global Positioning System.

But from Sputnik's launch to the launch of the first GPS satellite was just over 20 years later. It involved piecing together the strongest aspects of a number of technologies and a good deal of sparring and negotiation between branches of the U.S. military.

In 1995, Brad Parkinson delivered a lecture at Stanford University — reflections from a paper he wrote on GPS and Sputnik with Tom Stansell, then with Leica; Ronald Beard, Naval Research Laboratories; and Konstantine Gromov, Jet Propulsion Laboratory. Their paper was presented at the 51st ION annual meeting in Colorado Springs and published in ION's journal that spring.

The following story is taken from a report the Stanford press office wrote about Parkinson’s lecture.

After the launch of the Russian satellite, two researchers at the Johns Hopkins Applied Physics Laboratory (APL) in Baltimore — William Guier and George Wieffenbach — figured out a way

Sputnik, continued on page 22
The U.S. Institute of Navigation was founded in 1945, just at the close of World War II. Navigation was different then, with lighthouses still in regular use, sextants employed to shoot the stars, and radar just appearing on the scene. The launch of Sputnik was imminent, soon to signal the dawn of the Space Age. Inertial navigation was the novel technology.

Throughout this time, ION actively involved itself in the future of navigation, although its membership and fiscal position was modest in those early years.

But with the advent of GPS, the ION really took off.

The Satellite Division was formed with the express purpose of fostering this new technology. And as it grew, so did ION. Conferences that had been attended only by hundreds now had thousands.

ION and the Satellite Division used our new revenues for a number of remarkable new programs. We gave away hundreds of thousands of dollars in scholarship grants, travel grants, and competitions to future navigators. Support for young people took place at all levels of the organization. Local ION sections created educational materials for middle schools in Colorado, programs for high school students in Washington DC, and the immensely popular robotic lawnmower competition in Dayton, Ohio.

The effect of this work has been enormous, sowing the seeds of numerous careers in navigation, including electrical engineering, aerospace engineering, and geomatics. Other initiatives include establishing the government fellows program to provide service to the US Congressional and Executive branches.

New ideas and initiatives continue to come forward. We are developing a Virtual Navigation Museum on our website. We have committed resources and support to the Smithsonian Institution for an exhibit on time and navigation slated for 2010. We are improving our publications — taking steps to have our journal Navigation entered into the Science Citation Index and issuing a new red book on GPS Integrated Systems.

We are exploring ways to ensure the national office is properly structured and well supported with competitive benefits. I recently appointed Lisa Beaty to take on a new role as director of business development to support the diversification and strengthening of our business base. The ION has begun a program of issuing news releases to make the public aware of our conferences, awards, and events. I am grateful to say that each of the initiatives I have cited here is the result of many hours of volunteer time on the part of its members, plus the hard work, accomplished skills and professionalism of our national office staff.

So, the question before us, whither the ION? Where does the future lie for this innovative and successful professional organization? My sense is that the ION should continue to innovate and lead. It must continue to remain a player in the developing technologies in navigation, including commercial and foreign technologies.

I see three major areas of focus:

- **EXPAND OUR EXISTING BASE.** This includes broadening our membership, strengthening and updating our publications, and expanding our business base. We can do more to reach out to the operators and users of navigation technologies, incorporating activities that are of interest to them. We can do more to ensure we are benefiting companies and organizations involved in the field of navigation.

- **SUPPORT NEW INITIATIVES** in the art and science of navigation. ION has established its reputation in this area, and there is more we can do to support continued education programs for young people, to make them aware of the rich and diverse fields of navigation and encourage them to get involved. We can also do more to make the general public aware of the history, practice, and benefits of navigation technologies.

- **INTERNATIONAL INVOLVEMENT.** The world has greatly benefited from advances in positioning, navigation and timing technologies and many countries are taking steps to develop their own systems. The ION needs to continue to be an active participant on the world stage as these advances take place.

Your comments and suggestions can reach me by e-mail at president@ion.org.
Reversal of Fortunes: eLORAN Rises, NDGPS Falls

The uncertain but increasingly ominous fate of the Nationwide Differential Global Positioning System (NDGPS) continues to linger in bureaucratic limbo, while the enhanced LORAN (eLORAN) system received another vote of confidence as a back-up system for GNSS positioning, navigation, and timing (PNT).

NDGPS has a new date with destiny — January 30, 2008. That's when the U.S. Department of Transportation (DoT) is scheduled to complete its assessment of the need for an inland component of NDGPS, according to Tim Klein, senior policy advisor/NDGPS Coordinator for DoT's Research and Innovative Technology Administration (RITA).

NDGPS is an expansion of a maritime system the U.S. Coast Guard (USCG) begun in the late 1980s, which uses low-frequency radio beacon transmissions to communicate real-time differential corrections and integrity messages. User communities include farmers, public utilities, marine navigators, and geographic information system (GIS) developers.

If no transportation requirements or other federal user requirements appear during its investigation, DoT intends to develop a decommissioning plan for NDGPS, according to Klein. DoT would also be willing to establish cost-share arrangements with other agencies, if a transportation requirement is established.

In the event that DOT does not fund NDGPS in FY09, USCG has identified 12 DoT funded sites to preserve coverage. The FY09 USCG resource proposal requests O&M funding to maintain maritime DGPS. No matter what the outcome for inland NDGPS is, USCG will continue to and maintain maritime DGPS, Klein says.

eLORAN Rising
Meanwhile, another program that was once slated in the Federal Radionavigation Plan for decommissioning — LORAN-C — now appears likely to gain an

Cooperative Continuously Operating Reference Stations (CORS) for high-precision GPS positioning and the National Oceanic and Atmospheric Administration's National Weather Service/Water Vapor and Space Weather Prediction Center.

A public comment period, advertised in the Federal Register, ended October 1 with 139 mostly favorable replies backing completion of the full NDGPS network. Currently, the system has 86 operational sites established over the past 10 years — 8 sites short of complete coverage of the contiguous 48 United States.

Fiscal Year 2008 (FY08) funding for NDGPS is $5 million, which can be used only for operations and maintenance (O&M) of the existing system; no construction, expansion, expansion, or upgrade for NDGPS sites in FY 07/08. RITA agreed to be the interim program sponsor.

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NDGPS and eLoran
NDGPS and eLoran

Global Loran Coverage
Global Loran Coverage

Homeland Security
Homeland Security

U.S. Department of Homeland Security
United States Coast Guard
U.S. Department of Homeland Security
United States Coast Guard

ION Newsletter  3  Fall 2007
It’s getting to be a crowded GNSS world out there, with at least four global systems, two regional systems, and numerous augmentation systems under development.

