The Federal Aviation Administration’s (FAA) Loran Evaluation Team held its first public meeting in conjunction with this year’s annual meeting of the Institute of Navigation in Cambridge, Mass. The meeting, hosted by the Volpe National Transportation System Center, provided the attendees a summary of the findings contained in the Loran Evaluation Report that was delivered to the U.S. Department of Transportation’s Undersecretary for Policy (chair of the DOT Positioning and Navigation Committee) on March 31, 2004.

The Loran Evaluation Team’s purpose was to determine, from a technical perspective, whether Loran could be used as a safe, accurate, reliable, and effective alternative position, navigation, and time system during an outage of the Global Positioning System (GPS) or its augmentations (e.g., Differential GPS, Wide Area Augmentation System).

Thus, the evaluation was done for the benefit of current and future GPS users and not for the benefit of the existing Loran users — so the GPS users might retain the benefits they derive from their GPS applications.

Meeting attendees included national and international business and government representatives interested in the potential of using an enhanced Loran capability in their applications. The meeting began with the presentation of the same technical briefings given to senior officials in DOT, FAA, and U.S.C.G. during the report’s clearance process and ended with a lengthy question and answer period. Mitch Narins, the FAA program manager; Dr. Per Enge (Stanford University) and Dr. Ben Peterson, Capt. U.S.C.G. (Ret.) (Peterson Integrated Geopositioning), chairs of the Loran Integrity Performance Panel (LORIPP) and Loran Accuracy Performance Panel (LORAPP); and other members of the team briefed the report’s findings and recommendations and responded to questions from the attendees. These briefs and the questions and discussions that followed encompassed all aspects of the FAA’s multi-modal, multi-organizational, and multi-national team’s two-year evaluation to determine whether a modernized Loran system could satisfy the current requirements for aviation non-precision approach (NPA), maritime harbor entrance approach (HEA), and timing and frequency user communities.

The evaluation concluded that a modernized Loran system could satisfy the current NPA, HEA, and timing/frequency requirements.

Enhanced Loran-C
Can Mitigate Vulnerabilities
To GPS Users

Loran continued on page 12
The Institute of Navigation
Getting Better and Better!

The Institute continues to be in a sound financial position as it serves the needs of the membership and the navigation community at large. I believe we have set a good course toward enhancing programs and looking forward to new trends in technology and member services.

The ION® membership remains fairly strong with more than 2,600 members and 320 library subscriptions. Of these, 44 are ION Fellows, and over 180 are student members.

Our meetings continue to provide invaluable technical and networking benefits. To summarize the statistics for the past year: the 2004 Annual Meeting, co-sponsored by the Air Force Institute of Technology and the Air Force Research Laboratory, held in Dayton had 277 attendees, and included 81 papers in the proceedings; the 2004 ION GNSS Meeting sponsored by the Satellite Division in Long Beach, was our largest meeting as usual, with 1,853 attendees and 302 papers presented and published; and the 2005 National Technical Meeting in San Diego, Calif., hosted 327 attendees with 110 papers presented and published.

In the past year, we have improved the distribution schedule of the meeting proceedings to four weeks after the annual and technical meetings and six weeks after the ION® GNSS meeting. In addition, online availability of paper preprints for meeting attendees has dramatically enhanced the timeliness of access to new technical information.

Meeting Attendance Up
This year’s annual meeting was up 18 percent over the number of abstracts submitted over last year and included, in addition to the standard technical sessions, three new workshop format sessions (GNSS Modernization, the 2003 Solar Superstorms, and Atmospheric Models and Their Impact on Satellite Navigation Systems). I appreciate the extra efforts made by the conference organizers and session chairs to introduce this new innovation for the ION®.

PLANS 2006 Co-sponsorship
With the approval of council, in the past year we successfully completed an agreement with the IEEE Aerospace and Electronic Systems Society to co-sponsor the PLANS 2006 meeting to be held in San Diego, Calif., in April 2006. Several active ION members will be an integral part of the organizing and program committee, in particular, the ION Meetings Chair, Frank van Graas, and former ION® president, Per Enge. I am optimistic about this new opportunity for the ION® and hope that with an initial success in 2006, it will evolve into a long term collaboration between our two organizations.

Thanks to the efforts of Dorota Grejner-Brzezinska, the ION® is also reaching out to other professional societies to establish partnerships in areas of common interest.