**GPS**

Progress on the U.S. Global Positioning System came with another launch October 17 of a modernized Block IIR satellite — bringing the GPS constellation up to 31 operational satellites.

Expected to be set healthy for use in early November 2007, the spacecraft will be designated as PRN15/SVN55, referring to its pseudorandom noise code and space vehicle number, respectively. The spacecraft will operate in the F2 slot in the sixth of the six GPS orbital planes, near to a 16-year-old Block IIA space vehicle (SV29, PRN29) on which three of the satellite’s four atomic clocks have ceased functioning.

Meanwhile, the Air Force Space Command (AFSPC) has issued a draft performance standard (PS) for the Standard Positioning Service (SPS), which defines the service provided to non-military GPS users. The document is currently undergoing review by the Air Staff review, a body of high-ranking U.S. Air Force officials who assist the USAF chief of staff.

The GPS SPS PS has practical significance because it defines the Department of Defense (DoD) commitments for sustaining the level of service (accuracy, availability, etc.) of the SPS signal in space (SIS) — in effect, what users can count on the SPS signal in space to provide. SPS PS is the basis for all civil GPS safety certifications, for example, SPS use in instrument flight rules (IFR) navigation by civil aviation.

In May, AFSPC formed a GPS SPS PS Update Coordination Team to craft and informally coordinate the review of the current (2001) version of the standard. Representatives of about a dozen civilian federal agencies reviewed and commented on the draft version released in late July. The GPS system is functioning much better than required by the 2001 SPS PS (see accompanying figure: GPS Navigation Performance), and some users have argued that the new document should reflect a guarantee of service closer to what is actually being maintained.

Following review by the Air Staff and then the Office of the Assistant Secretary of Defense for Networks and Information Integration (ASD NII), a final document is expected to be published by April 30, 2008.

**New Signals.** The GPS -17(M) satellite is the fourth in the GPS IIR series with a modernized military code (M-code) and second civil signal (L2C). Currently 12 IIR and 4 IIR-M satellites are on orbit. These are the first new signals to be broadcast by GPS since the program’s first production satellite was launched in 1978.

But the full signals are not on the air yet. In a presentation to the ION GNSS 2007 session on GPS Modernization, Bill Marquis of Lockheed Martin Space Systems pointed out that the L2C and L1M/L2M signals are currently being broadcast in dataless mode.
— that is, without navigation message data being modulated on the signal. Although this enhances the signal acquisition of the new signals, Marquis said, it fails to provide the high-accuracy navigation data potentially available on these signals.

Limitations in the current and near-future Operational Control Segment (OCS) prevent full access to these modernized capabilities, according to Marquis, who added that the recently implemented Architecture Evolution Plan (AEP) for the control segment will not provide modernized capabilities in terms of commanding, data upload, and signal monitoring. Consequently, workarounds and off-line tools are required to provide the modernized capabilities on-orbit.

The next launches of GPS IIR-M satellites are scheduled for “no sooner than” December 2007 and March and June 2008.

**Glonass**

The big news for Russia’s GNSS system recently was the announcement that GLONASS has received “preliminary approval” to add code division multiple access (CDMA) signals to future satellites. A Proton-M rocket failure in September appeared to threaten the schedule for continued rebuilding of the GLONASS constellation, but an investigation of the incident paved the way for a successful October 26 launch of three satellites.

Since its initiation in the early 1980s, the Russian GNSS system has employed frequency division multiple access (FDMA) techniques in which the same code is used for the signals broadcast by the system, with individual spacecraft being distinguished from one another by a specific frequency allocation. Russia would almost certainly continue broadcasting FDMA signals on existing frequencies.

That approach has left Russia as the exception to the use of CDMA signals by the U.S. Global Positioning System (GPS), Europe’s Galileo system and China’s Compass/Beidou. In CDMA systems, satellites are distinguished by different pseudorandom noise codes broadcast on the same frequencies. As a result, GLONASS signals are not as easily incorporated into user equipment that exploit a combination of GNSS systems to provide positioning, navigation, and timing (PNT).

In a presentation at the Civil GPS Service Interface Committee (CGSIC) meeting before the ION GNSS 2007 in Fort Worth, Texas, Sergey Revnivykh said that preliminary approval had been obtained for updates to requirements documents that would allow transmission of CDMA signals on L1CR and L5R frequencies on future GLONASS satellites. That would help make GLONASS more “interoperable with GPS and Galileo.” Final approval is expected by the end of the year, Revnivykh added.

Revnivykh is deputy director general of the Russian Space Agency’s Central Research Institute of Machine Building and head of the PNT Information Analysis Center (IAC).

A Russian investigation of the September 6 accident concluded that a defective cable had prevented the firing of explosive bolts, which allow the rocket’s first stage to separate from the second stage at the appropriate moment. The GLONASS launch will be the first since the rocket failure.

As of October 19, GLONASS had 13 operational satellites in orbit, three of which were temporarily switched off. Another three spacecraft are being decommissioned. Another three GLONASS-M spacecraft are scheduled for launch on December 25, 2007.

**Galileo**

As if the dissolution of a long-standing public-private partnership (PPP) approach hadn’t created problems enough, the launch of a second Galileo In-Orbit Validation Element satellite (GIOVE-B) has been delayed until at least March 2008.

The most recent schedule had called for a late-December launch from the Baikonur Space Center in Kazakhstan. However, Russian space officials notified the European Space Agency (ESA) that unavailability of an upper stage of the Soyuz launcher would force a postponement.

The GIOVE-B program was already behind schedule as the result of an electrical...
short that caused widespread damage to the spacecraft during laboratory tests in summer 2006. It is currently in ESA’s technical center in Noordwijk, The Netherlands, undergoing final tests.

The missing Soyuz component is a Fregat module, the portion of the Russian rocket that releases the spacecraft into its final orbit (shown with GIOVE-A in the accompanying ESA illustration). A silver lining may emerge from these latest clouds, however. The delay allowed the European Space Agency and its prime contractor for GIOVE-B, the European Satellite Navigation Industries (ESNI), to retrofit the spacecraft’s signal generator to be able to broadcast the new MBOC common civil signal recently agreed to by the United States and Europe.

In an October 2, 2007, meeting the European Transport Council generally reaffirmed its commitment to the Galileo program without resolving underlying differences about how to finance the system following abandonment of earlier this year. Taking its first look at the European Commission (EC) plan to complete the system by 2013 under a more traditional public procurement process, the council confirmed its intention “to take an integrated decision on the European GNSS before the end of the year.”

The EC, the executive branch of the European Union (EU), had drafted a new proposal in response to a June 8 request from the council. In a September 19 communication to the Transport Council and the European Parliament, the EC’s Directorate-General of Energy and Transport had laid out a plan that would rechannel funds from the EU current budget to eliminate a gap in financing the program.

The proposal, advanced by EC Vice-President and transport commissioner Jacques Barrot, had suggested plugging the gap mainly with unused EU funds earmarked for administration expenses and the agricultural sector.

Since the EC’s proposal became public, however, Germany, the United Kingdom, and The Netherlands have expressed doubts about the plan. Those three nations would prefer to see individual states contribute the extra funds to the European Space Agency (ESA), which would finance and manage the project.

The EC’s communications and an accompanying proposed regulation would also designate ESA as the “design authority” for Galileo, which would oversee deployment of the system under a contract with the EU.

Finally, the EC plan would impose several substantial changes in governance of the program, bringing under its jurisdiction the European GNSS Supervisory Authority (GSA)—a semi-autonomous European Community agency established to oversee the concession contract and perform other important functions in the Galileo program. GSA Executive Director Pedro Pedreira took part at the ION GNSS 2007 plenary session.

Without an industry contribution through a PPP, the EC will need to eliminate a funding gap between the slightly more than 1 billion allocated for the public share under the PPP and the 3.4 billion projected cost to make the 30-satellite system fully operational by 2013. The EC’s plan would take 2.1 billion from other line items in the EU’s 2007-8 budget and 300 million from budgeted for GNSS research and development under the so-called 7th Framework program of European capital investment.

The issue will be taken up at a meeting of the EU economics ministers in November, who must approve any change in the EU budget. And transport ministers want to revisit the subject at the December meeting.

**Compass**

Although closely watched by researchers and political leaders around the world, China’s Compass (Beidou 2) Navigation Satellite System (CNSS) has manifested little change since launch of its first medium Earth orbit (MEO) satellite in April (See GNSS Program Updates, ION Newsletter, Summer 2007 issue).

Politically, however, the People’s Republic of China has been very active around satellite navigation issues. They have joined the UN-supported International committee on GNSS (ICG) and take part in the ICG’s Providers Forum (see accompanying article in this newsletter).

In a September 4 presentation to the Providers Forum, Chen Jianyu, senior engineer from the China Satellite Navigation Project Center (CSNPC), described the plans for Compass. (Chen said that the CSNPC would “take charge of the research, building, and management of CNSS.”)

The space segment of CNSS will consists of 5 geostationary earth orbit (GEO) and
extended lifetime as eLoran.

Following a DoT Volpe Research Center report on the vulnerability of GPS, issued September 10, 2001, LORAN got a new lease on life. More than $160 million has been spent, most of it since 2001, to turn the maritime-oriented LORAN–C into eLORAN, which could support a wide user base (maritime, aviation, timing, land-mobile navigation).

Improvements have included the following:

❖ upgrade existing station transmitting equipment to new solid state transmitters and associated timing equipment (atomic clocks)
❖ transition to time of arrival (TOA) positioning techniques, similar to pseudorange-based navigation used in GPS
❖ incorporate new messaging channel to increase position and time accuracy (differential Loran, integrity, and time messages)
❖ support operation of modern all-in-view equipment (improves fix geometry for better accuracy and extended coverage).

The latest support for the eLORAN program emerged in an analysis completed last summer by ITT Corporation’s Advanced Engineering & Sciences Division for the NGATS Institute that is backing the Next Generation Air Transportation System, a joint government-private sector partnership that would transform the national air system.

In its report to the institute, “Satellite Navigation Backup Study,” ITT said that eLORAN received the highest overall rating as a GPS backup. The report was released in October by the multiagency Joint Planning and Development Office, charged with developing NGATS by 2025.
Operators of the world’s four GNSS systems and regional augmentation systems have laid the foundation for a multilateral environment in which to discuss issues of compatibility and interoperability.

Meeting last September 4 in Bangalore, India, in advance of a session of the International Committee on GNSS (ICG), six nations established a Providers Forum that will operate in parallel with the United Nations–backed group.

Ken Hodgkins, deputy director of the State Department’s Office of Space & Advanced Technology, co-chairs the new group, with Suresh Kibe, satellite navigation program director for the Indian Space Research Organization (ISRO). Hodgkins characterized the ICG gathering as “a huge success.”

“The PF [Providers Forum] was particularly notable in that we reached a common understanding on the general concept of compatibility and interoperability in a multilateral setting,” Hodgkins said.

The group will meet for the second time next December, 2008 at the ICG annual meeting to be held in Pasadena, California, USA.

Although the Providers Forum does not make policy, it does represent a comprehensive membership and focus on GNSS affairs that has not previously existed.

The members of the forum and their current and future systems include:

- China — Compass/Beidou Navigation Satellite System (CNSS)
- European Union — Galileo and European Geostationary Navigation Overlay Service (EGNOS)
- India — GPS Aided Geo Augmented Navigation (GAGAN) system and Indian Regional Navigation Satellite System (IRNSS)
- Japan — Quasi-Zenith Satellite System (QZSS) and MTSAT Satellite-based Augmentation System (MSAS)
- Russian Federation — GLONASS and terrestrial Wide-area SDCM (System of Differential Corrections and Monitoring)
- United States — GPS and Wide Area Augmentation System (WAAS).

The PF goals are compatibility — systems can be used separately or together without interfering with each other’s service or signals. And interoperability — systems used together can provide better service for the users than either system used separately.

The new group agreed on several baseline principles, including open publication and dissemination of signal and system characteristics, performance monitoring of open signals and timely updates of critical performance characteristics, adequate spectrum protection through national and international regulation, and physical separation of satellite constellations and addressing end-of-life disposal orbits.

A Little Background

The ICG and Providers Forum is the culmination of an eight-year process that began in 1999, with the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III). One of the objectives of the conference was to promote the use of space technologies, particularly among developing nations. These technologies included satellite navigation which “lends itself by nature to regional and
Six years of conferences, workshops and outreach efforts followed to help broaden nations’ understanding of GNSS technology and applications.