Future Collaborations
In January, the ION Council approved memoranda of agreement with the International Society for Photogrammetry and Remote Sensing (ISPRS) and the International Association of Geodesy (IAG); which have now been signed by representatives of each organization. These agreements will pave the way for future collaborations between our groups such as jointly sponsored sessions within existing conferences and cross-listing of conferences events on our respective Web sites. I am optimistic that such activities will be beneficial to ION® members and also raise the visibility of ION® activities to a wider professional audience.

In addition to the three conference proceedings, four issues of NAVIGATION were circulated this last year thanks to the efforts of our publications chair, Chris Hegarty, as well as four issues of the ION® newsletter. The newsletter now includes new feature articles championed by our technical area chairs, which focus on navigation technology and policy in the areas of land, marine, air, and space navigation.

The newsletter also continues to highlight regular features from Joe Portney and Marvin May, who are greatly appreciated for their continuing contributions. Articles on outreach activities also serve to highlight the many exciting activities devised by our members and sponsored by the ION® sections to bring navigation and navigation technology to the community.

Education & Student Involvement
The ION® has been able to continue its support of student involvement and education at many levels. Since 2002, the ION® has provided matching travel grants for up to five students to present papers at the National Technical and Annual Meetings. Several sections are sponsoring fellowships and student awards for undergraduate and graduate students within their areas. The Satellite Division has also continued its commitment to student learning with the ION® Autonomous Lawnmower competition now in its second year; 10 navigation lessons for middle school students now available both from the ION® and online as part of Teach Engineering sponsored by the National Science Foundation and the Department of Education, and the establishment of the Parkinson Award to recognize excellence in graduate research.
Government Fellows
The ION® is now in its fifth year of supporting a Government Fellows program and we anticipate sending both a Congressional and Executive Fellow to Washington, D.C., next year. As a fairly small professional society, we should be particularly proud of our support of this program; which provides great benefit to our lawmakers and a unique life experience to our member participants. Our current Congressional Fellow, John Plumb, has begun service for the junior senator from Colorado, Ken Salazar, and Bill Klepczynski has graciously extended his service to the State Department.

Web Services
The ION® has continued to improve its online resources for both members and the general public. Our measures of Web usage, such as number access, page hits, etc., have about doubled since 2002. Close to 2,000 members have at some point accessed the Members Only features of our Web site. Access to the proceedings/journal paper database tends to be the major motivation for members to access the site, with additional members signing in for the first time in 2005 to access the online voting system for ION® officers. Online registration has also streamlined the registration and hotel reservation process, simplifying things for attendees and providing for better conference planning and support by the national office.

Welcome Jim Doherty
It has been a full year! Many exciting programs are in the works and a fine group of people are poised to take over the leadership of the ION Council. I am especially pleased to welcome Jim Doherty as our new president. He brings to the position broad experience in the navigation community, in depth technical knowledge, and overall wisdom and integrity that I greatly admire. I wish him much success.

Respectfully Submitted by,

Dr. Penina Axelrad
Outgoing ION® President
In our computer age, one may acquire some programming skills; learn some rudimentary astronomy and celestial navigation; and with a regressive ephemeris reconstruct the celestial tapestry of the past and focus on great historical events.

Let us revisit Columbus’s first voyage. The eminent Columbus scholar Samuel Morison always characterized Columbus as a dead reckoning (DR) sailor who muffed his opportunity to determine his longitude on two occasions when observing eclipses. Another view holds that Columbus may have relied upon celestial observations for his navigation. This view contends that certain eclipses, conjunctions, and culminations could aid Columbus in determining his latitude and/or longitude. Columbus had no sailing instructions to steer to a specific set of coordinates. His quest was to find a western route to Cipangu (Japan) and Cathay and he had a perception of a smaller world which encouraged him to believe that Cipangu was 2,760 miles away as opposed to roughly 12,200 miles away. He sailed with crude instruments and experienced the changes in magnetic variation as noted by comparing the direction of the pole star to his magnetic compass. The magnetic variation was dominantly westerly. Columbus’ charts showed that he held the latitude of 28°N for close to 1,400 nmi after departing the Canaries without altering course. He was not concerned that his track would be deflected to the left as a result of the westerly magnetic variation. The return voyage would experience the same deflection to the left of course in the dominantly westerly variation that prevailed. His charts showed constant course segments with no evidence of changes (other than to avoid weather) leading one Columbus researcher, Admiral Robert McNitt USN (ret.), to conclude that Columbus relied exclusively on dead reckoning in his navigation. Implicit in this conclusion was that if a celestial observation was made and it showed a difference in latitude over the DR position one would expect a course change to be made.