By December 2005, these efforts had coalesced. That month, the UN Committee on Peaceful Uses of Outer Space COPUOS met in Vienna and established the International Committee on GNSS as an informal, volunteer body to promote cooperation on civil satellite-based positioning, navigation, timing, and value-added services.

The new ICG included system providers and international organizations of cartographers, surveyors and navigators – a cross section of GNSS users.

At that time, China and Russia decided not to join the new group. Other participants in the meeting were caught unawares by the resistance of two of the four main GNSS developers. Within a year, however, the concerns of the two countries were addressed sufficiently to bring them back into the fold.

In a presentation to the National Space-Based PNT Executive Committee’s Advisory Board on October 5, USCG Capt. Curtis Dubay described the coast guard’s efforts to upgrade Loran. USCG operates 24 LORAN stations, with 19 modernized to handle the eLORAN data channel, according to Dubay.

In order to provide full U.S. eLORAN coverage, USCG would need to upgrade the five remaining stations, build three new ones, and add monitoring stations to check integrity and accuracy at a cost of $450 million, he said.

Annual operations and maintenance costs (as of FY06) are $45 million, a figure expected to decline to $22 million a year projected upon implementation of full eLORAN system architecture with reduced staffing at automated stations.

The federal agency source of funding for eLORAN remains an obstacle, but a decision on the program’s future is expected by the end of this year.
Our story so far:

Elmer Sperry was born a year before the Civil War began, but the gyrocompasses, inertial navigators and voyage management systems that stem from his innovations still steer our ships and aircraft. By 1986, the eight companies he founded had merged into Unisys, the giant information technology firm. His most successful venture sprang from the compass he developed based on the gyroscope. Sperry tried to improve Hermann Anschütz-Kaempfe’s design for a working compass, which the German scientist had already patented. Sperry patented his own version in England and the United States in 1908, and was sued for patent infringement in 1914. The Berlin court selected Albert Einstein as an expert with whom both parties could agree. Einstein first testified in Sperry’s favor, then reversed himself. Anschütz-Kaempfe won the case in 1915.

By 1914, Sperry’s marine and aviation gyrocompass products were both technological and commercial successes. War in Europe created a burgeoning demand for ship gyrocompasses and the Allied navies turned to Sperry Gyroscope, the Brooklyn company Sperry had founded four years before. In December 1914, the British Admiralty ordered 55 submarine and ten battleship compasses, and Russia ordered one submarine and 10 battleship compasses.

That same year, Sperry received a career-capping aviation award, the Robert J. Collier Trophy (then called the Aero Club of America Trophy), for “gyro controls, the greatest achievement in American aviation in 1914.” *

*In 1992, the principal development activities of the Global Positioning System won this same award, now called the Robert J. Collier Trophy, for the “most significant development for safe and efficient navigation and surveillance of air and spacecraft since the introduction of radio navigation 50 years ago.”

Sperry Gyroscope expanded its facilities, as well as its profit margins. Gyroscope sales went up even further as the United States prepared to enter the war.

Elmer Sperry might well have been satisfied at the age of 56 to sit back and admire the successful company he had created. But he was an inventor and engineer by nature. Sperry Gyroscope Co. did not evolve primarily as a manufacturing concern but rather as an enterprise organized around what we know today as “R & D” — research and development.

Among the major innovations resulting from the devastating carnage of World War I were gas, tank, submarine and aerial warfare. Sperry’s expertise and investments in R & D resulted in significant advances in aerial warfare, particularly in guidance and control.

With major contributions from Sperry’s sons, Lawrence and Edward, the company developed drift meters, fire control systems, searchlights, bombsights, and aircraft stabilization systems. The Sperry name became synonymous with sensitivity and precision for ship’s and aircraft’s navigation, guidance and control systems.

Instrument flying had been progressing...
SiRF Technology, Inc. is a world leader in creating technologies that confer “location awareness” or “location intelligence” to a wide range of consumer products. SiRF’s location-awareness solutions are based on the Global Positioning System (GPS), the same technology used to guide everything from the space shuttle to car navigation systems to handheld devices used by backpackers.

SiRF capitalizes on its architectural innovations, system design and silicon expertise, RF capabilities and state of the art semiconductor manufacturing technology to make GPS capabilities accurate, affordable, power efficient and compact enough to be used in consumer applications. SiRF’s extensive patent and intellectual property portfolio improves on conventional GPS by providing location awareness where other approaches cannot, including under dense foliage, in steep ravines, in “urban canyons” and even in some indoor environments. In the constant tension between lost and found, SiRF’s GPS solutions tip the odds in favor of being found.

Since the Sperrys and their innovative research and development department introduced the bank-and-turn indicator in 1918.

In 1923, the remaining challenge was pure instrument flying, the subjection of the pilot’s own senses. Lawrence Sperry was quite a genius in his own right and became a test pilot, using advanced Sperry Gyroscope instruments to attempt blind flying.

Lawrence Sperry was quite a genius in his own right and became a test pilot, using advanced Sperry Gyroscope instruments to attempt blind flying.

That December, he took a small Sperry airplane across the English Channel. When engine trouble forced the plane down near the French coast, the cold water proved too much for him as he attempted to swim to shore. Lawrence’s tragic death not only disheartened his father, but also delayed further experimentation in blind-flight flying for five years.

The project picked up again in 1928. By then, Lt. James H. “Lucky Jimmy” Doolittle — aviator, aeronautical engineer, and future WWII hero — was already a legend in the U.S. Army Air Corps for his daredevil flying.

Doolittle asked Sperry for an instrument that could instantly show the direction of flight during large vertical and horizontal maneuvers. Sperry was treading 70 and semi-retired, but he still kept his hand in the research aspects of the business.

He developed a combined artificial horizon, directional gyro, and radio direction finder. This instrumentation, with a novel barometric altimeter developed by Bernard Kollsman, enabled Doolittle to attempt blind flying.

On September 24, 1929 Jimmy Doolittle made the world’s first blind flight at Mitchel Field, Long Island. (Seventy years later, one of the Sperry Gyroscope Co. descendents moved to Mitchel Field: the division of Lockheed Martin responsible for the Trident submarine navigation system.)

Elmer Sperry died the following year, in 1930. His inventive spirit endures in the ship, airplane and spacecraft automatic control and guidance systems that bear his name.

More information:
Elmer Sperry - Inventor and Engineer
Thomas Parke Hughes, John Hopkins Press, 1971
Sperry Marine/Northrop Grumman company history: www.sperrymarine.northropgrumman.com/company-information/corporate-history

— Historian Marvin B. May received the ION’s 2006 Weems award for enduring contributions to navigation. He is chief scientist of the Pennsylvania State University’s Applied Research Laboratory Navigation Research and Development Center in Warminster, Pennsylvania
For 20 years, the ION Satellite Division’s September conferences have emphasized the GNSS in the title (and before that, the GPS).

But 2007 may stand as the year that International came to claim rights of equal billing.

At ION GNSS 2006, 36 percent of attendees came from outside the United States, a new record for the event — which was broken again this year. International participants comprised 37 percent of the nearly 1,600 ION GNSS 2007 registrations. Of this year’s 80 exhibitors, 23 represented international companies and organizations.

In terms of authors, international participation was even higher — in fact, a majority of the primary authors for papers presented at this year’s conference arrived from outside the United States. Out of 430 total primary authors (including accepted alternate papers), this is regional breakout: U.S., 142, 34%; UK/Europe, 161, 35%; Canada, 40, 9%; Asia/Australia, 80, 20%; South America, 6, 1%; Middle East, 1, 1%.

The international flavor of this year’s conference was underscored — and almost certainly driven by — the emergence of GNSS systems under development by other nations, including Russia’s GLONASS, Europe’s Galileo, and China’s Compass (Beidou).

Technical sessions covered these systems and included papers on related augmentation systems, such as the Federal Aviation Administration’s Wide Area Augmentation System and the European Geostationary Navigation Overlay Service (EGNOS), and regional systems including Japan’s Quazi-Zenith Satellite System.

(In his column on page 2 of this newsletter, ION President John Lavrakas indicates his hopes to see this international involvement in and by the Institute to be a hallmark of ION in the 21st century.)

Winner of the 2007 ION Kepler Award for lifetime achievement is Dr. Richard Langley, professor of surveying engineering at the University of New Brunswick, Canada. Andria Bilich, University of Colorado, received the Satellite Division’s Bradford W. Parkinson Award given to an outstanding graduate student in the field of GNSS. The accompanying special section features photos and articles of these and other highlights from ION GNSS 2007.

Dr. Todd Walter of Stanford University served as this year’s general program chair. This year’s program chair was Dr. Mikel Miller, currently the Technical Director for the Advanced Guidance Division of the Munitions Directorate of The Air Force Research Laboratory at Eglin Air Force Base, Florida. Track chairpersons were John Kelly, Rockwell Collins; Dr. Sherman Lo, Stanford University; Lt. Col. Jeffrey Hebert, USAF; Dr. Jade Morton, Miami University; Dr. Andrey Soloviev, Ohio University; and Dr. Jose Angel Avila-Rodriguez, University of Technology Munich, Germany.

Plenary: Off-Road and into the Future

As usual, a highlight of the conference came at the plenary session that opened the conference.

Sebastian Thrun regaled the opening night’s audience with an informative, enthusiastic, and frequently amusing keynote address that provided an insider’s view of the Grand Challenge and competition sponsored by the Defense Advanced Research Projects Agency (DARPA), as well as its successor event, the Urban Challenge.

Thrun, a professor of computer science and electrical engineering at Stanford...
The Bradford Parkinson Award was presented during the ION GNSS 2007 awards luncheon on September 28, 2007 to Andria Bilich from the University of Colorado for her thesis titled: “Improving the Precision and Accuracy of Geodetic GPS: Applications to Multipath and Seismology.”

The Satellite Division of The Institute of Navigation presents the Bradford W. Parkinson Award annually to an outstanding graduate student in the field of Global Navigation Satellite Systems (GNSS). This award, which honors Dr. Parkinson for his leadership in establishing both the U.S. Global Positioning System and the Satellite Division of the ION, includes a personalized plaque and a $2500 honorarium. The award will only be presented when deemed worthy. Any graduate student who is a member of the ION and is completing a degree program with an emphasis in GNSS technology, applications, or policy is eligible for the award. The Institute of Navigation must receive all entries no later than June 30.

University, oversees the Stanford Racing Team (SRT) that won the 2005 UAV cross-country race. Lacking funds to support participation, team members were brought together by means a venerable ploy: creation of a new course with academic credits (but no scheduled classes or assigned textbooks) for the purpose of designing and building an entry in the DARPA race.

Thrun described the extensive range of advanced technologies that needed to be integrated into Stanley, SRT’s winning entry in the second running of the Grand Challenge. The 132-mile trek across brutal desert terrain used driverless vehicles guided by 2,400 GPS “breadcrumbs” or pre-positioned points along the route provided to contestants.

In addition to GPS, inertial navigation, lasers, machine vision, map-matching, and other sensors and techniques were brought to bear on the challenge. Stanley finished in just under 6 hours 54 minutes and averaged more than 19 mph on the
The Institute of Navigation’s (ION) Satellite Division awarded Dr. Richard Langley its Johannes Kepler lifetime achievement award September 28, 2007 at the ION GNSS 2007 conference in Ft. Worth, Texas. The Kepler Award is designed to honor an individual during their lifetime for sustained and significant contributions to the development of satellite navigation. Langley received the 2007 award for his sustained research in the general area of navigation and for the education of scientists, engineers, students and the general public in the principles of navigation and GNSS.

During his acceptance Langley thanked the Satellite Division of The Institute of Navigation for honoring him with the award. He stated that, “I could never have achieved this distinction without the support and contributions of the UNB GPS research team over the years, particularly the hard-working graduate students, as well as that of my colleagues in academia, industry, and government in Canada, the United States, and elsewhere. And I would be remiss if I did not thank my wife, Marg, for giving me a reduced load of domestic duties, so that I could spend more time on many GPS-related interests.”

Langley has been involved in GNSS for a number of years; as well as teaching and conducting research at Canada’s University of New Brunswick (UNB) since 1981. Langley’s research team in UNB’s Department of Geodesy and Geomatics Engineering has made many significant contributions to GPS positioning and navigation, including understanding atmospheric effects on satellite signal propagation. Virtually every GPS receiver sold today contains a code module based on UNB atmospheric research.

His research team is currently working on a number of GNSS-related projects, including its continuing study of atmospheric effects, space-based augmentation systems, error mitigation techniques, and the development of applications for space-borne GNSS.

Langley is also the principal investigator for a GPS-based instrument on Canada’s future research satellite, CASSIOPE, determining the position and attitude of the satellite and measuring the density of electrons in the ionosphere—important for understanding space weather and its effects on systems such as power lines and satellites.