Dead Reckoning

In Columbus’ age, dead reckoning was the dominant method used for navigation. It required knowing one’s course as determined from the magnetic compass and speed by timing the movement of a chip log thrown over the side with reference to external markers on the side of the ship (although Morison believed that Columbus just estimated his speed). The distance made good per hour was noted by placing a peg in a hole along a radiating line marked on a peg-board representing the course of the ship hourly. The results of this peg-board tracking were then transferred to the map at the end of the day. The DR position could be updated by celestial observations obtained by observing Polaris, low grazing stars, and conjunctions according to the recent paper by Arne Molander who noted correlation of Columbus’ fixes with certain celestial events. The problem was that the astrolabe and the quadrant, both capable for use to measure the elevation angle of the celestial body to yield latitude, were sensitive to gravity owing to their pendulous element for establishing the vertical. In a ship subject to the vagaries of the ocean motions, the pendulous element was almost constantly in motion. These instruments were primarily used for observing celestial bodies from the land or the quiet waters of a harbor. The cross staff would have improved the sighting accuracy, but it was not in use until the next century.

Figure 1 shows the diagram for obtaining latitude when a celestial body is on your meridian. It is a cross section of the celestial sphere when the celestial triangle degenerates into the arc of a circle when a celestial body is observed on your meridian. Latitude can be calculated by the addition or subtraction of measured angles with known values. The elevation of the star or Sun is measured and the declination of the body is obtained from a table. On Columbus' first voyage, his chart indicated adherence to 28°N after departing the Canaries. If he were relying upon celestial observations to maintain this latitude line, he could verify his adherence to the course by observing the pole star with his quadrant or astrolabe (despite their susceptibility to error at sea). Molander believes that Columbus may have used low grazing circumpolar stars when they appeared above the northern horizon at their culmination (on his meridian as they were at their lowest elevation) to determine his latitude to maintain adherence to his course. He may have used a kamal in his measurements, a simple instrument held by both hands and held taught by string whose one end was clenched in the observer’s teeth and the other end bridled to the instrument. Determining one’s latitude by observing the culmination of
a low grazing star is not susceptible to verticality errors as the tangent to the arc of the measured star remains close to parallel to the horizon over a wide range (1-cosine effect for small angles) as viewed in Figure 1. We cite Schedar (Cassiopeia) as the star Columbus could have used on his return trip at the latitude of the Azores. It is an example of a low grazing circumpolar star to aid in establishing latitude adherence.

In Figure 2, we see how one obtains latitude by observing Polaris. The pole star is at P with the horizon at (HH'). Since its declination (angle between the celestial body and the equatorial plane QQ') is 90°, the polar distance to the horizon arc PH' is equal to the latitude of the observer arc QZ.

In this example, the elevation angle of Polaris is 37°, therefore Columbus's latitude is 37° N latitude. We ignore the effects of refraction and dip. The question will be what elevation angle should Schedar be at culmination to establish that the observer is at 37° N latitude? We assume that Schedar's declination is 56° in the Columbus era. Determining longitude was accomplished on land by observing lunar eclipses. Columbus had access to Ephemerides for lunar and solar eclipses. Both the Regiomontanus's Ephemerides and Zacuto's Almanach Perpetuum contained the predicted times of total eclipses at Nuremberg and Salamanca. A total lunar eclipse occurs when the Moon enters the umbra sector and ends when the Moon exits the umbra sector and enters the penumbra sector as seen in Figure 3.

On February 29, 1504, Columbus observed a lunar eclipse from the middle of the north coast of the island of Jamaica. A lunar eclipse can be observed by anyone within a hemisphere if the full Moon is observed. One need only note the local time of the event and compare it to the local time at the reference location in the ephemeris. This is an observation of simultaneity. He concluded that the difference in time between the Isle of Cadiz in Spain and the center of Jamaica was 7 hours 15 minutes. As the eclipse began before sunset, he based his calculation on observing the end of the eclipse when the illumination of the Moon returned. He knew the elapsed time between the end of sunset and the end of the eclipse which was two-and-a-half hours as timed by the half-hour glass (five half-hour glasses in duration). He obtained the altitude of Polaris as 18 degrees using his quadrant. This was close to the correct latitude of his location presumed to be Santa Gloria (today's St. Anne's Bay) at 18° 27'N, 77° 14'W. The difference of longitude between Cadiz and his location was actually 70°56' or 4 hours 44 minutes. He incurred an error of 2 hours 31 minutes. It appears that Columbus knew the difference in longitude between Salamanca and Cadiz. (~ 39 arcminutes of longitude) since his ephemeris was based on observations made at Salamanca and Nuremberg.

There are various reasons that could explain Columbus' colossal errors in determining longitude by timing the lunar eclipse. The one half-hour glass introduced an error. If he backed into his estimate for the beginning of the eclipse by using the elapsed time from sunset to the end of the eclipse to establish the beginning of the eclipse was another source. He could have exaggerated the longitude difference to establish a vaster domain under discovery. Clearly this dependence on a half-hour glass as a basis for time reference was an error source and extrapolating the time of the beginning of the eclipse was another error source.

Let us assume for this Brain Game that our Columbus had a clearer awareness of the beginning of the lunar eclipse and concluded that the difference in time between the island of Cadiz and Santa Gloria for the beginning of the eclipse was 4 hours 30 minutes. He also knew that the reading of the half-hour glass reference introduced an error of 1 percent of the time on the slow side. Assume that 5.5 hours elapsed from local noon (last setting of the half-hour glass) to the time of the eclipse. Columbus knew that his time master was slow. We will presume that he also read the time of the eclipse using his nocturnal (an instrument used to determine time at night and not available until the next century). It had an index error of -0.1 hour. Based on his uncorrected nocturnal reading, he concluded that the longitude difference between the two sites was 4 hours 30 minutes. He then corrected the readings of his time sources for their errors and averaged them.

What was his measurement of the difference of longitude between Cadiz and St. Anne's Bay?

The elevation angle of Schedar and the longitude difference between Cadiz and St. Anne's Bay was:

A. Schedar 3°, longitude difference 4 hours 35 minutes
B. Schedar 4°, longitude difference 4 hours 30 minutes
C. Schedar 6°, longitude difference 4 hours 32 minutes
D. Schedar 5°, longitude difference 4 hours 26 minutes

Portney continued on page 11
Cambridge, Massachusetts

Celebrating the 60th Anniversary of the ION®
 At Its 61st Annual Meeting!

At its 61st Annual Meeting, the Institute of Navigation celebrated its 60th Anniversary, marking a significant milestone in the life of the Institute.

Approximately 340 people attended the meeting, which was co-sponsored by The MITRE Corporation and Draper Laboratory. This year’s program organizers were General Chair James Arnold, Federal Highway Administration; ION Program Chair Dr. Anthea Coster, MIT Haystack Observatory; and MITRE Program Chair Elliott Kaplan, The MITRE Corporation. Many thanks go to the organizers of the meeting for their efforts. The technical program included three new discussion workshops: one on GNSS Modernization, one on Superstorms of 2003, and another on Atmospheric Models.

One of the highlights of this meeting was the recognition and celebration of the Institute of Navigation’s 60th Anniversary. Anniversary festivities were held at the Boston Museum of Science where more than 250 ION® members and friends were treated to dinner in style — mad-scientist style that is.

The Institute of Navigation also hosted its Annual Awards Banquet and named its new fellow members for 2005. (See the following pages for more on the award winners and fellows.)

As is customary, at the conclusion of the ION Annual Meeting, the new officers and committee chairs were announced and confirmed.

MITRE program chair, Elliott Kaplan (left), and ION® program chair, Dr. Anthea Coster (far right), accept congratulations from outgoing ION® president, Dr. Penina Axelrad.

Outgoing ION® president, Dr. Penina Axelrad, passes the gavel to incoming president, Jim Doherty.

A Collection of ION’s Past Presidents at Annual Awards Banquet

Some of the ION’s past presidents assembled at the ION Annual Awards banquet.


Thank You Exhibitors!

AG Davis - AA Gage
CAST
GPS World
L-3, Interstate Electronics
Navtech Seminars & GPS Supply
Omnicom Engineering
Raytheon
Spirent Federal Systems
USAF, 746th Test Group
The Institute of Navigation had the pleasure of honoring an outstanding group of contributors to the art and science of navigation at its 61st Annual Meeting held in Cambridge, Massachusetts, June 27–29, 2005.