He has overseen the publication of more than 170 articles covering the full breadth of GPS theory and practice. He has written many of the columns, especially the tutorials, himself. In addition to this Langley is also a co-author of the Guide to GPS Positioning published by Canadian GPS Associates.

Most significantly he has supervised numerous Master’s and Ph.D. students, many of whom have gone on to their own distinguished careers in the general field of GPS and navigation.

Langley has a bachelor’s degree in applied physics from the University of Waterloo and a Ph.D. in experimental space science from York University, Toronto. Langley has received numerous awards, including the ION’s Burka Award, which recognizes outstanding achievement in the preparation of a technical paper contributing to the advancement of navigation and space guidance and NASA Group Achievement Awards. Langley is currently an elected Fellow of the International Association of Geodesy, the Royal Institute of Navigation (UK) and The Institute of Navigation (North America).
ION GNSS 2007 Program Committee: Dr. Sherman Lo, Track Chair; Dr. Jose Angel Avila-Rodriguez, Track Chair; Dr. Mikel Miller, Program Chair; Dr. Todd Walter, General Chair; Dr. Andrey Soloviev, Track Chair; John Kelly, Track Chair and Lt. Col. Jeffrey Hebert, Track Chair. Not Pictured: Dr. Jade Morton, Track Chair.

ION GNSS 2007 Sponsored Students.
GNSS 2007 continued from page 13

Thrun also looked ahead to the ever-greater requirements posed by DARPA's new competition: the Urban Challenge. In November 3 finals at an urban military training facility located on the former George Air Force Base in Victorville, California, the robot-guided vehicles needed to operate entirely autonomously, without human intervention, and obey California traffic laws while performing maneuvers such as merging into moving traffic, navigating traffic circles, and avoiding moving obstacles.

SRT's new entry, a 2006 Volkswagen Passat named Junior, is competing against 35 other semi-finalists in a qualifying event leading up the race.

Plenary Panel

Thrun was joined in the plenary session, chaired by Dr. Per Enge, by a panel of GNSS experts who explored a range of current topics. Gaylord Green, principal in the consulting firm Navastro; Major General William “Willie” Shelton, commander of the USAF Joint Functional Component Command for Space JFCC/Space, Vandenberg Air Force Base, California; Pedro Pedreira, executive director of the European GNSS Supervisory Authority (GSA), Brussels, Belgium; and Prof. Dr. Günter Hein, head of the Institute of Geodesy and Navigation at Germany’s Federal Armed Forces University Munich.

Green, the second director of the NAVSTAR GPS Joint Program Office (JPO, now the GPS Wing), described the effects that advances in electronics and manufacturing technology have had on the cost of GPS user equipment and the popularization of GNSS in mass markets. In parallel with “Moore’s Law” of integrated circuits (ICs) — starting with the Z-set at $225,000 and continuing up to today’s cell phone with integrated GPS chip — the price of the lowest-cost GPS set was reduced 50 percent every 18 months since 1978, he said.

“As we look forward,” Green continued, “the cost will not be coming down significantly, but the continuing IC advances will continue entirely autonomously, without human intervention. Therefore, ION GNSS 2007 plenary session, Green revealed some of those 10-year-old predictions, a few of which hit surprisingly close to the mark while others missed (see examples below).

Green also invited his ION GNSS 2007 audience to repeat the exercise, describing the world of GNSS that they foresee in 10 years. We’ll describe some of the responses in a moment.

But now we want to expand the invitation to all ION members: Just give us a quick sketch, 100 words or less, of what you think the world of GNSS will look like in 2017. Send your ideas in an e-mail to membership@ion.org with "TEN YEAR PREDICTIONS" in subject line.

As inspiration, here are a few of the 1997 prophecies for 2007, as well as some of this year’s predictions for 2017.

1997/2017

Sensors w/ integrated maps will be in all mid-priced automobiles in the world, as well as in all pleasure boats, private aircraft, all-terrain vehicles, etc. These will be available as cigarette-pack sized modules for hikers, climbers, etc. at very cost — well under US$100, even allowing for inflation. All significant fleets (railcars, police & other emergency vehicles, truck fleets of all types, etc.) will have sensors automatically feeding information back to vehicle management systems — along with multi- tudes of ancillary data.

Jim Cain, Western Geophysical Company, Houston, Texas

GNSS will be pervasive in 2007 as digital watches today and virtually all requirements for navigation and positioning will be satisfied by simple, reliable, and inexpensive off-the-shelf equipment. Therefore, ION GPS ’07 (or probably ION GNSS ’07) will probably focus more on integrating GNSS PVT information into a growing number of different applications and less on the technical details of GNSS itself.

Steve Girant, Electronic Navigation Consulting International, Dartmouth, Nova Scotia, Canada

2007/2017

GPS will no longer be the premier system. GNSS users will be hybrid (multiple providers).

John Lavrakas, Advanced Research

Phased array antennas will be used in all GPS equipment. The civilian community will have cracked the M-code.

Adam C. Everspaugh, ARNIC Space Systems

Galileo still not be fully operational due to funding squabbles. QZSS fully operational. COMPASS operational. Indian system near operational. GPS IV competition under way.

Francois Belanger, University of South Hampton, UK

GNSS 2007 continued on page 18
The 2007-08 Galileo program now that a long-proposal for completion of Europe's crowded field of operations. identifies hazards in an increasingly Command. JGCC's vision includes the direction of the U.S. Strategic which was activated last year under mission element for JFCC/Space, a part represents an important space assets of which GPS is just systems.

Through FY13 for procurement, commitment by the U.S. Air Force (including procurement, operations to maintain the GPS constellation approximately $1 billion spent each year systems and equipment, approximate $32+ billion invested to date in military space activities.

Leading this surge is GPS, with $32+ billion invested to date in systems and equipment, approximately $1 billion spent each year to maintain the GPS constellation (including procurement, operations & maintenance), and $8+ billion commitment by the U.S. Air Force through FY13 for procurement, modernization, and upkeep of GPS systems.

Preserving the extensive U.S. space assets of which GPS is just a part represents an important mission element for JFCC/Space, which was activated last year under the direction of the U.S. Strategic Command. JGCC's vision includes establishing a space situational awareness clearinghouse that identifies hazards in an increasingly crowded field of operations.