The Institute extends its warmest congratulations to the recipients, its sincere thanks to all those who submitted nominations and its appreciation to the members of the ION® Awards Committee who served so effectively in selecting the honorees. The Annual Awards Program is sponsored by the Institute of Navigation to recognize individuals making significant contributions, or demonstrating outstanding performance, relating to the art and science of navigation.

Nominations for these awards may be submitted by anyone, but all nominations must conform to ION® nomination guidelines.

Award recipients need not be members of the Institute.

Details of the nomination process and nomination forms are available at www.ion.org.

Dr. Sherman Lo
For his pioneering work on the modernization of LORAN and its use as a high-integrity backup to GNSS navigation for aviation users.

Lt. Col. Michael F. Peet
For significant and enduring contributions and exceptional navigational expertise in transforming Joint Specialized Undergraduate Navigator Training, ensuring production of the world’s preeminent combat systems officers.

Major James E. Griffin
Capt. Jeremiah R. Monk
For his pioneering work in mission planning systems, increasing the capabilities of United States Special Operations forces and ensuring future safe mission accomplishment.
Burka Award

Dr. Christopher R. Carlson

Professor J. Christian Gerdes
(pictured above)

Weems Award

Curtis A. Shively
For his continuous significant contributions to the understanding and rigorous statistical analyses of air navigation operational requirements with respect to their impact on GNSS augmentation system design alternatives.

Tycho Brahe Award

Dr. E. Glenn Lightsey
For his pioneering work in the development, implementation, and testing of practical, low-cost GPS receivers for space applications.

Hays Award

Mitchell J. Narins
For his leadership and dedication in championing safe, secure, efficient, and effective navigation services that provide a robust position, navigation and timing infrastructure.

Thurlow Award

Anthony S. Abbott
For significant contributions to the performance of navigation and all weather precision weapon delivery systems on the B-2 bomber.

Mr. Abbott entertains audience with his attire during his acceptance address.
Election to Fellow membership recognizes the distinguished contributions of Institute of Navigation 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.

Former members of the ION who are not currently active members of the organization may be elected to non-voting fellow membership. A limited number of individuals will be accepted as posthumous fellow members.

Election to honorary fellow membership is authorized for non-members of the Institute of Navigation who are qualified by their accomplishments for recognition as non-voting fellow members. Members of other national institutes of navigation are also considered in this category. Fellow nominations may be submitted by currently active ION members.

All nominations must conform to ION nomination guidelines. Nominations must include a brief biography and a proposed citation.

Details of the nomination process and deadlines can be found at www.ion.org.

Welcome New 2005 ION® Fellows

Anthony S. Abbott
For his significant lifetime contributions to the art and science of navigation and his leadership and technical innovations in the development of GPS user equipment and integrated systems.

Dr. James L. Farrell
For his sustained contributions to inertial navigation technology, GPS integrity, and integrated navigation systems.

BGen (Ret.) Keith R. Greenaway
For his authority and extensive experience with arctic air navigation, his years of study and research in the subject, and his ever-ready willingness and ability to teach others.

Larry D. Hothem
For sustained contributions to the development and application of geodesy and surveying techniques and professional leadership at the national and international level.

Joseph N. Portney
For his leadership and sustained contributions to the development of inertial navigation systems.
Referring to Figure 4, the elevation angle of Schedar to yield a latitude of 37°N latitude:

\[
\text{Arc PF} = 37°\text{ elevation Schedar}
\]
\[
\text{Arc CQ} = 56°\text{ declination Schedar}
\]
\[
\text{Arc HP} = 56°\text{ - 37° = 9° elevation Schedar}
\]
\[
\mathbf{t = (90° - d)} + h
\]
\[
\mathbf{h = (56° - 90°)} - d
\]
\[
\mathbf{h = 56° - 90° = 34°}
\]

Figure 4, Computing Elevation Angle of Schedar

Regarding the longitude difference: The half-hour glass error after 5.5 hours was -0.01 x 330 minutes = -3.3 minutes. Correction is +3 minutes to be added to 4 hours 30 minutes = 4 hours 33 minutes. The nocturnal error was -0.1 hour or -6 minutes. Correction is +6 minutes to be added to 4 hours 30 minutes = 4 hours 36 minutes. Then the average difference in longitude is:

\[
\frac{4\text{ hrs 36 min} + 4\text{ hrs 33 min}}{2} = 4\text{ hrs 35 min}
\]

His actual longitude difference was 4 hours 44 minutes west of Cadiz. What we find with the ascribed nominal errors to the instruments is that Columbus in this simulation would be within 9 minutes or 2.25° of his actual longitude. We would then conclude that the balance of the error was due to his perception of the beginning of the eclipse and other errors. It is known that he measured his altitude of the pole star as 18° at St. Anne’s Bay which was close to the actual latitude of 18° 27’. Columbus typically had a history of determining his latitude with significant error. He blamed this on his quadrant. Some scholars believe he was reading his instrument high to record higher latitudes initially to keep his discovery within the bounds ascribed to the Spanish sovereignty by the Pope in accordance with an agreement.