Pedreira outlined a new proposal for completion of Europe's Galileo program now that a long-sought public-private partnership (PPP) has failed. In the absence of a private concession agreement to monitor, the GSA's role and responsibilities would change substantially under the European Commission proposal that places the European Space Agency (ESA) in the role of technical lead/design authority for the system.

As the world's oldest and largest GNSS conference, the event has come a long way since the first ION GPS conference in 1987.

In a presentation titled “Towards a GNSS System of Systems,” Hein wove the history of the various satellite navigation systems, the technical challenges of RF compatibility and GNSS system interoperability, the efforts to achieve interoperability (especially in the E1/L1 band), and the tasks facing GNSS systems operators and experts in the years ahead.

Past Is Prologue to Future

As the world's oldest and largest GNSS conference, the event has come a long way since the first ION GPS conference in 1987 (which was not billed as an international event) when the Satellite Division gambled on the future prospects of a still incomplete and still controversial Global Positioning System. At the time only 10 GPS satellites were on orbit — out of a fully operational capability (FOC) of 24 and the actual current constellation's total of 30 spacecraft. And no additional GPS satellites would be launched for nearly 1-1/2 years.

The ION GPS 1987 program had only 37 presentations (compared to 300 papers at this year's conference, including those in the classified session held yesterday and cosponsored with the Joint Service Data Exchange and the Air Force Research Laboratory.)

From that original pioneering venture in 1987, the Satellite Division has continued to clarify the mission of the conference and of the division overall: encouraging the development, operation, and use of satellite-based navigation and position determination systems.

Acknowledging the increasing number of GNSS systems in existence and under development, in 2003 ION changed the name of the event from “GPS” to “GPS/GNSS.” The following year, it became just “ION GNSS.”

ION GNSS 2008 is scheduled for September 16-19, 2008, at the Savannah International Convention Center, Savannah, Georgia. Pre-conference tutorials will take September 15-16. For more information, visit the ION website: http://www.ion.org/meetings/#gnss.
Annual Award Nominations

Members are encouraged to submit nominations for one or more of the following annual awards given by The Institute of Navigation for excellence in navigation.

- Early Achievement Award — for an individual early in his or her career who has made an outstanding achievement in the art and science of navigation.
- Norman P. Hays Award — for outstanding encouragement, inspiration and support leading to the advancement of navigation.
- Superior Achievement Award — for individuals making outstanding contributions to the advancement of navigation.
- Thomas Thurlow Award — for outstanding contributions to the science of navigation.
- Tycho Brahe Award — for outstanding achievement in space navigation.
- Captain P.V.H. Weems Award — for continuing contributions to the art and science of navigation.

Official nomination forms, along with brochures on the background and purpose of each award, are available from the ION National office by phone, 703-383-9688, or via the website at www.ion.org. Nominations must be received by January 31, 2008.

The awards and accompanying engraved bronze plaques will be presented at the IEEE/ION PLANES 2008, May 5-8, 2008, in Monterey, California. The ION urges you to participate in the process so deserving individuals will receive appropriate recognition.

In addition to the above awards, the winner of the Samuel M. Burka Award — for outstanding achievement in the preparation of papers advancing navigation and space guidance — as chosen by the editorial panel of ION’s journal, NAVIGATION, will be honored.

Address correspondence to Awards Committee, The Institute of Navigation, 3975 University Drive, Suite 390, Fairfax, Virginia 22030, phone: 703-383-9688; fax: 703-383-9689; e-mail: mlewis@ion.org.
You Can’t Beat FREE!

It’s a big world out there on the Internet, and navigators can find their share of the spoils:

FREE model GPS IIR-M
Build your own museum-quality paper GPS satellite model at home courtesy of Baseband Technologies, Canadian designers of GNSS OEM receivers. All you need are the supplies in the average third-grader’s school desk and two or three hours of free time.

The finished product fits nicely on a corner of your desk. Download the design package and instructions here: <http://www.basebandtech.com/free_sat.html> (Baseband says it will post a Compass satellite model soon….)

FREE Countdown Ringtone
Marketed as the “blog by folks who actually launch satellites into orbit,” Really Rocket Science offers a free downloadable countdown ring tone at <http://blog.reallyrocketscience.com/home>. Hosted by communications satellite company Americom Government Services, blog contributors post about space, satellites, rockets, engineering and “really cool stuff.” (including nice visuals ”)

FREE comic book
Galileo: A Compass to the Future. The story begins on an 18th century sailing ship, drifting over Jupiter’s moons and Harrison’s clock sailing straight to present-day London and Toulouse and wonderful illustrations of GNSS capabilities including GPS, Galileo, EGNOS, WAAS, MITSAT and GLONASS (with favor given to the European systems, of course.). Published by Thales Alenia Space, with art by Fred Vignaux and story by Eric Pailharey.

ARGOS Satellite System:  
Save the Whales . . . Stay Away from the Crocodiles

The environmental group Greenpeace and scientists from New Caledonia and the Cook Islands are using ARGOS satellites to track 20 endangered South Pacific humpback whales from the South Pacific to Antarctica in an effort to gather information without hurting the animals.

Greenpeace wants to stop Japan’s whaling research program — one that kills whales by the hundreds and that the environmental group says is commercial fishing, not research. This year, Japan plans to hunt 50 humpback whales during the summer season in the southern hemisphere.

Already, the data has shown previously unknown travel patterns by the whales. The sea-going mammals from the Cook Islands are heading in a westerly direction, not south to their summer feeding grounds. Greenpeace thinks they may be swimming towards a current that crosses the Pacific to the east coast of Australia before they turn south.

The New Caledonian group is heading south as expected, but are fanning out over a large area and not staying together. (A couple of outliers are heading west).

The research group Whalenet says a tagging team using compound crossbows to shoot barbs with the tab and antenna into the area behind the whale’s blowhole (Officials say this doesn’t cause undue stress, but whales aren’t writing the news stories.)

The tag collects data while the whale is underwater and then transmits it when the animal surfaces. The tag antenna sends a signal each time the animal surfaces, with time, date, position, dive depths and durations, amount of time at the surface in the last six hours and quality of the transmission. The ARGOS instruments collect the information when the satellite passes overhead. Depending on the location of the satellite in relation to the animal, opportunities for the data to reach the satellite in any given day are short and limited.

The ARGOS satellite system was set up in 1978 by CNES, NASA and NOAA, joined later by EUMETSAT. It can locate a data source from anywhere on Earth using the Doppler effect.

You can access data on a number of tagged marine animals in satellite observation programs at http://whale.wheelock.edu/whalenet-stuff/stop_cover.html.