The committee recognized retiring Chairman Larry Chesto for his hard work and leadership since the establishment of SC-159 in 1985. The committee reviewed current Working Group activities.

WG-2, GPS/WAAS. An update to DO-229C is planned for the second quarter 2006. Inputs are expected for in-band interference and antenna patterns, which will be used for setting a cross-correlation number — high power to low power satellite spread. WG-2 will provide WG-7 suggestions for setting specifications on hazardously misleading information (HMI) to ensure the “chain” from antenna to receiver output meets HMI and continuity requirements.

WG-4, GPS/LAAS. The group received presentations on the FAA’s LAAS program status and the Local Airport Monitor (LAM) concept. The FAA is supporting several R&D activities: an integrity analysis for CAT-1, an investigation of a simplified LAAS architecture (LAM), an analysis of the RFI susceptibility and security of GPS-based landing systems and a cooperative engineering effort with Boeing for CAT III requirements. LAM is a new concept the FAA is assessing for achieving CAT I precision approach. The current WG-4 work plan address three areas: LAAS MASPS and MOPS maintenance, CAT II/III MASPS and ICD maturation and initial work for LAAS MOPS and ICD including CAT II/III.

WG-6, GPS/Interference. Work is continuing on an update to DO-235A, Assessment of Radio Frequency Interference Relevant to the GNSS, with a target date of March 2007. Issues discussed included susceptibility, an aggregate RFI model, the out-of-band pulsed RFI environment at L1 and a Transmitting-Portable Electronic Device (T-PED) scenario for SC-202.

WG-7, GPS L1/L5 Antenna. The group has started work on a new L1/L5 antenna MOPS, but initially will produce an L1-only MOPS as an alternative MOPS for “more demanding” applications. DO-228 would be retained. The intent is not to replace existing antennas but to better characterize their performance.

WG-8, GPS/GRAS. Completion of the GRAS MOPS is expected at the October meeting and the Final Review and Comment (FRAC) process is planned for the March 2006 meeting. The MOPS will include three functional classes — Beta, Gamma, Delta and one operational class — Class 3.
Loran continued from page 1

requirements in the conterminous United States and could be used to mitigate the operational effects of a disruption in GPS services, thereby allowing the GPS users to retain the benefits they derive from their use of GPS.

Reason for Evaluation

The U.S. Coast Guard (U.S.C.G.) has provided the Loran service for over 40 years. Loran has been used for navigation in various transportation modes and for precise timing and frequency applications. In the 1980s, in response to user and industry requests, the U.S.C.G. and FAA jointly conducted a project to expand the area of Loran-C coverage to close the so-called “mid-continent coverage gap.” Although the desired coverage was achieved, other required aspects of the system’s performance were not met. Consequently, the system failed to gain full FAA and aviation user acceptance, and attempts to obtain FAA certification of NPA-capable receivers were unsuccessful.

Then, in 1994, the U.S. Federal Radionavigation Plan (FRP) stated that Loran-C would be terminated in 2000. In the late 1990s, this situation changed due to the growing concern about the vulnerability of GPS and how the loss of GPS might affect the U.S. critical infrastructure. This was the topic of the John A. Volpe National Transportation System Center (Volpe) report, “The Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System,” of Aug. 20, 2001, and the FAA ASD-1 report, “Navigation and Landing Transition Strategy,” of August 2002. This concern refocused attention on Loran-C and its use as a possible redundant system for position, navigation, and timing/frequency services. Due to the renewed interest, the evaluation of Loran has received significant support, beginning in 1997, by congressionally mandated funding that directed the FAA “... to further develop the Loran-C system.” Using this congressional funding, extensive work has been accomplished to overcome both transmitter and user equipment performance limitations and to conduct analyses that determine whether the modernized Loran system can meet the NPA, HEA, and time/frequency performance requirements.