The Whalenet program is funded by National Science Foundation and sponsored by Wheelock College in Boston, Massachusetts.

CROCS!

Humans often remove crocodiles from areas where they bother our species, thinking that the reclusive, cranky animals won’t find their way home.

Incorrect.

An Australian research group removed three wild saltwater crocodiles from estuaries in Far North Queensland and flew them by helicopter to new waters 32 to 80 miles from home. They tagged and followed the animals using the same ARGOS satellite tracking techniques described in the humpback whales.

All three made it home.

Fast.

One, who was actually flown across a peninsula from the east coast to the west coast, swam all the way across the peninsula for a total of 250 miles in 20 days. The trio swam between 6 and 19 miles per day.

Researcher Craig Franklin, a University of Queensland professor, said the crocodiles probably used many factors to navigate, including their position relative to the sun, magnetic fields, sight, and smell.

“Crocodiles are more closely related to birds than they are any other reptile, so they are possibly using navigation systems similar to birds,” he said.

A complete report on the project is available at the Public Library of Science (PLOS: http://www.plosone.org/article/fetchArticle.action?articleURI=info:doi/10.1371/journal.pone.0000949)
to determine Sputnik’s orbit simply by measuring the Doppler-induced changes in the frequency of the simple radio signal that it transmitted.

A few months later, Guier and Weiffenbach were called before their boss, Frank McClure, who asked them to reverse the Sputnik tracking technique: use a known orbit and the same Doppler shift to calculate the position of a ground receiver. McClure was seeking a system that would allow Polaris nuclear submarines to keep precise track of their locations. He realized that this could be done by “inverting” the approach of Guier and Wiefenbach: by measuring a radio signal from a satellite whose position is known, a submarine could determine its own position.

This introduced an era in which a number of U.S. government programs began investigating ways to create a satellite-based system for positioning, navigation, and timing.

**TRANSIT.** At APL, McClure persuaded a colleague, Richard Kerschner, to design a system of satellites that would provide navigation information. The system, TRANSIT, began operating in 1964, with five satellites that broadcast two different tones. The use of two tones allowed the system to compensate for variable signal delays that occurred in the ionosphere.

It took the submarines 6 to 10 minutes to get a fix, which was accurate to within 25 meters.

**TIMATION.** Meanwhile, the Naval Research Laboratory and the Space and Missile Systems Organization of the U.S. Air Force favored different satellite navigation systems.

The naval lab backed the TIMATION program, which used high-precision clocks to provide both accurate position and precise time measurements to ground observers. The time measurements improved the system by allowing more precise determinations of the satellite location and lengthening the time between required position updates.

Two TIMATION satellites, each bearing a quartz clock accurate to one part per billion, were orbited: one in 1967 and the other in 1969.

**621B.** The U.S. Air force Space and Missile Systems Organization pushed a program called 621B, which used a signal that employed pseudo-random noise to resist jamming.

Unlike the various Navy systems, 621B provided altitude, as well as latitude and longitude. “To the Navy, navigation is essentially a two-dimensional problem, but the Air Force was definitely interested in the third dimension,” Parkinson says.

The 621B system was tested using aircraft between 1968 and 1971.

**Setbacks**

“There was a fierce competition over dollars,” Parkinson recalls. And each of the systems had some major drawbacks.

TRANSIT fixes could be updated only four to six times a day, and if too many satellites were launched they would begin jamming each other. TIMATION was easy to jam and only two-dimensional. 621B needed...
continuous signals from a ground station to operate.

In 1972, Parkinson was transferred by the Air Force to the 621B program over his objections, and thus got into satellite navigation through what he terms a “lucky failure.”

He soon was called upon to give an extended briefing on the system to the new director of research and engineering for the Department of Defense, Dr. Malcom Currie. Currie liked the system and wanted to do something new, so he encouraged Parkinson in his many trips to Washington, D.C., to sell the program.

In August 1973, the 621B proposal went before a streamlined Department of Defense decision-making process, called the Defense System Acquisition and Review Council (DSARC), that had been set up by David Packard in 1972.

All the decision-makers were convened in one room and DSARC said “no” to the project.

But the rejection turned out to be another “lucky failure.” Currie determined that what the panel wanted was a joint project, with all the services participating, and he put Parkinson in charge of pulling such a project together.

**NAVSTAR GPS**

Parkinson and a small staff met in an empty Pentagon over the Labor Day weekend in 1973, coming up with a system that incorporated the best features of each of the competing systems: the signal structure from 621B, the orbits and orbital prediction method from TRANSIT and the clocks from TIMATION.

They called the new system Global Positioning System/NAVSTAR — an acronym originally without a meaning, but later explained as variations on the theme of Navigation by Satellite Timing and Ranging.

The project went before the DSARC panel on Dec. 17, 1973 and was approved.

The first “phase 1 bird” was launched in February 1978, on time and within budget. When the system was up and running it provided positions accurate to within 10 meters.

The signal was specially encoded so that civilian users were only able to obtain locations with an accuracy of about 50 meters. Nevertheless, civilians — surveyors being among the first — immediately started finding uses for this new capability.

The GPS/Navstar development group had predicted that the military would have use for 27,000 GPS receivers and set of goal of making these for less than $10,000 each.

And the rest is history . . . and current events.
The plenary panel will discuss innovative ways that Global Navigation Satellite Systems are being used to help humanity. Topics will include use of GNSS in robotics, in remote sensing of earth, for weather monitoring, and in monitoring/detection of earthquakes and tsunamis.

**Session Topics**

- GNSS Interoperability & Compatibility
- QZSS: Quasi-Zenith Satellite System (QZSS)
- Galileo
- Land-Based Applications
- GPS Modernization & GPS III
- Augmentation Systems: GBAS & SBAS
- Space Navigation Applications
- Carrier-Phase Positioning
- Advanced Topics in Location-Based Services
- Marine Navigation Applications
- Military Applications
- Novel Applications
- Emerging Navigation Technologies
- Aviation Applications & Precision Approach
- Interference & Spectrum Management
- Surveying & Geodesy
- Algorithms & Methods
- Scientific, Timing, & High-Precision Applications
- Receiver & Antenna Technologies
- Urban & Indoor Navigation Technology
- Integrated Navigation Systems
- Atmospheric Effects
- MEMS & Inertial Systems
- Multipath & Multipath Mitigation

January 5 is the last day to pre-register to avoid a late fee and to obtain the discounted hotel rate!