Evaluation Team’s Work

Since the beginning of the evaluation, numerous papers and presentations that document and support the work and conclusions of this report have been provided to both national and international audiences. The team used the extensive existing technical body of knowledge on Loran-C and developed significant additional data to support the evaluation’s conclusions. This documentation includes a report prepared by the evaluation team for DOT on the interim status of the evaluation, titled “An Analysis of Loran-C Performance, Its Suitability for Aviation Use and Potential System Enhancements.” These reports, now public, present the work conducted, the conclusions reached regarding the structure and capabilities of a modernized Loran system, and the recommendations for further work. The website for the report “Loran’s Capability to Mitigate the Impact of a GPS Outage on GPS Position, Navigation, and Time Applications” is https://ksn.faa.gov/km/navservices/navservices/tech/Loran_Eval_Report/default.aspx.

—For further information on the Loran evaluation please contact Tom Gunther at Gunther_Thomas@bah.com.

Loran continued from page 15

DAYTON SECTION. On May 13, 2005, Jacob Campbell was awarded the Institute of Navigation Section Sponsored Graduate Student Award by Ohio University. Campbell is a full-time doctoral student in the Russ College of Engineering and Technology, School of Electrical Engineering and Computer Science. Campbell was recognized for his demonstrated excellence in the advancement of the art and science of navigation for his work as follows. During the past 5 years, Campbell has amassed an impressive 12 technical conference papers (of which he was the primary author on 8) and one journal publication. These papers have been published in proceedings or journals of the ION®, IEEE, and SPIE. He has received a certificate of appreciation from NASA, best student paper and best track paper awards from the IEEE, and a fellowship from the Ohio Space Grant Consortium. He has significant aviations experience in Lidar and synthetic vision systems. Campbell is a member of the ION® and the IEEE.

SOUTHERN CALIFORNIA SECTION. On August 8, the Southern California Section of the ION® delivered a check for $800 to Dr. Ilir Progri to fund the first student chapter of the ION® at the California State Polytechnic University at Pomona. Dr. Progri is the student chapter’s advisor.

Left to Right: Clyde Edgar, ION® SoCal chair; Raul Robles, ION® California Poly Pomona chair; Dr. Ilir Progri, ION® California Poly Pomona faculty advisor; and Dr. Raymond Di Esposti, ION® So Cal treasurer.
Congratulations Graduates

Cadet Brandon E. Burns, proudly accepts the Outstanding Cadet Aviation Instructor Award presented by Lt. Col. Mark Bontrager. The award is sponsored by the ION® in memory of Capt. William S. Davis III.

Dr. Michael McKaughan presents the ION® sponsored U.S. Coast Guard Academy award to Cadet Hunter Tenzing Atherton.

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IEEE
ION®
Co-sponsored by the IEEE and The Institute of Navigation

TECHNICAL MEETING
April 25–27, 2006
Tutorials: April 24
Abstracts Due: November 15, 2005
Manuscripts Due: April 3, 2006

PLANS 2006
POSITION LOCATION AND NAVIGATION SYMPOSIUM

The IEEE and the ION® are hosting PLANS together in 2006!

Details at www.plans2006.org

Loews Coronado Bay Resort, San Diego
Coronado (San Diego), California
This is the last article devoted to Albert Einstein’s impact on navigation. The year 2005 is the 100th anniversary of Einstein’s Annus Miraculis.

As in many sciences, Einstein’s contributions to navigation have not always been totally understood or accepted.

For a while it appeared that the General Relativity’s Equivalence theorem that stated that one could not distinguish gravitation from linear acceleration would actually impede the progress of inertial navigation. Inertial navigation’s mechanization seemed to rest on being able to measure gravitation and acceleration independently within a proverbial black box. To a physicist embedded with Einstein’s general theory, this raised an apparently profound conundrum that seemed to imply that the quest for an autonomous inertial navigation system was futile and a monumental waste of money.

It Cannot be Done!
This position was championed in the 1940s by the eminent Russian-American physicist George Gamow. Gamow had made major contributions in the fields of quantum mechanics and thermonuclear physics. He was a collaborator of Edwin Teller, the father of the hydrogen bomb, and also a proponent of the expanding universe theory for which he coined the term “big bang.” Gamow was not only a respected physicist, he was a member of the powerful Guidance and Control Panel of the Air Force Scientific Board. Gamow’s, along with other scientists’ objections, engendered a sense that the military’s quest for inertial navigation was something that fundamentally could not be achieved.

The downfall of Gamow’s ideas on the feasibility of black-box navigation has been attributed to Professor Charles Stark Draper. Doc Draper, himself a member of the Air Force’s Scientific Advisory Board, used this position to force a confrontation, arranging a major classified conference to review the progress in the field of inertial navigation. Apparently the preponderance of evidence showing the progress in the field discouraged Gamow and others from pursuing the challenge to the feasibility of black-box navigation. The determination of gravity became recognized as a parallel, practical technical challenge for the achievement of precise inertial navigation, rather than as an insurmountable obstacle.

Technical Controversy
The application of Einstein’s theories have also stirred technical controversy in the satellite navigation arena. The precision of GPS measurements is so great that it necessitates the application of both Einstein’s special and general theories of relativity. Simplistically, according to special relativity theory, a moving clock appears to run slow with respect to a similar clock that is at rest. This effect is called “time dilation.” In addition, a clock in a weaker gravitational potential appear to run fast in comparison to one that is in a stronger gravitational potential.

GPS satellites revolve around the earth with a velocity of 3,874 kilometers/second at an altitude of 20,184 kilometer. Thus on account of its velocity, a satellite clock appears to run slow by 7 microseconds per day when compared to a clock on the earth’s surface. But on account of the difference in gravitational potential, the satellite clock appears to run fast by 45 microseconds per day. The net effect is that the clock appears to run fast by 38 microseconds per day.

Synchronizing Clocks
This is an enormous rate difference for an atomic clock with a precision of a few nanoseconds a day. At the time of launch of the first NTS-2 satellite (June 1977), which contained the first Cesium clock to be placed in orbit, there were some who doubted that the above relativistic effects were real. A frequency synthesizer was built into the satellite clock system so that after launch, the rate of the clock could be adjusted to account for the observed effective drift. Indeed, after 20 days of operation of NTS-2, there was a validation of these effects to an accuracy of 1 percent. Thus to account for this net effect, operational GPS satellites have been given a frequency of 10.2299999543 Mhz such that
their nominal frequency would appear to be 10.23 MHz, in synchronism with a clock on the earth's surface. In addition to this offset applied to every satellite, each satellite has a small, but unique eccentricity, that requires the GPS receiver to perform an additional relativistic compensation.

A third effect, referred to as the Sagnac effect, accounts for the displacement of a receiver on the surface of the earth due to the earth's rotation in inertial space during the transit time of the signal from the satellite to the receiver.

The above relativistic corrections are critical to GPS performance and have appeared to be satisfactory for present applications.

Nevertheless, their interpretation and extension to future applications has been the subject of considerable debate. Ronald Hatch, a distinguished pioneer in satellite navigation, past ION® president and a winner of the ION's prestigious Kepler award, has written extensively on his theories which differ with Einstein's. In a note to me, Hatch attempted to explain his disagreement with the Sagnac effect interpretation by stating:

"The critical question concerning any motion is: "In what frame is the speed of light assumed to be isotropic--and in which the clocks are synchronized?" If receiver motion occurs relative to that frame, the speed of light relative to the receiver can not be assumed to be isotropic. … The above general rule about motion relative to a frame disagrees with Einstein in that he taught the speed of light automatically adjusted to be isotropic relative to the moving receiver. It does not do so. You have to resynchronize your clocks to a new frame, or map the clocks across using a Lorentz transformation—before the speed of light will be observed to be isotropic. Einstein taught that the Lorentz transformation was required because the speed of light automatically adjusted."

What would Einstein himself have thought of the controversies over his theories? I believe he would have welcomed them. As he wrote in “Induction and Deduction in Physics” in 1919: "The truth of a theory can never be proven, for one never knows if future experience will contradict its conclusions."

—For more information on Ron Hatch’s theories, refer to his many articles such as: Hatch, Ronald R., “Clocks and the Equivalence Principle”, Foundations of Physics, Vol. 34, No. 11, November 2004.

—Marvin B. May is the chief scientist at Penn State’s Applied Research Laboratory’s Navigation Research and Development Center.
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Meeting Chairs

Dr. Naser El-Sheimy
ION General Chair
The University of Calgary, Canada
naser@geomatics.ucalgary.ca

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dbrzezinska@osu.edu

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THE INSTITUTE OF NAVIGATION
3975 University Drive, Suite 390
Fairfax, Virginia 22030